The Manufactured Gas Industry:
Volume 2 Gasworks

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Front Cover Image: The grade II listed gasholder No.1, located at the Kennington Oval, London. It was designed by the eminent engineer, Sir Corbet Woodall, and was the world's largest when built in 1847. It was later rebuilt in 1879 to its present form, ahead of the first test match played at The Oval cricket ground in 1880.

SUMMARY

This document provides a summary of the development of the different processes used to manufacture, process, store and distribute gas. Where applicable it gives a description of the buildings and structures used and comment regarding the engineering involved. Given the long history of gas manufacture, the evolution of the different processes are described sequentially. A description is provided of the latter processes used in the industry, where gas was manufactured from oil and refinery by-products. Where relevant a description of gas distribution technology is also provided.

CONTRIBUTORS

This Report was written by Russell Thomas and desktop published by Rachel Forbes.

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CONTENTS

3. GASWORKS

This section summarises the processes involved in the gas industry. The purpose is to identify the function of components (including plant) which are to be used in the site assessments.

Items are described under class headings:

Manufacture of Gas, covering:

- The Manufacture of Gas from Coal by Carbonisation
- Gas Processing and Purification
- Manufacture of Gas by Gasification
- Gas Storage
- Chemical Works Processes
- Ancillary, Welfare and Administrative Buildings

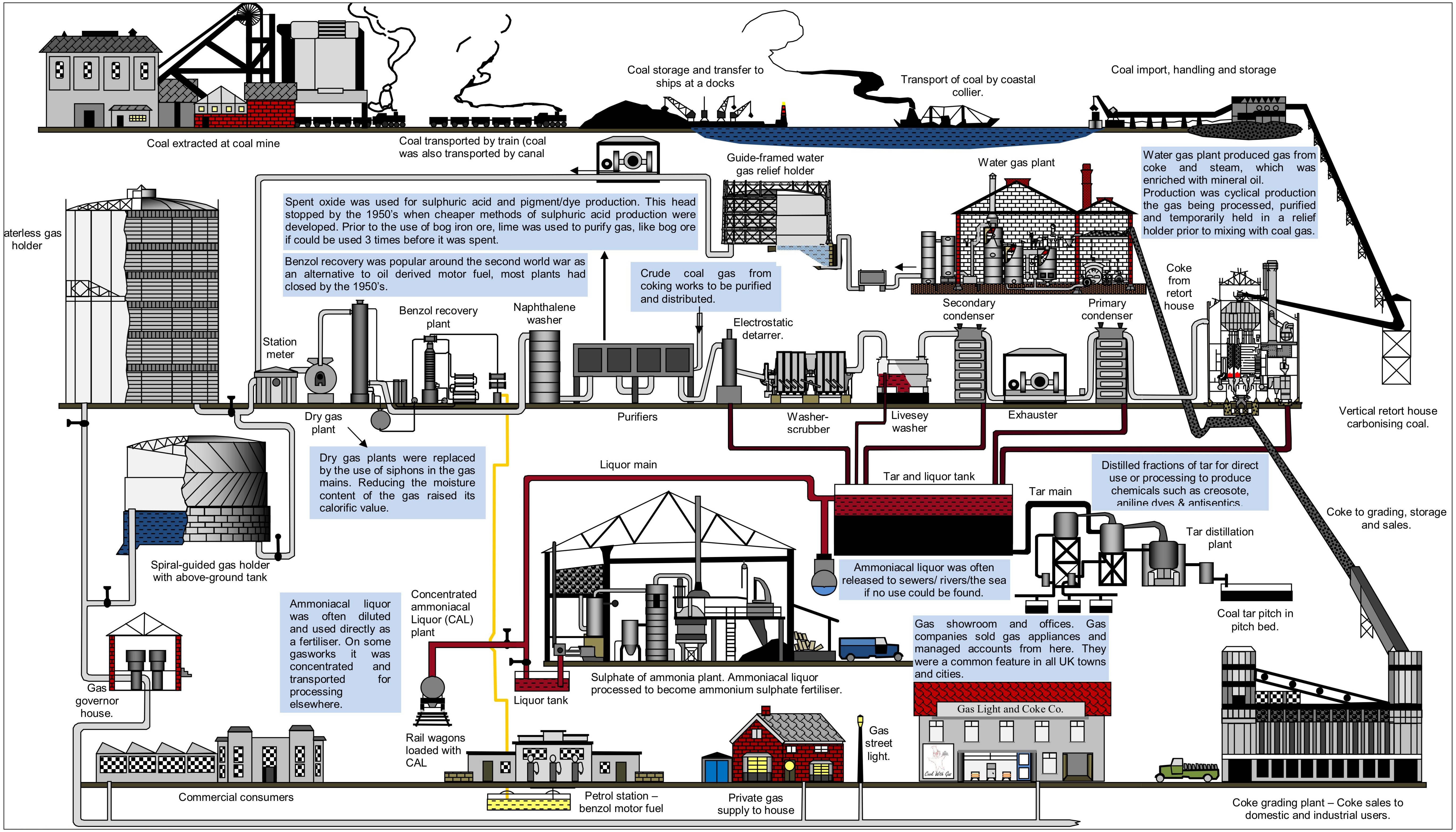
3.1 Manufacture of Gas

3.1.1 A Summary of the Process

The next section of this document explains how a gasworks operated, listing the plant and buildings used, and the way in which they were operated. It also describes the by-products produced and how they were processed. A general overview of the gas manufacturing process from coal is shown in Figure 3.1 and explained very briefly below.

Manufactured gas was produced firstly by loading coal into a sealed vessel called a retort. The retort was heated externally by a furnace or secondary burner fired with producer gas. Without oxygen, the heated coal did not burn; instead, moisture was driven off and the large organic molecules within the coal were thermally broken down into smaller and smaller compounds. This process released molecules of hydrogen and compounds such as methane, carbon dioxide, water and hydrogen sulphide into the gas, as well as the organic compounds that formed the gaseous, oily and tarry phases within the by-products. The process was very similar when gas was made directly from oil.

The gas left the retorts and passed up the ascension pipes and through the hydraulic main. The hydraulic main was filled with water and provided a water seal to prevent the gas flowing back into the retorts. The hydraulic main also cooled the gas and removed some of the tar. The gas then passed out of the retort house via the foul main to the condensers. The condensers which were cooled atmospherically or by water, further cooled the gas removing most of the tar and oil vapours trapped in the gas. The gas was then drawn into a pump called an exhauster. The exhauster pushed the gas through a tar washer and/or tar extractor to remove residual tar and then to the scrubbers (tower or rotating) to remove soluble compounds such as ammonia and phenol which formed ammoniacal liquor. Both the coal tar and ammoniacal liquor drained to below ground tanks or wells for storage.



Spent oxide was used for sulphuric acid and pigment/dye production. This head stopped by the 1950's when cheaper methods of sulphuric acid production were developed. Prior to the use of bog iron ore, lime was used to purify gas, like bog ore if could be used 3 times before it was spent.

Benzol recovery was popular around the second world war as an alternative to oil derived motor fuel, most plants had closed by the 1950's.

Crude coal gas from coking works to be purified and distributed.

Water gas plant produced gas from coke and steam, which was enriched with mineral oil. Production was cyclical production the gas being processed, purified and temporarily held in a relief holder prior to mixing with coal gas.

Dry gas plants were replaced by the use of siphons in the gas mains. Reducing the moisture content of the gas raised its calorific value.

Distilled fractions of tar for direct use or processing to produce chemicals such as creosote, aniline dyes & antiseptics.

Ammoniacal liquor was often released to sewers/ rivers/the sea if no use could be found.

Ammoniacal liquor was often diluted and used directly as a fertiliser. On some gasworks it was concentrated and transported for processing elsewhere.

Gas showroom and offices. Gas companies sold gas appliances and managed accounts from here. They were a common feature in all UK towns and cities.

Figure 3.1 This drawing is based on the small sketch of a similar design which was called "The making of Gas and By-Products" and featured in "Gas Utilisation of Distribution" by Norman Smith, published in 1945. The diagram shows the whole gas making process from the mining of the coal to the distribution of the gas to consumers. Efforts have been made to comment on the various uses of the by-products and to include plant not available in 1945. Some plant is shown in cross section with detail of the internal workings. It should be noted that this flow diagram does not show every type of plant or every configuration of plant used on a gasworks. The actual configuration of plant varied significantly between gasworks and this is just a representation of a potential layout. Source R. Thomas.

The gas was then pushed through the purifiers (using lime or bog iron ore) to remove sulphur and cyanide compounds. The gas was then passed through benzole and sometimes naphthalene washers to remove these substances from the gas using activated carbon or oil washing of the gas. The treated gas, sometimes described as "town gas" was stored in a gasholder, ready for distribution through the gas mains beneath the streets to customers.

For a large portion of the history of the UK's manufactured gas industry, coal was the predominant feedstock used. Oil did become an important feedstock from the 1890s for carburetted water gas production and oil gas production from the 1950s.

3.1.2 Geology and raw materials

Prior to conversion to natural gas, which started in the 1966, coal was the primary feedstock used for gas manufacture. Coal is a sedimentary rock, which consists primarily of carbonized vegetable matter compressed under great pressure and sometimes temperature. As this vegetable matter is compressed it proceeds through the coalification process. During this process, the carbon content in the coal increases and the oxygen content decreases. The coal becomes more ordered, forming large collections of aromatic ring structures. It would eventually form the most ordered form of coal, anthracite. The flammability, bitumen content and its ability to be coked, vary, dependent on the state of coalification (Davidson 2004, Buchanan 1972 p69-71, Gould and Cranstone 1992 p1-2).

Coals are comprised of a series of large organic molecules, derived from the original plant substances from which they were formed. This plant matter is subject to considerable variation ranging from trees to algae. The mineral content also varies within the coal affecting its properties. Due to the large molecules found in coal, they are very difficult to characterise using analytical chemical techniques and for this reason the chemistry of coal is still not fully understood (Davidson 2004).

The composition of the coal is dependent on its stage within the coalification process and the original vegetable from which it was formed. As the coalification process proceeds, the hardness of the coal increases and the proportion of volatile components decreases, coals are graded as follows:

- Lignite or brown coal (which has strong traces of plant structure and is part way between bituminous coals and peat).
- gas coal
- coking coal
- steam coal
- cannel coal
- bituminous coals (which burn with a smoky flame) and
- anthracite (a clean burning hard coal of almost pure carbon):

The economic importance and scientific interest in coals has meant that many attempts have been made to characterise them, with different approaches adopted in different countries. This section only attempts to briefly describe those methods applicable to gas manufacture.

Not all coals were suitable for gas making. The preferred types of coal have varied throughout the history of the gas industry, depending on the primary purpose of the gas (lighting or heating), the type of carbonising plant used, and the types of coal available.

The descriptions of the coal used differ dependent on the systems of classification used. Using (Marie) Stopes classification by Maceral, the types of coal suitable for gas production included (Stopes 1919):

- bright (soft) coal: vitrain, clarain, and fusain
- dull (hard) coal: durain
- cannel coals
- bogheads and torbanites

Alternatively, the Seyler Classification (based on elementary composition and suited to British carboniferous coals) would identify suitable coal as being from the Meta bituminous to Meta lignitous, the Meta lignitous being the preferred coals used in vertical retorts circa 1950, (King 1948, Speight 2012 108-109).

Coking coals formed the basis of the English gas industry. They produce a good quality coke and gas and are found in the coal field Durham, Northumberland. Lancashire, Yorkshire, the Midlands. Somerset, and Kent. The oily 'Cannel Coal' was particularly valued by the gas industry, as it was by the coal-oil industry, it produced a rich gas and it provided the foundation of the early Scottish gas industry, an advert for Scottish Cannel can be seen in Figure 3.2. A drawback with cannel coal was that it produced a poor-quality coke. In England there were large deposits of Cannel Coal in South Lancashire (Trueman 1997).

JAMES McKELVIE & Co.,

CANNEL AND GAS COAL MERCHANTS,

Haymarket, Edinburgh, and at 37 & 38, Mark Lane, London. E.C.

CONTRACT FOR THE SUPPLY OF ALL THE PRINCIPAL

SCOTCH CANNEL & GAS COALS.

PRICES AND ANALYSIS ON APPLICATION.

ESTABLISHED 1840.

Figure 3.2 An advert for Scottish cannel coal. Source the Gas Engineers Textbook and Gas Companies Register 1898.

In Britain, the coal used for gas making would have a high volatile content with medium to strong caking properties, although slightly caking coals could be used in vertical retorts. These coals covered British National Coal Board coal types 401, 501, 601 and 701 (Speight 2012, 51-52). The ASTM method used in the USA suggested that 'Bituminous-Common Banded Coal' was the most suitable for gas making (ASTM 2005).

Cannel coal was preferred for gas production prior to the advent of the gas mantle. This was because it produced a gas with a greater quantity of volatile organic compounds, which had better illuminating properties, making it more suitable for lighting. There was only a limited supply of cannel coal, which made it expensive; however, it was often mixed with other coals to improve the illuminating properties of the gas. It was also the coal of preference for many country house and estate gasworks, especially in Scotland, where this type of coal was more abundant. It left little ash and made the management of a small gasworks very simple (Meade 1916, Stewart 1958).

The gas industry's dependence on cannel coal for enriching the illuminating properties of gas started to diminish as the gas mantle took over from older aerated burner designs and before the Gas Regulation Act was introduced in 1920, when the switch was made from illuminating power to the calorific value of the gas. The move away from using cannel coal would have changed the composition of coal tar, decreasing the amount of paraffinic substances and light oil present in the coal tar. This was recognition of the changing markets which the gas industry was serving, moving from lighting to heating (Meade 1916, Stewart 1958, Lowry 1945).

Proximity to market, combined with coal type, had a considerable influence on the type of carbonisation process used in UK gasworks. There was a preference for the Durham and Northumberland gas coals to be used in horizontal retorts. This coal was transported down the Eastern and along the Southern coasts as far as Cornwall in ships called colliers and influenced gas production in these areas. An example of a collier, the S.S. Brixton, is shown in Figure 3.3, a painting of a collier being unloaded at Beckton gasworks is shown in figure 3.4). Further inland, Midland, Lancashire and Yorkshire coals were more easily available by canal and rail transport and there was a preference to carbonise these in vertical retorts, when they became available. The coals in Scotland were preferentially carbonised in vertical retorts where it was cost effective to build such plants. (King 1948).

The South Wales coalfield contained the entire spectrum of coals, some of which would have been suitable for gas production. Other smaller coal fields would have provided locally important coals for gas production, for example North Somerset (King 1948).

Coal was transported from the coal mines to the gasworks by colliers, canal barge, or train. If train sidings or navigable water routes were not adjacent to the gasworks, then it would be further transported to the gasworks by cart or wagon. Transporting coal by cart or wagon was both expensive and inefficient increasing the cost of gas manufacture (Stewart 1958, p1, p4). During the First and Second World Wars, great reliance was placed on railways as the coastal colliers were more vulnerable to enemy attack.

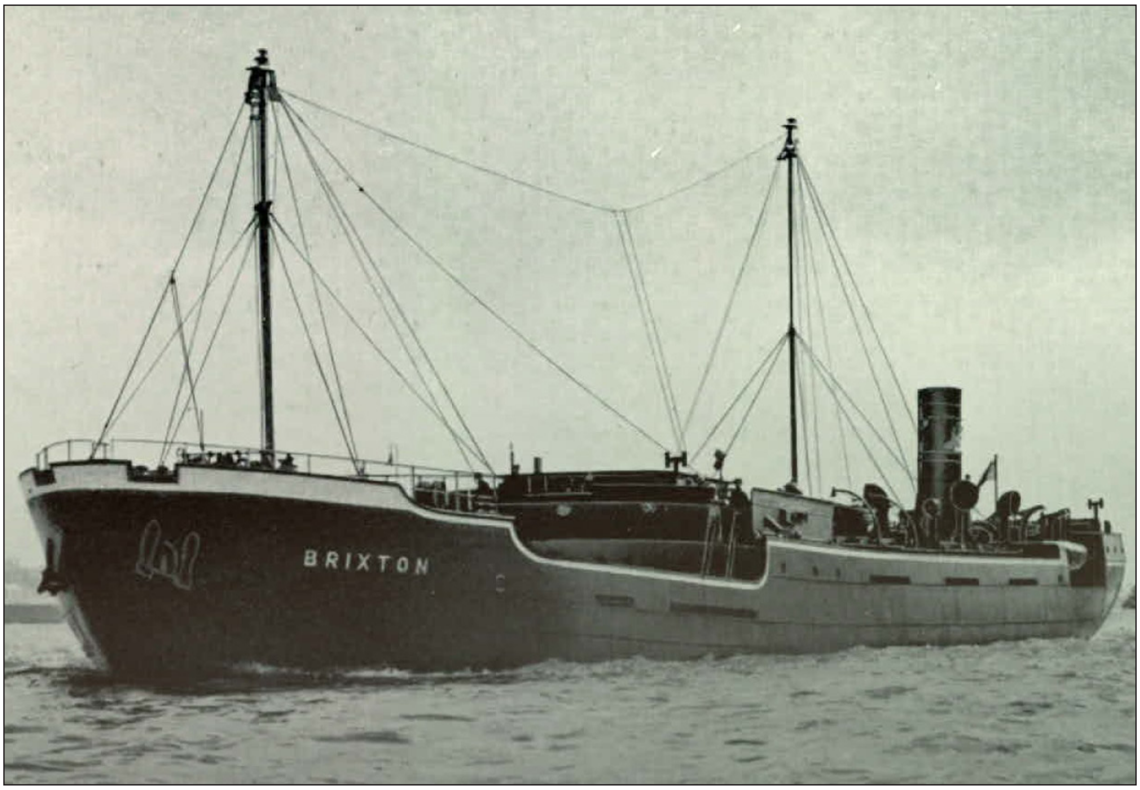


Figure 3.3 The S.S. Brixton a coastal collier of the South Metropolitan Gas Company. Image courtesy of National Grid Gas Archive.

Figure 3.4 Painting by Norman Wilkinson of unloading coal from a coastal collier by steam cranes at the wharf at Beckton. Image courtesy of National Grid Gas Archive.

At the gasworks, any large lumps of coal were broken up into smaller pieces in a coal-crushing plant. At larger gasworks, the coal would be taken to hoppers for loading into the retorts. If the coal was destined for a coke oven, it was first crushed to a fine powder (Stewart 1958).

The gas industry in England primarily used gas and coking coals, which produced a gas with a typical illuminating power of 16 candle power. Candle power was a measure of the brightness of light. With the emerging threat of electricity, the development of new heating and cooking technologies combined with the development of the incandescent gas mantle, the illuminating standard was replaced by the thermal standard. The formal change to the thermal standard was introduced by the Gas Regulation Act of 1920, which required all gas undertakings to declare the calorific value of the gas they supplied (Williams 1981, Chantler 1938).

As the available quantities of suitable gas coals diminished, the gas industry looked towards the gasification of low-grade coal through complete gasification (see section on Complete Gasification) and the Lurgi process, before the later switch to reformed gas manufactured from oil refinery by-products and then natural gas (Williams 1981).

3.2 The Manufacture of Gas from Coal by Carbonisation

3.2.1 Definitions

For the purposes of this report a distinction is drawn between manufactured gas and natural gas. Manufactured gas was also known as 'Towns Gas', but in both cases, they refer to a combination of combustible gases distributed through mains for domestic, commercial and industrial uses. Manufactured gas started to be used on a commercial scale from the first decade of the nineteenth century up until the adoption of natural gas in the 1960s, finally being phased out of use in England in 1976.

Gas was manufactured from fossil fuels, primarily coal. Gas manufacture from coal was referred to as 'carbonisation' as the feedstock was converted to coke, a purer form of carbon, with gas and other by-products being released as part of the process. Gas or coking coals were primarily used for carbonisation processes, this was often supplemented with up to 10% oil rich cannel coal, obtainable from the coal fields in the Midlands and Northwest of England, as well as from Scotland. Some gas companies supplied gas made purely from cannel coal, such as the Western Gas Light Company who built a gasworks at Kensal Green. This richer gas had a luminosity of 20-28 candle power (cp), compared to 12-18 cp of coal gas, but produced poorer coke. A premium would be charged for the gas produced from cannel coal, which was rarer and more expensive than typical coals used for gas making, with the advent of the incandescent mantle the importance of cannel coal decreased (Stewart 1958, p18-19).

Other methods of gas manufacture were also used, these processes are described as 'gasification' where the feedstock is converted to gas without leaving any carbon rich residue. Such feedstock fuels included coal, coke, resins, oils and wood. In some locations methane rich natural gas was abstracted from coal mines in a process known as 'methane gas drainage'. This gas could be used directly to enrich the calorific value of gas or reformed into manufactured gas (Stewart 1958 p48).

Hence, in brief the main forms of manufactured gas were:

- Coal Gas – produced by thermally decomposing coal to release combustible gases such as hydrogen, carbon monoxide and methane, undertaken in retorts and ovens at gasworks and within ovens at by-product coking works.
- Producer Gas – A lean gas produced by the partial combustion of coal under oxygen limited conditions. The combustible component of the gas was carbon monoxide. It was primarily produced at gasworks to heat retorts at gasworks, although, at times of high demand, it could be diluted with coal gas, to supplement coal gas. It was also produced in factories to power gas engines.
- Water Gas – A lean gas produced by the partial combustion of coal under oxygen limited conditions. Steam was injected into the fuel bed releasing hydrogen gas. The combustible components of the gas were carbon monoxide and hydrogen, it was produced at times of high demand and diluted with coal gas.
- Oil Gas – a gas made by thermally decomposing (cracking) the oil into smaller molecules fixed into the gas phase.
- Carburetted Water Gas – A combination of Water Gas and Oil Gas, where the water gas was enriched with oil to increase the calorific value of the gas.
- Complete Gasification, this process combined carbonisation and gasification into one process, where the coal was first carbonised and afterward water gas could be made from the coke produced. The Tully Gas Plant was an example of this process.
- Reformed Gas – a gas made from reacting light oil, refinery gases or natural gas with steam at high temperature and sometimes pressure, and often in the presence of a catalyst to produce a hydrogen rich gas.

Each of these processes are described in greater detail within this document.

Natural gas is different both in its formation and composition compared to manufactured gas. Natural gas is formed deep underground over a period of millions of years. The remains of plants and animals which had been built up in thick layers on the earth's surface and ocean floors, sometimes mixed with sand, silt, and calcium carbonate, became buried over time. Subsequently covered by layers of sand, silt, and rock and changed by pressure and heat, this organic material was gradually converted into coal, oil and natural gas (Cassidy 1979, p13-18).

Natural gas reserves are found under pressure deep inside the earth near other solid & liquid hydrocarbons beds like coal and crude oil. Natural gas is a mixture of hydrocarbon gases, mainly methane, ethane, propane and butane. With methane being the largest component. Natural gas has a high calorific value (1000 btu), roughly twice that of manufactured gas (500 btu) (Cassidy 1979 p13-18, Williams 1981).

When the decision to switch the gas network from manufactured gas to natural gas was made in 1966, it required the modification of all gas appliances. The burners used for manufactured gas, were often not suitable for burning natural gas. This was due to the higher calorific value of natural gas (1000 Btu) compared to manufactured gas (500 Btu). New burners (or modifications to existing burners) were required, which allowed a higher quantity of air to be mixed in the burner, for the natural gas to burn effectively. This necessitated a major conversion programme for domestic, commercial and industrial gas appliances as each section of the gas network was switched from manufactured gas to natural gas (Elliot 1980, Williams 1981).

3.2.2 The Retort House

The heart of a gasworks was the retort house, which was where the gas was manufactured from coal, in vessels called retorts.

A retort was a sealed vessel in which the coal was heated in an oxygen free environment. Instead of combusting, the volatile components were driven off, leaving a relatively pure form of carbon called "Coke" as a residue. The coke was a valuable by-product used by other industries such as metallurgy and as a smokeless fuel. Some of the coke was also used to heat retorts, leaving behind a residual ash composed of the siliceous and metallic substances which were not combustible.

The design of the retort house was dependent on the types and number of retorts it contained and the era in which it was built. The retorts were either used in horizontal, inclined or vertical designs, described later. In simple terms, the retort was heated by a furnace. Several retorts heated by the same furnace were known as an Oven or Setting, and a row of adjoining Ovens was known as the Retort Bench. (Cotterill 1981, p25; Stewart 1958, p12-13). Irrespective of the type of retorts housed, all retort houses incorporated a chimney for exhausting of waste gases from the furnaces (King 1948). An example of a retort house chimney typical of many small town gasworks in shown in Figure 3.5.

Figure 3.5 The surviving horizontal retort house, showing the chimney and louvered roof, Fakenham gasworks 2018. Source R. Thomas.

Retort technology changed as the gas industry evolved, becoming gradually more advanced. Most early retort houses for horizontal retorts had a characteristically low and wide profile. The roof was typically wrought iron or later steel trussed and covered with slates, tiles or corrugated galvanised iron sheets with the clerestory or louvered roof running along the pitch of the roof to provide ventilation (Newbigging 1889 p59). Ventilation would also be provided by openings built into the walls above the retort benches.

The retort house was generally flanked by stores or sheds on one or two sides. These were used for storing the coal and coke. Examples of horizontal retort houses can be seen in Figures 3.6, 3.7 and 3.8. (Hughes and Richards 1880 p86, Newbigging 1889 p59)

The design of retort houses found on small country gasworks, such as that still standing at Fakenham (Figure 3.6) followed this layout, this design remained very similar throughout the history of the industry, almost always using horizontal retorts, with ground level furnaces and the retorts arranged above the furnaces. Such small retort houses were typically 26 feet wide, which allowed 12 feet for the retort stack and associated equipment and 14 feet for the working of the retort. A space was left between the retort stack and the wall of the building otherwise the thermal expansion of the retort stack would damage the brickwork of the retort house (Hughes and Richards 1880 p89).

In 1889, Newbigging reported that the retort house may be adapted for either a single or double stack of retorts. For a single stack of retorts Newbigging reported

Figure 3.6 The surviving horizontal retort house and store, Fakenham gasworks, 2018. Source R. Thomas.

a width of 30 feet and height of 20 feet. For a double stack of retorts, he reported a width of 60 feet and a height of 26 feet (Newbigging 1889).

The Ground-Floor layout shown in Figure 3.7 had been the traditional design of the horizontal retort house. The Stage-Floor layout shown in Figure 3.8, was recorded, by Hughes and Richards, as rarely used in 1880 was said to be in regular use by Newbigging in 1889.

With ground-floor retort houses, the generator furnaces would be placed below ground by taking the foundation of the retort-stack to a depth of 9 feet 6 inches below the floor-line, and making an underground passage, at least 7 feet wide, in front of the retort stack (Newbigging 1889 p59).

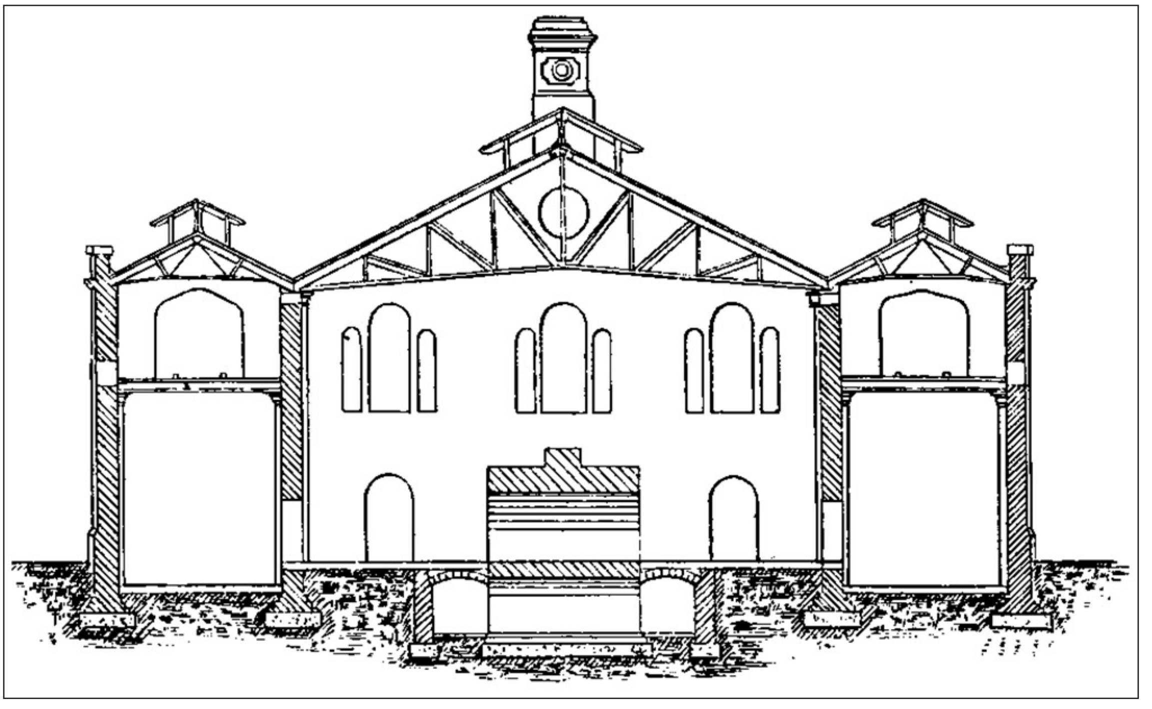


Figure 3.7 A ground-floor horizontal retort house. Source Newbiggin 1889.

The retorts would be situated on the stage-floor level, with the heating provided from furnaces or equivalent located on the floor beneath. The stage-floor could either be situated at a ground or first floor level. The stage-floor was required to be robustly built to withstand heat and a heavy weight. It was usually formed from brick or concrete arches, or cast-iron plates, laid on girders having their ends built into the wall of the house and the division piers of the retort-stack foundation, and supported at intermediate points by cast-iron columns. A similar design was adopted for other gasworks buildings where heavy weights may have required supporting, such as the purifier house (Newbigging 1889 p61).

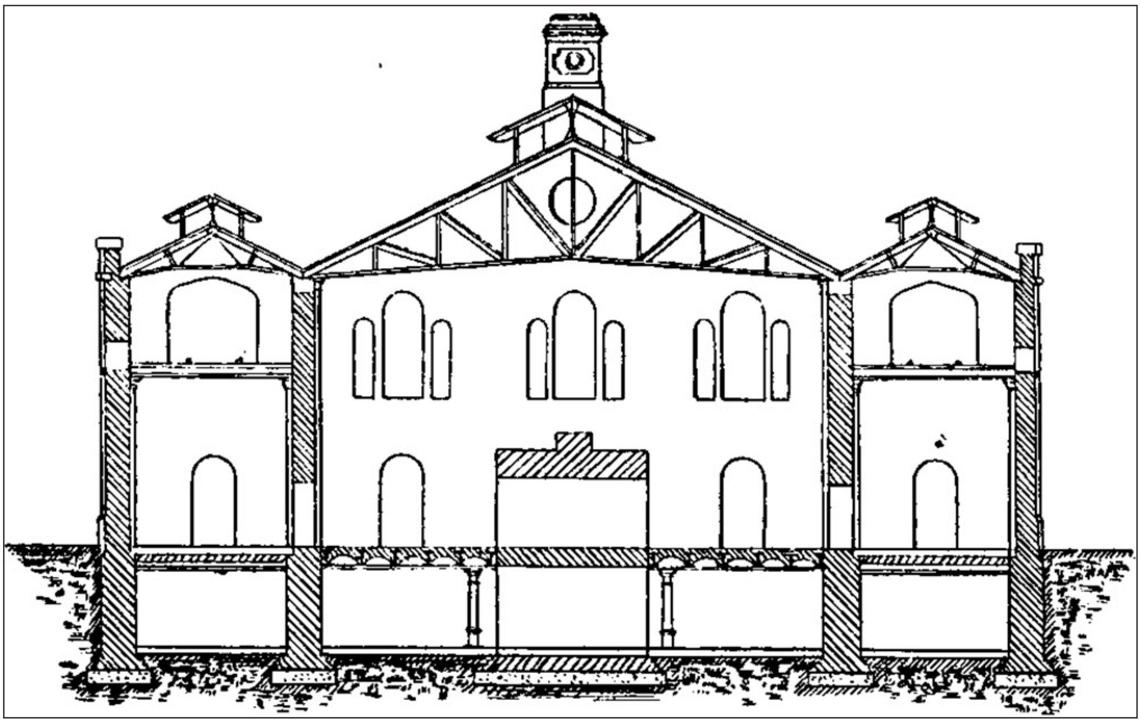


Figure 3.8 A stage-floor horizontal retort house. Source Newbigging 1889.

The area directly in front of the retort stack for eight feet would typically be paved with firebricks, the rest of the retort house floor being paved with flags. Blue Staffordshire bricks or tiles could be used to pave the entire floor. There would be a slight incline built into the floor towards the retort stack, this allowed the waste water from cooling the coke to run into the ash-pans, and it was also beneficial in aiding the stokers to charge the retorts (Newbigging 1889).

More notable changes were observed at larger gasworks where horizontal retort houses evolved to become taller and developed deep basement features (as described above), they adopted the use of through retorts, became increasingly mechanised and improved the methods of heating the retorts as shown in Figures 3.7 and 3.8. In later stage-floor designs, the basements were removed, and furnaces housed at ground level and the retorts housed on the first-floor. Such a design being suitable for sites where flooding was a risk. Flooding was often a risk, as gasworks tended to be located adjacent to rivers and canals for transportation and because they used a lot of water in the gas making process.

Inclined retorts evolved in the late 19th century, pioneered by Emile Coze, the gas engineer at Rheims gasworks in France. The inclined plane of the retort allowed gravity to assist the loading and unloading of the retorts. This brought rival competition to manufacturers of horizontal retorts and led to the increased adoption of mechanisation in the retort house to compete with inclined retorts. The retort houses used for inclined retorts followed the same principals as those for horizontal retorts except for the increased height required for the inclined retorts. The similar look can be observed in Figure 3.9 which shows the former inclined retort house in Rochdale. The inclined retort was regarded as outdated by Meade in 1916, although he recognised they were still in use (Meade 1916 p75).

Figure 3.9 The former inclined retort house, Rochdale gasworks, 1909. Image courtesy of National Grid Gas Archive.

Vertical retorts evolved in the early 20th century. Their advantage was twofold, they occupied less ground space, allowing greater productivity to be achieved on an equivalent footprint of land and they took advantage of gravity to aid the flow of coal and coke in the retorts, significantly reducing the amount of manual labour required to load and unload the retorts. The move to the adoption of vertical retorts which started in the first decade of the 20th Century led to the construction of some much taller and narrower buildings, distinct from other retort houses and having characteristic wall ventilation (King 1948).

In the late 19th century, chamber ovens started to be developed in Germany, where they better suited the available continental coals. Some of the chamber oven based processes did away with the housing altogether, as was often seen on the continent (Lessing 1909). These processes received limited use in England, Woodall-Duckham Introduced the German designed Intermittent Vertical Chamber, with a works built at Ramsgate. As the availability of quality gas coals diminished, some large chamber oven plants were constructed, this included that built at White Lund (near Morecambe), the last conventional coal gasworks built in England.

The construction materials used in the building of retorts houses evolved overtime. Where the earlier and small retort houses were built from brick or where more cost-effective local stone built on top of footings, the larger horizontal and vertical retort houses built in the 20th Century were more typically built using steel frames with panels infilled with bricks and foundered on top of piled foundations. Such later steel framed buildings with brick panels are rare in England with only 2 known surviving examples for horizontal retort houses and no examples of such vertical retort houses in England.

3.2.3 The Early development of the Retort

The very early development of the retort for scientific purposes was described in the first volume of this report which described the history of the manufactured gas industry. This section starts with the work undertaken by William Murdoch whilst developing gas apparatus at the Boulton and Watt factory near Birmingham.

William Murdoch experimented with retorts of different configurations at the Soho Foundry. These included vertical, inclined and horizontal retorts as shown in Figure 3.10. His first retort design was a pot still which was set in the vertical plane, shown in far left of Figure 3.10. The major drawback with this design being that no allowance had been made for the removal of coke at the base of the retort. Murdoch moved on to experiment with horizontal and inclined retorts. Murdoch did later return to the vertical retort design, with the inclusion of a tube at the base to enable the coke to be removed, shown in Figure 3.10 labelled Murdock's retort 1804, this design however did not allow for the heat to adequately penetrate the coal (Glover 1906, Hunt 1900).

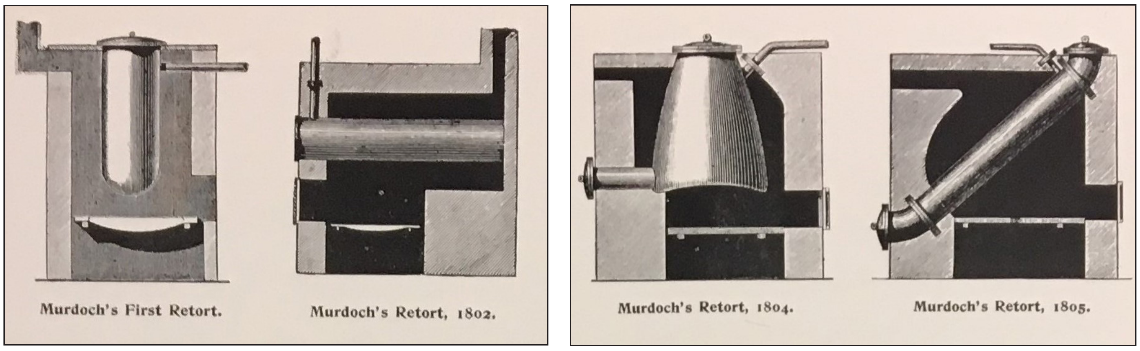


Figure 3.10 Designs of retort variants used by William Murdoch. Source Thomas Glover Transactions Institution of Gas Engineer, 1906.

The gasworks Murdoch installed for Phillips and Lee at the Salford Twist Mill originally used the design shown in Figure 3.10 labelled Murdock's retort 1804, but he later replaced these with horizontal retorts as shown in Figure 3.11. Murdoch's D-shaped retorts were placed with the flat side horizontal, were 22 inches wide by 14 inches deep and 3 feet 9 inches long holding about 1 cwt of coal (Stewart 1958, p12).

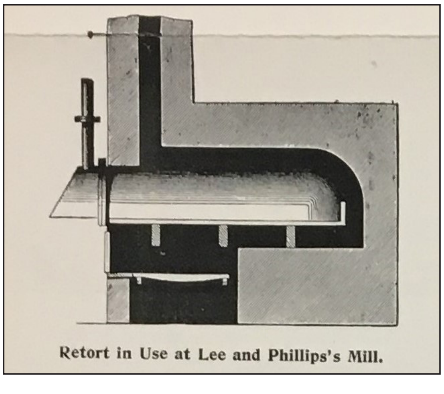


Figure 3.11 Designs of retort used by William Murdoch to replace the original vertical retorts at Phillips and Lee's Salford Twist Mill. Source Thomas Glover Transactions Institution of Gas Engineer, 1906.

3.2.4 Horizontal Retorts

The horizontal retort was a long horizontal tube of varying shape, sealed at one end and open at the other, which was covered by mouthpiece in which a door was placed. Examples of this design are shown in Figure 3.11 and cast-iron variants shown in Figure 3.12.

The horizontal retort was used by Samuel Clegg at Henry Lodge's Mill in Sowerby Bridge (Hunt 1907). Clegg had favoured the horizontal retort and developed the design which was to become the standard for the first forty years of the gas industry (Stewart 1958, p12-15).

The horizontal retort adopted by Clegg was a cast iron D-shaped retort of either 12 inches wide by 12 inches deep or 20 inches wide by 14 inches and some 7 feet long (see Figure 3.8). The larger size held a charge of 2 ¼ cwt of coal, which would carbonize a charge of coal in six hours. These retorts were set in individual arches of five retorts clustered around a single furnace (Stewart 1956, p12-15, Clegg 1841, Richards 1877).

Whilst the D-shaped retorts proved popular initially, other designs were used, such as the circular retort (Figure 3.12), elliptical, rectangular and kidney bean shaped retorts as shown in Figure 3.13. The D-shaped retort proved to be the most widely adopted and its popularity increased again toward the end of the 19th Century (see figures 3.11 & 3.12, Hunt 1900 p24).

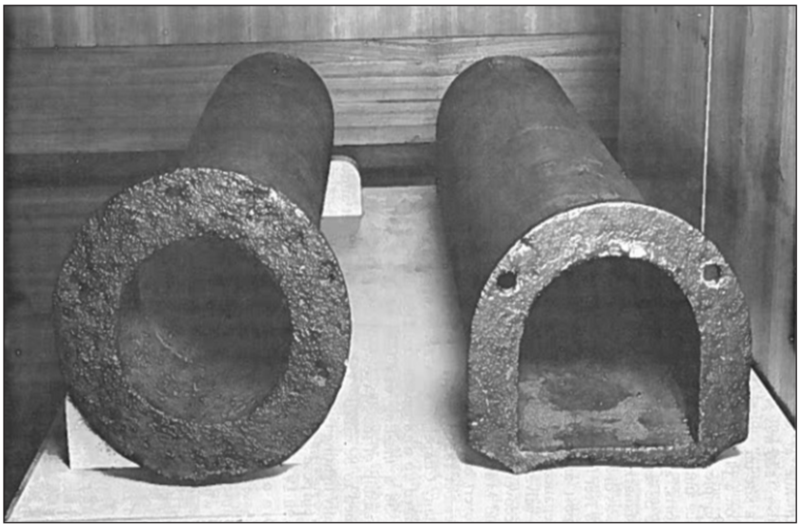


Figure 3.12 Circular and D shaped cast iron retorts. Source Jones and Reeve 1978.

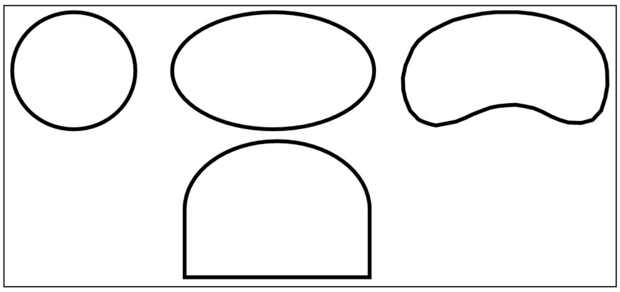


Figure 3.13 Evolution of the horizontal retort, from circular, through elliptical to kidney bean shaped, to D-shaped. Adapted by author from Hunt 1900.

All early retorts were manufactured from cast iron as seen in figure 3.12. Cast iron retorts had good conductivity (keeping down fuel consumption) and were non-porous (allowing the production of gas at a high pressure, which aided its carriage through the purification plant). They had a short lifespan, as they easily expanded, disturbing the brickwork they were set in and once cracked. they could not be repaired (Hunt 1900, Richards 1877).

Whilst most retort designs were static, Samuel Clegg introduced the innovative and advanced rotating retort seen in Figure 3.14, and anti-dip seal in his design for the gasworks installed by Frederick Accum at the Royal Mint in 1815 (Accum 1819, Chandler and Lacey 1949). This design was not used in future gasworks, but other attempts at moving or rotating retorts were developed. In 1827 Henry Pinkus patented (No. 5541) a rotating retort which contained four carbonising compartments. A moving web retort was described by Clegg dating to 1830, where the coal was carbonised on a moving metal belt (Clegg 1841). Benjamin Simmons patented (No. 7023) a revolving retort in 1836 (Stewart 1960, Anon. 1860). Yeadon again patented a revolving retort in 1889 (Glover 1906).

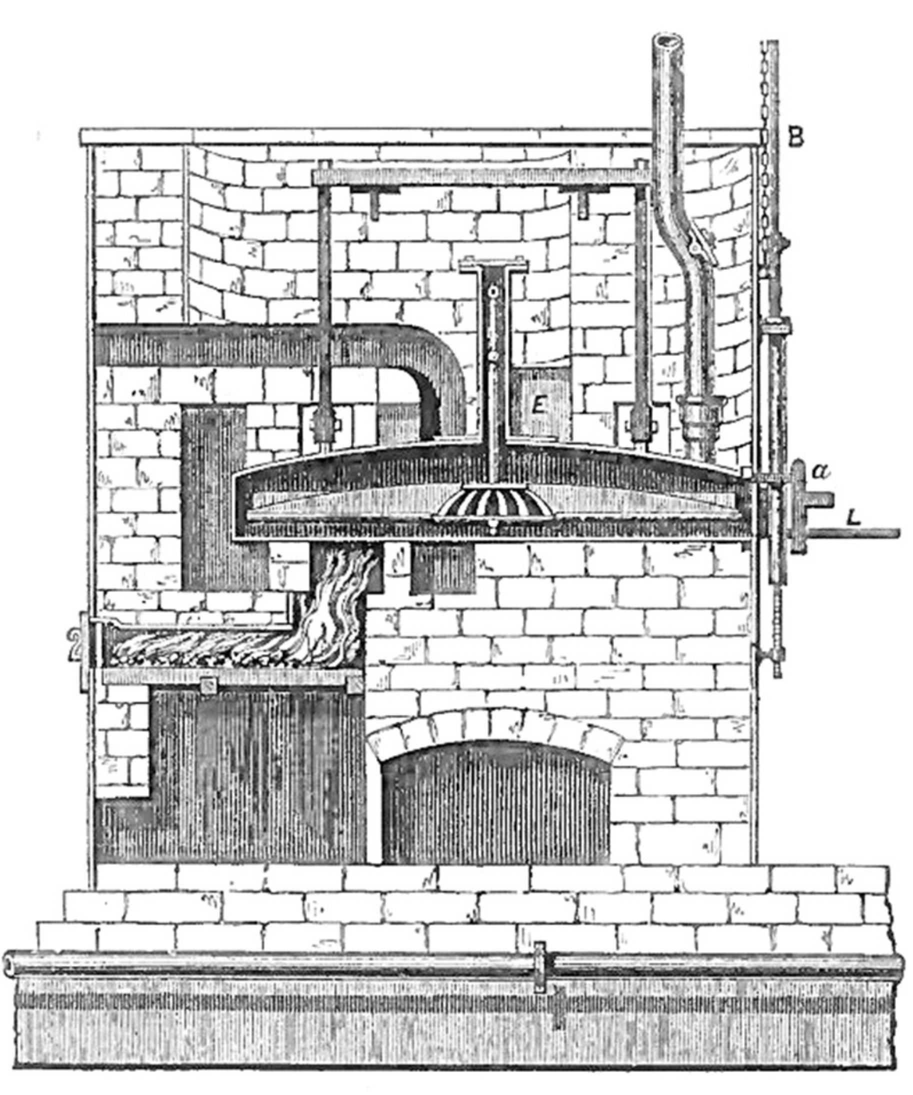


Figure 3.14 Samuel Clegg's rotating retort installed at the Royal Mint. Source Accum 1819.

3.2.4.1 New Materials for Retort Construction

Whilst cast iron retorts were successful, they were only effective up to a temperature of about 600°C, a temperature which was not optimal for efficient gas making. When the carbonisation temperature was increased to around 750°C, it was found to cause excessive wear of the retorts which led to them having to be replaced after a period of only nine months. This greatly increased the cost of gas making (King 1948).

John Grafton experimented first with square and later with D-shaped fireclay retorts at the works of Messrs Butcher in Wolverhampton in 1820 (British patent No. 4483, Anon. 1860) and clay retorts had also been unsuccessfully used two years later at the Westminster gasworks of the GLCC (Richards 1877, Stewart 1960).

John Eunson, the gas engineer at Wolverhampton gasworks, had used clay retorts successfully before Grafton and they had also been used at various Scottish gasworks by James Reid, the engineer of Montrose gasworks. The clay retorts were often built in sections and jointed using fireclay when the setting was constructed (Clegg 1841), British patents for such retorts were filed by Alexander Croll with William Richards (No. 10,096) and Joseph Cowan (No. 10,215) in 1844. Cowan was recorded to have been making clay retorts at his Blaydon Burn works from 1826 (Anon. 1900b). Croll's patent had a similarity to that developed by George Lowe and John Kirkham (Patent No. 8298) where retorts of clay and iron were combined in the same setting, with Lowe proposing the upper retorts constructed from clay and lower retorts from iron. Alexander Croll had proposed a similar arrangement of iron retorts heated by residual heat from a separate setting of clay retorts in 1843 (Stewart 1960).

John Malam patented (No. 4832) moulded clay retorts, which were manufactured from a mixture of pulverized fire stone, red lead, bullocks' blood and ordinary fireclay (Stewart 1960, Anon. 1860). Thomas Spinney, the gas manager at Cheltenham Gasworks also patented the use of earthenware retorts in 1832, they were to be made of Stourbridge Fireclay (Anon. 1860), in combination with sand, iron sulphate and lead ore. Spinney also devised a valve that did away with the need for the hydraulic mains, although it did not supersede it. Kirkham and Kirkham combined wet and dry hydraulic main in 1852 (Stewart 1960). Holmes also developed an anti-dip valve in 1855, such valves tended to stick and devices which allowed the liquor in the dip pipe to be raised or lowered were preferred (Meade 1916).

As well as resisting higher temperature and having much greater durability, the fireclay had the added advantage of retaining their heat, between charges (Richards 1877). Fireclay was unfortunately more porous than iron and gas loss due to leakage from the retort would be higher. This loss was reduced by reducing the back pressure from the gasholder by using an exhauster. The exhauster (described later), was a form of pump which would draw the gas from the retorts. The exhauster was not a requirement when iron retorts were used but it became an important feature of all but the smallest gasworks (Hunt 1900, King 1948).

An alternative approach was developed by Bevington Gibbins and Charles Wilkinson (British Patent No. 4587, Anon 1860) who introduced the idea of lining metal retorts with Stourbridge bricks or clay, which would protect the retorts from the aggressive conditions of distillation and reduce porosity (Anon 1860). Retorts built from fireclay bricks were also developed, with a trial conducted on the Brick Lane gasworks of the GLCC in 1844.

George and Frederick Evans patented (No. 2005) the internal glazing of fireclay retorts in 1854, the glazing was designed to reduce the escape of gas from the retort (Anon 1860).

Iron retorts such as those early examples at Great Peter Street shown in Figure 3.16, did remain useful in small gasworks, such as those supplying factories, country houses and villages, where the "make" was very irregular and the retorts were required to be kept on standby for intermittent periods (Richards 1877). Iron retorts were described as "seldom used" by 1880 and six times as expensive (Hughes and Richard 1880 p68).

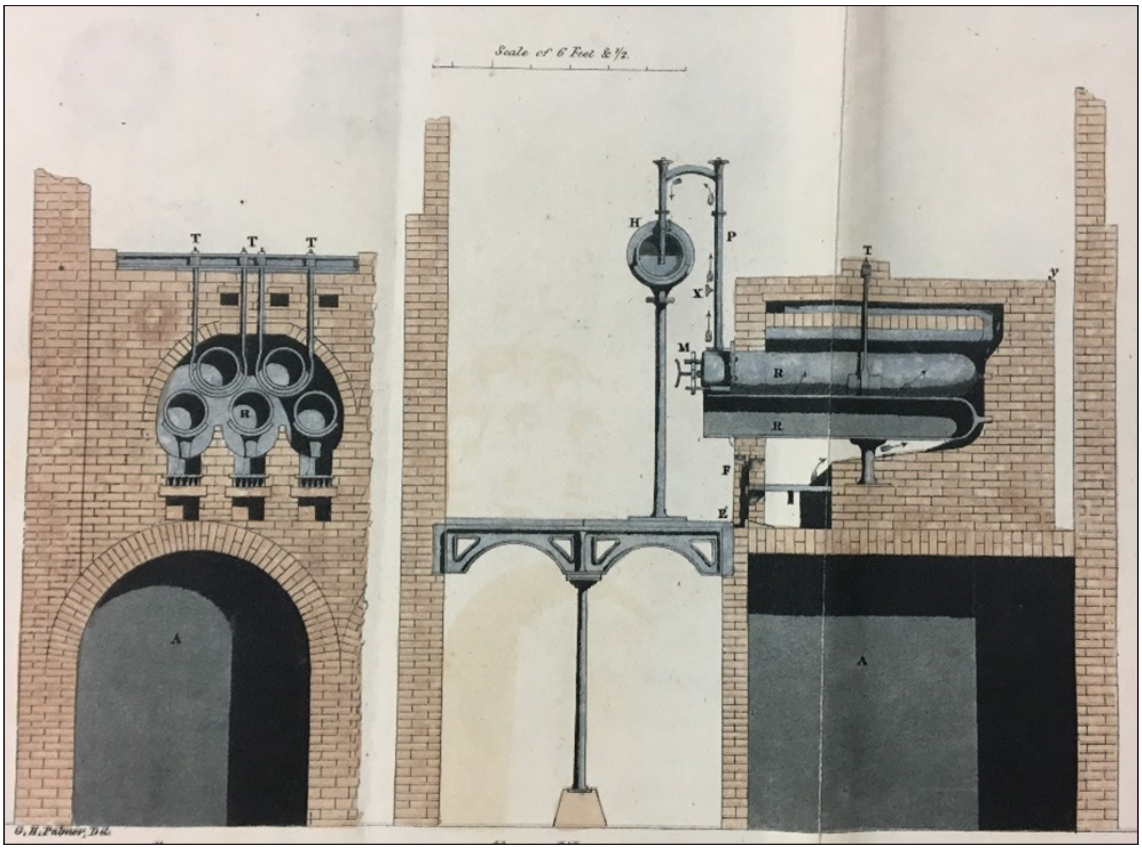


Figure 3.15 Cylindrical horizontal retorts installed at the Great Peter Street Gasworks of the GLCC. Source Accum 1819.

Fireclay retorts were primarily used as a D-shape retorts, although some large gasworks opted for the elliptical retorts. Such fireclay retorts were approximately 22 to 24 inches wide and 15 to 18 inches high, with the clay about 3 inches thick. Their length could vary from around 6 to 9 feet long for a stop ended retort to about 22 feet long for a through retort (King 1948). The Gas engineer Methven devised the setting of 10 horizontal retorts in two vertical rows of five retorts in 1852. This setting became popular.

The efforts of the stoker (Figure 3.16) on the charging and discharging of the retorts, meant the retorts would suffer from wear and tear so had to be replaced on a regular basis. The fireclay retorts on average lasted two to three times longer than the cast iron retorts. The settings were designed to be taken apart and rebuilt within a permanent brick arch as required (Hunt 1900, King 1948).

Between 1916 and 1923 Silica refractories started to replace fireclay for retort bench construction (Stewart 1960). Silica could withstand higher temperatures than fireclay.

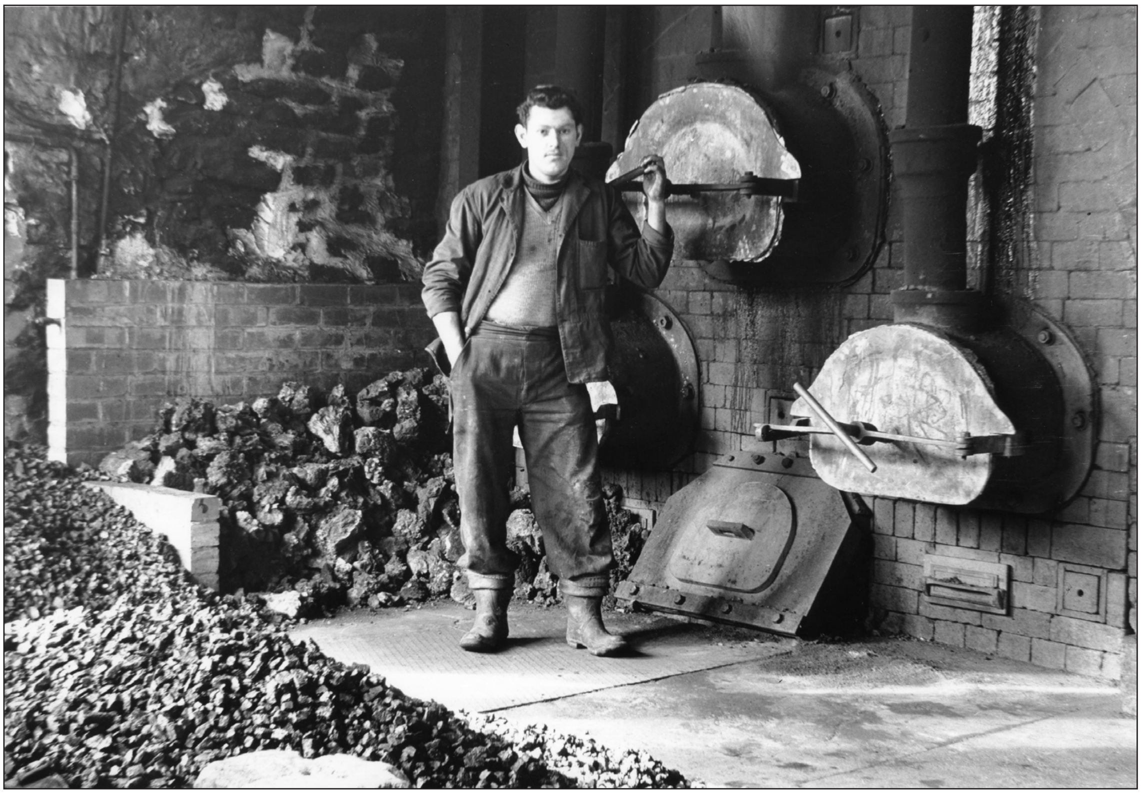


Figure 3.16 A stoker stood aside the retorts of the very small gasworks in Robin Hood's Bay, Yorkshire. Image courtesy of IGEM archive.

3.2.4.2 The Development of the Retort Mouthpiece

An important part of the retort was the mouthpiece. This was the opening through which the coal was placed, and coke removed, it was also the point at which the gas would be removed via an ascension pipe which was connected to the top of the mouthpiece. An early form of retort mouthpiece can be seen in Figure 3.17. The mouthpiece was bolted on to the retort by means of a flange and eight bolts, a fire-clay cement was used to bed the mouthpiece and retort together once the bolts were tightened to prevent gas escaping (Newbigging 1889).

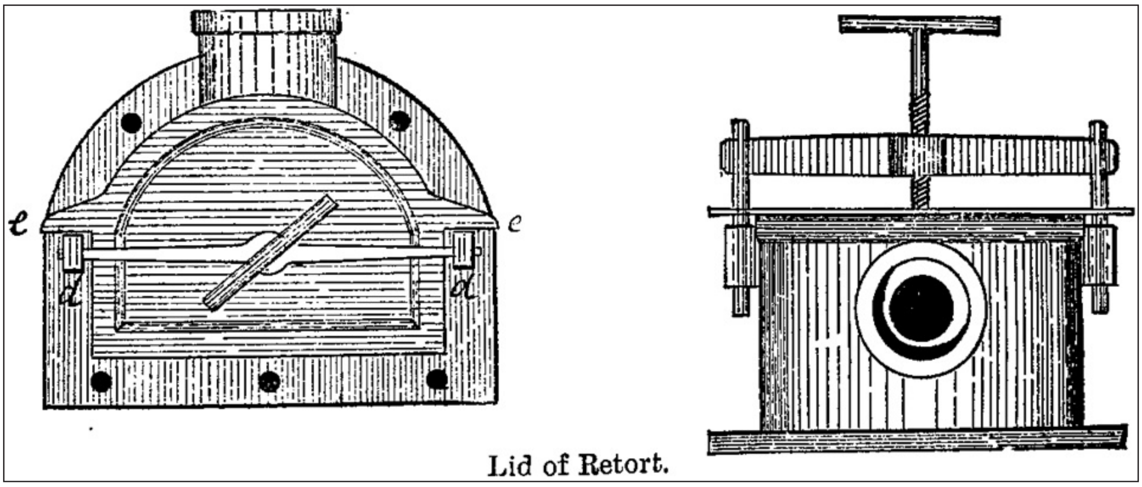


Figure 3.17 Early retort mouthpiece for D-shaped retort. Source Hunt 1900.

The concept of having a mouthpiece which was both separate and removable from the retort was proposed by John Hobbins the Gas Engineer of the Walsall gasworks in 1824 (Anon. 1860, Stewart 1960).

The lid of the retort was originally held on cottars and tightened using the cross bar and screw (see Figure 3.17). To form an airtight seal, spent lime or cement was placed as luting on the adjoining surfaces of lid and mouthpiece (Hunt 1900). This method would have been very difficult to operate, given the extreme heat and was superseded by Holman's fastening, which can be seen in Figure 3.18 and which replaced the lid with a hinged door. The lime cement luting was replaced by self-sealing lid, which was developed by Morton, the engineer at the Nine Elms gasworks in 1869. It had a v-shaped groove on the door which would form the airtight seal with the mouthpiece (Hunt 1900). The Holman style of fastening was used throughout the remaining life of the manufactured gas industry.

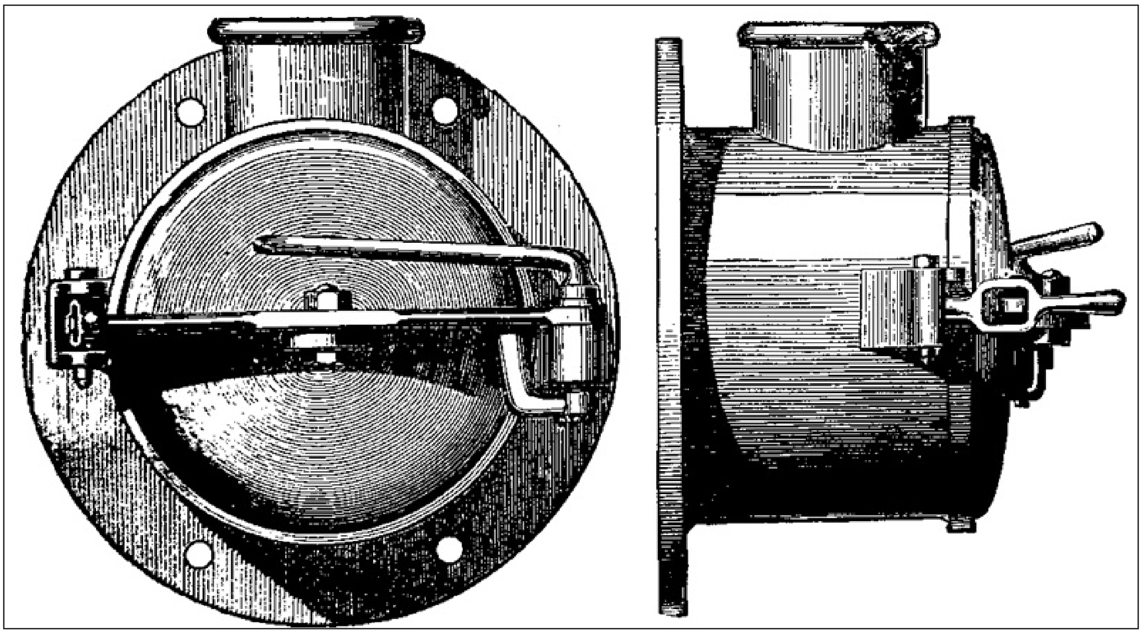


Figure 3.18 Holman's fastening retort mouthpiece. Source Hunt 1900.

From the mouthpiece the gas passed up the ascension pipe, which rose vertically before dipping into the hydraulic main. The ascension pipe was made of cast or wrought iron and had an internal diameter of no less than 5 inches. These were bolted to the mouthpiece and caulked with fireclay or slaked lime. The ascension pipe could occasionally become clogged with tarry substances (Newbigging 1889 p87). The flow of the gas from the hydraulic main is described later in section 3.3 (Hunt 1900, Meade 1921, King 1948).

In 1831 George Lowe patented (British patent No. 6179) a retort, with a door and ascension pipe at each end. This was known as the double ended retort, through retort or reciprocating retort. His patented concept for the retort was that the retort could then be charged alternately from each end. A later development in 1839, Lowe suggested that the through retorts could be charged at alternate ends. The development of the through-ended retort made it much easier to charge and discharge the retorts and aided later mechanisation (Hunt 1900, King 1948, Stewart 1960).

3.2.4.3 The Use of Coal Tar as a Fuel

The markets for the sale of coal tar were limited in the early to mid-19th century. It was found that it could be used directly as a fuel, a concept patented by George Lowe and John Kirkham in 1839 (No. 8298). The coal tar would be withdrawn from the hydraulic main and passed directly in the furnaces. As coke was a valuable by-product, the burning of the tar allowed the amount of coke used to be reduced and coke sales could be increased (Anon. 1860, Richards 1877). Around 1847 Mr Paterson the gas engineer of Berwick on Tweed, devised a method by which steam could be used to inject a spray of tar into the furnace. The process was very effective in increasing the heat of the furnaces to a white heat, such high heat led to the rapid deterioration of the retorts. The recovered tar was also used to enrich the gas by releasing vapours of the tar into the gas, this was tried by Lowe in the 1820’s and was patented by Malam in 1843 (Hughes and Richards 1880 p384). Attempts were also made to carbonise pitch briquettes in the retorts to produce gas in 1846.

In the latter half of the 19th century it became more economical to sell the tar for processing than to burn it as a fuel (Richards 1877).

3.2.4.4 Heating the Retort Bench

Beneath the retort bench was a furnace or producer, which was used to heat the retorts. The coal was heated for a period of between 8 and 12 hours. During this time the structure of the coal was changed significantly; the large aromatic compounds within the coal were broken down by the action of heat, releasing gas and vapour-phase compounds from the coal. These escaped up the ascension pipe, leaving behind the spongy coke which was largely composed of carbon.

Early retorts were heated directly by a shallow (1 foot deep) fuel bed of coke, which was lit beneath in the furnace as can be seen in Figure 3.19. The direct radiant heat from the furnace and the hot waste gases heated the retort. This design only heated the retorts to temperatures *circa* 600°C. As a result, the amount of gas produced was relatively low and the decomposition of the organic compounds in the tar fog produced was limited. Being simple and robust, this method of heating was used in early gasworks and continued in use in the very small gasworks, which would have produced less than 3 million cubic feet of gas per year (Meade 1921).

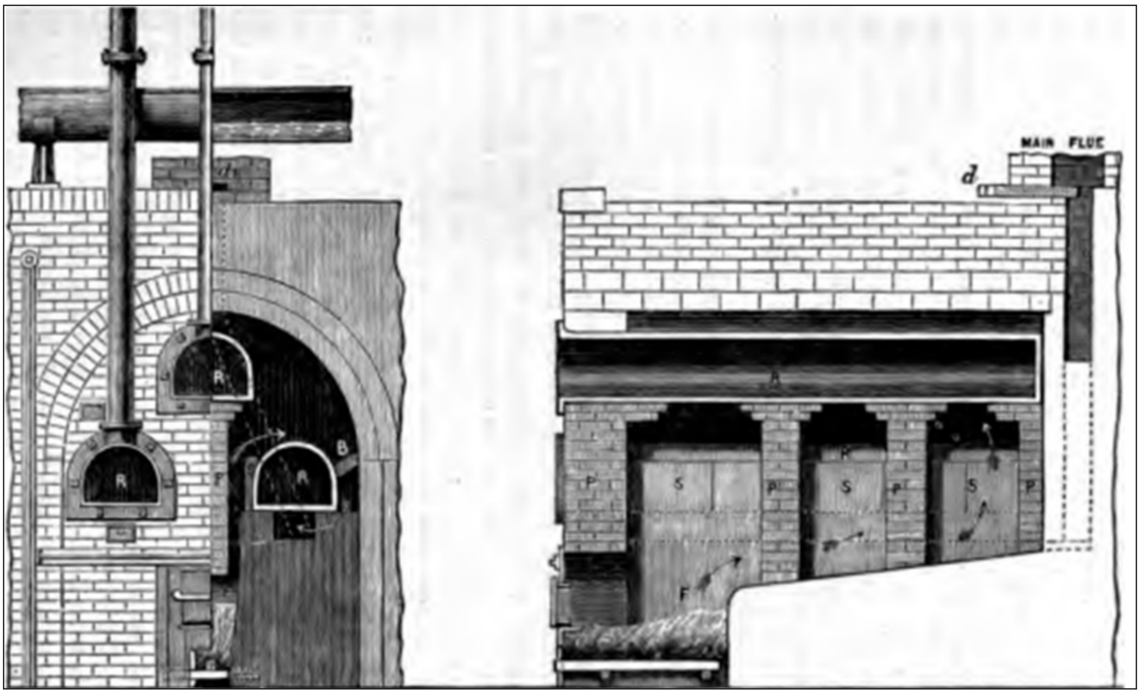


Figure 3.19 A schematic of a bench of three directly fired retorts which would be found in a small gasworks. Source Clegg Jnr 1841.

The semi-gaseous setting had a deeper fuel bed (2 feet deep), and provided some control over air supply, allowing some carbon monoxide gas to escape and burn adjacent to the retorts. This allowed higher carbonisation temperatures to be achieved with lower fuel consumption.

The more advanced gaseous-fired settings (Figure 3.20) appeared as a result of Frederick Siemens' work in 1857 to design an effective combined gas producer and regenerative furnace. This system was gradually improved and introduced to the UK through William Siemens in 1861, it was adopted at the larger gasworks and led to a great improvement in the efficiency of gas manufacture, reducing the cost of heating by a half (Dowson and Larter 1907, Stewart 1958). The development of the gas producer is described in more detail in Section 3.4.1.

The gaseous-fired setting used a gas producer to heat the retorts (Figure 3.20). The fuel bed in the producer would be about 5 to 6 feet deep. The primary air supply was very carefully controlled to maximise the carbon monoxide formation in producer gas. The carbon monoxide in the gas producer gas was then channelled gas to a combustion chamber directly adjacent to the retorts, where it was mixed with a secondary supply of air and burned. The gaseous-fired setting was the most fuel efficient and exerted the most accurate temperature control, with even heating along the retort and the highest carbonisation temperatures if required (Meade 1921).

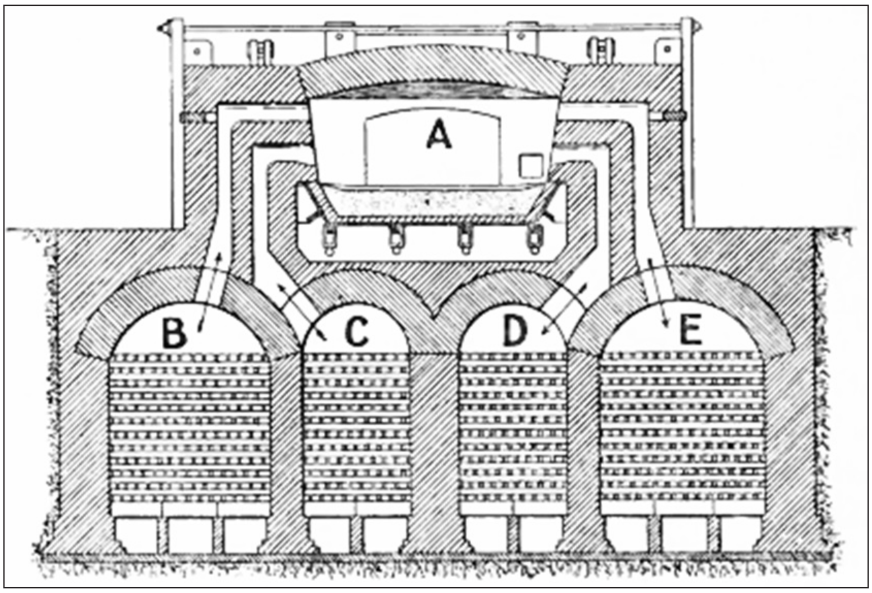


Figure 3.20 A schematic of a Siemens gas furnace. Source Dowson and Larter 1907.

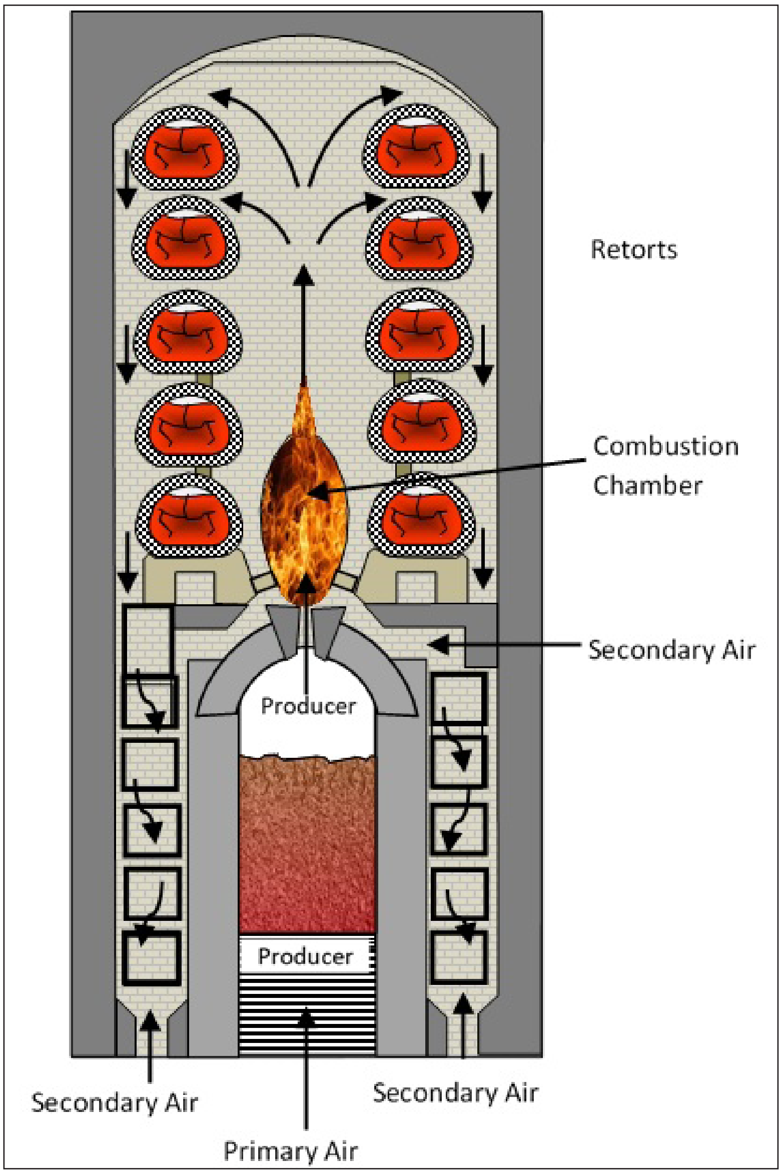


Figure 3.21 Retort setting showing gas producer and combustion chamber. Source R. Thomas.

The producers were often integrated into the retort setting, however later designs of producers could be separate to the retort house, with the gas being delivered via pipework between the plant. This design could provide more flexibility over how the producer gas was used, including using the gas to supplement gas supplies at times of peak demand (Meade 1921).

Two types of retort setting were used, the generator and regenerator setting, the essential difference being the way that the waste gases were circulated, and in the latter type how the heat was extracted from the waste gas. In the generator setting the main waste-gas flue travelled along the top of the main arches and was vented to chimneys built at intervals along the retort house. The regenerator setting had a waste flue which generally ran longitudinally through the entire bench, just above foundation-level (Meade 1921).

The generator setting was also used with a double furnace (Figure 3.22a), whilst the regenerator setting was generally employed with a single furnace (Figure 3.22b). The single furnaces advantages included better working condition for the reduced labour required in charging and clinkering, greater control over the heats produced and less wear and tear. The 'Generator setting' was used from 1865 to the 1930s in smaller works, it was seldom used on through retorts. The regenerator setting remained in use on carbonisation plant up until conversion to natural gas (Meade 1921, Stewart 1958).

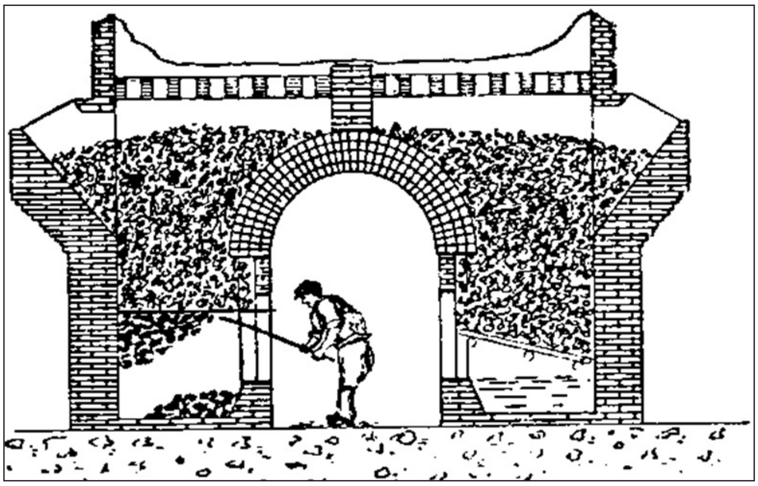


Figure 3.22a A schematic of a Double Furnace. Source Meade 1921.

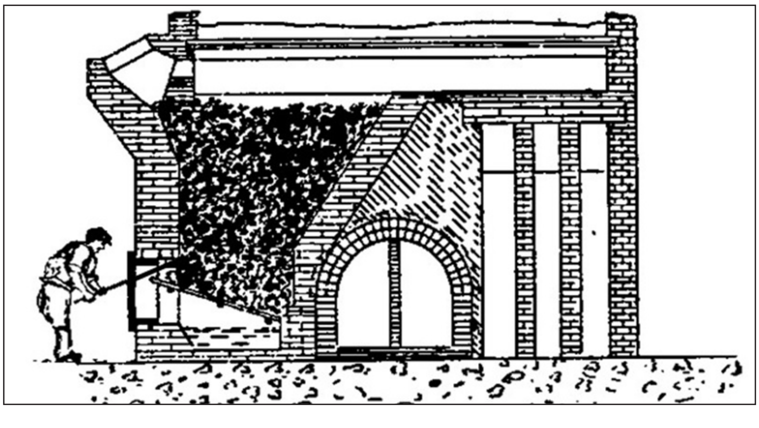


Figure 3.22b A schematic of a Single Furnace. Source Meade 1921.

Another important factor was whether the waste gas from the producer was used to heat incoming air, thus enabling greater efficiency and higher carbonisation temperatures to be achieved. This was called a ‘recuperative’ or ‘regenerative’ gaseous-fired setting (Stewart 1958).

The maximum carbonisation temperature was dependent on the combustion temperature achieved by the burning of the producer gas in the combustion chamber adjacent to the retorts. This maximum temperature was governed in part by the temperature of the gas mixture before combustion. By heating the incoming secondary air, it was therefore possible to increase the maximum temperature in the combustion chamber and therefore the retorts. The normal temperature of the burnt gases leaving the setting was approximately 950°C, however, by recovering heat from the exit gases and transferring this heat to the inflowing secondary air, it saved fuel (about a 6-11% reduction), cooled the exit gas and increased the maximum combustion temperature (Meade 1921).

Siemens original regenerator gas furnace (see Figure 3.20), worked intermittently, when operational the hot gases from the furnace (A) were made to pass downwards through two of the chambers below the furnace, for example D and E, which contained chequered firebricks which absorbed the heat of the exit gas whilst the incoming gas was passed through chambers B and C. After a period of 20 to 30 minutes, the direction of the flow of gas was reversed with the incoming gas absorbing heat stored in the firebricks (Dowson and Larter 1907).

In 1885 the Klönne regenerator system which used specialised regenerator blocks (Figure 3.23) was developed in Germany and soon adopted in the UK. Using this system outgoing wastes gases from the producer passed through a series of flues in very close proximity to the flues bringing in the secondary air which was then heated.

Other systems were also developed by Schilling of Germany and British Companies such as Drakes, and Gibbons and Masters (Meade 1916).

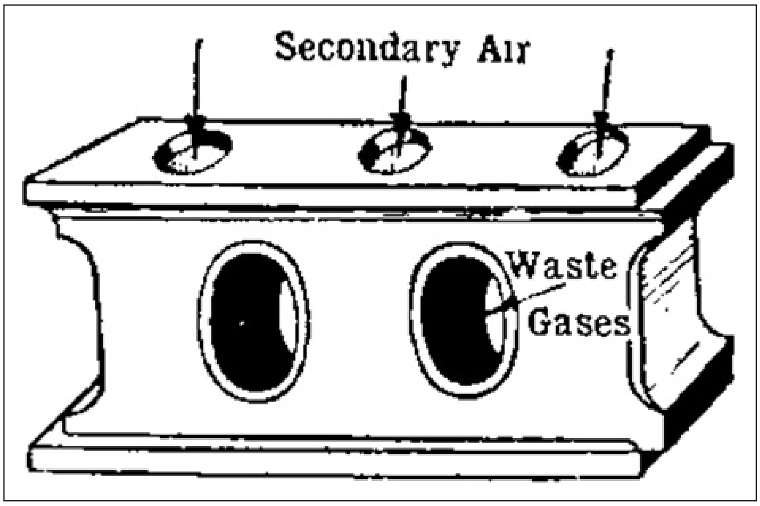


Figure 3.23 The Klönne Regenerator Block. Source Meade 1921.

3.2.4.5 Charging and Discharging Retorts

Charging (loading) and discharging (unloading) a retort was hot, arduous and dangerous work (Figure 3.24) and the conditions within the early retort houses were grim as depicted by Gustav Dore in Figure 3.25. It was however, often the only practical option in small gasworks. The tools were relatively simple, using a shovel typically 16 inches long by 11 inches wide to charge the retorts and a shovel which was an inch wider for the firing of furnaces.

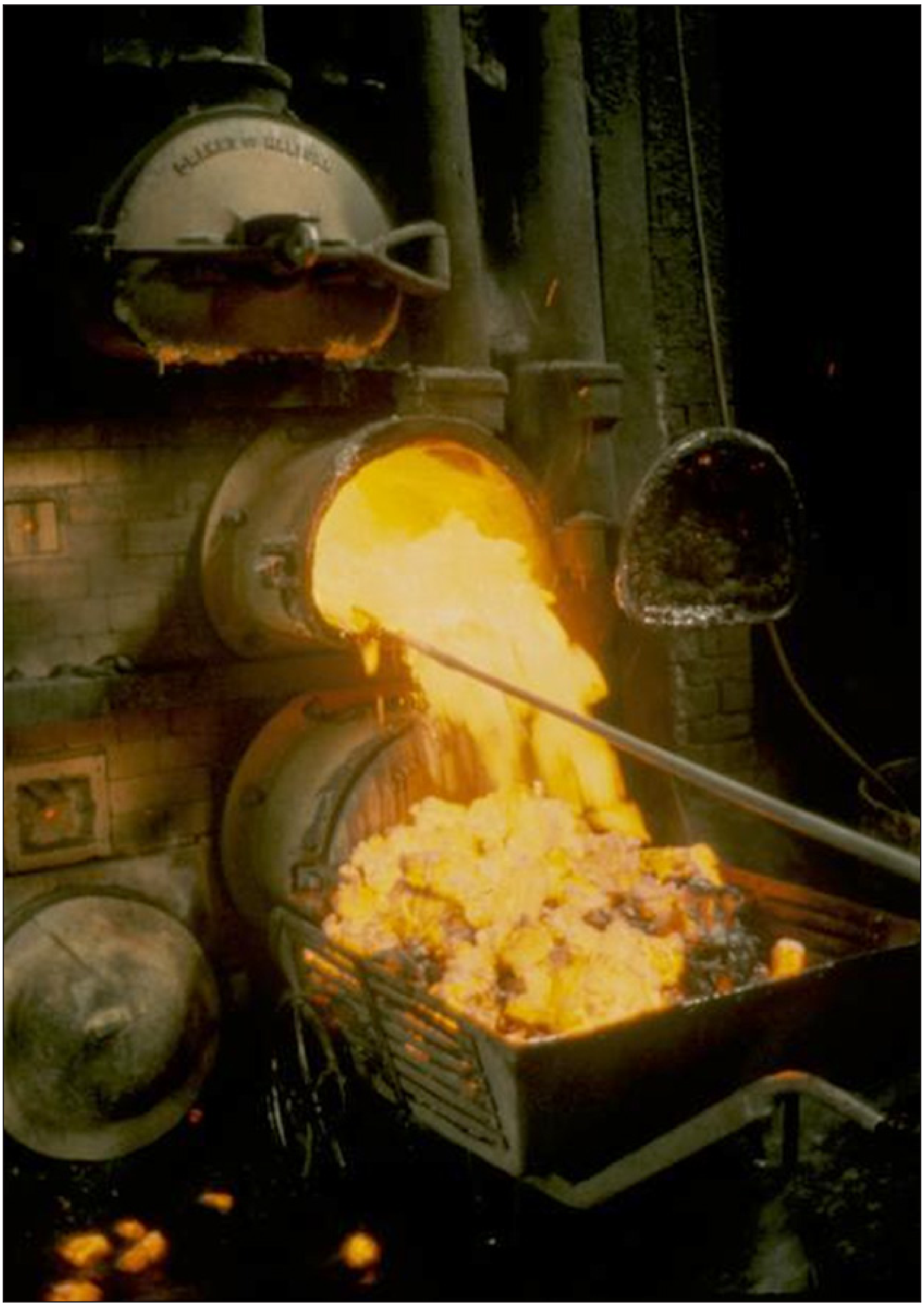


Figure 3.24 Manually emptying hot coke from a stop-ended horizontal retort. Image courtesy of National Grid Gas Archive.

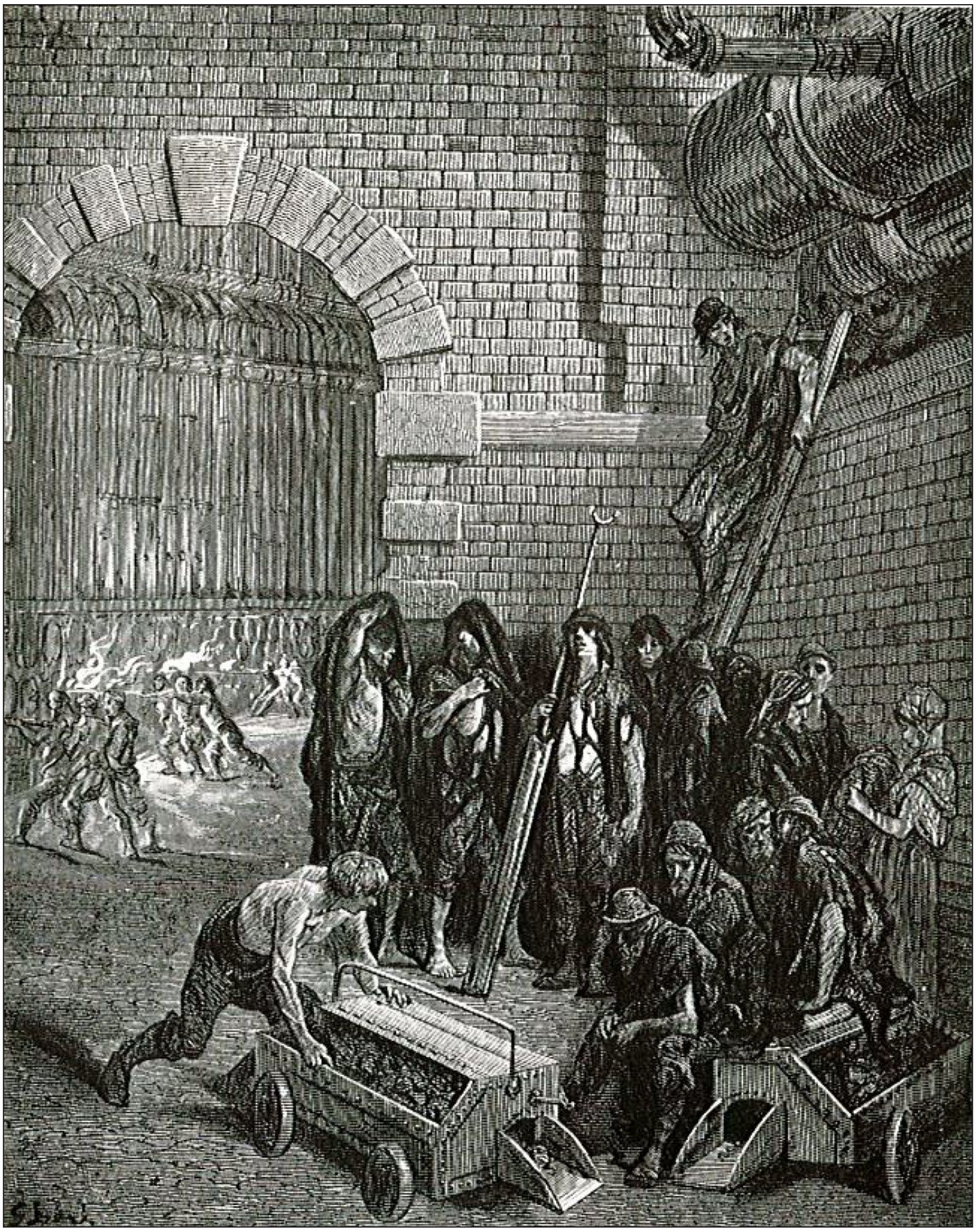


Figure 3.25. A drawing by Gustav Dore entitled ‘Lambeth Gas Works’. Source Chandler 1936.

A scoop (Figure 3.26a) was also a popular tool for gasworks which employed a team of at least 6 stokers. The scoop was a semi-circular trough of sheet iron (or steel) which held between 1 ½ or 1 ¾ cwt of coal and was half the length of the retort. It required 3 stokers to handle the scoop and they were used to load through retorts, with a team of stokers loading the retort twice from each end (Newbigging 1889 p63-64). A range of other hand tools including rakes, shovels, augers and tools used in the operation and maintenance of a retort house are shown in Figure 3.26. The barrow used for moving coke and coal was an important tool in the gasworks, two examples are shown in Figure 3.26.

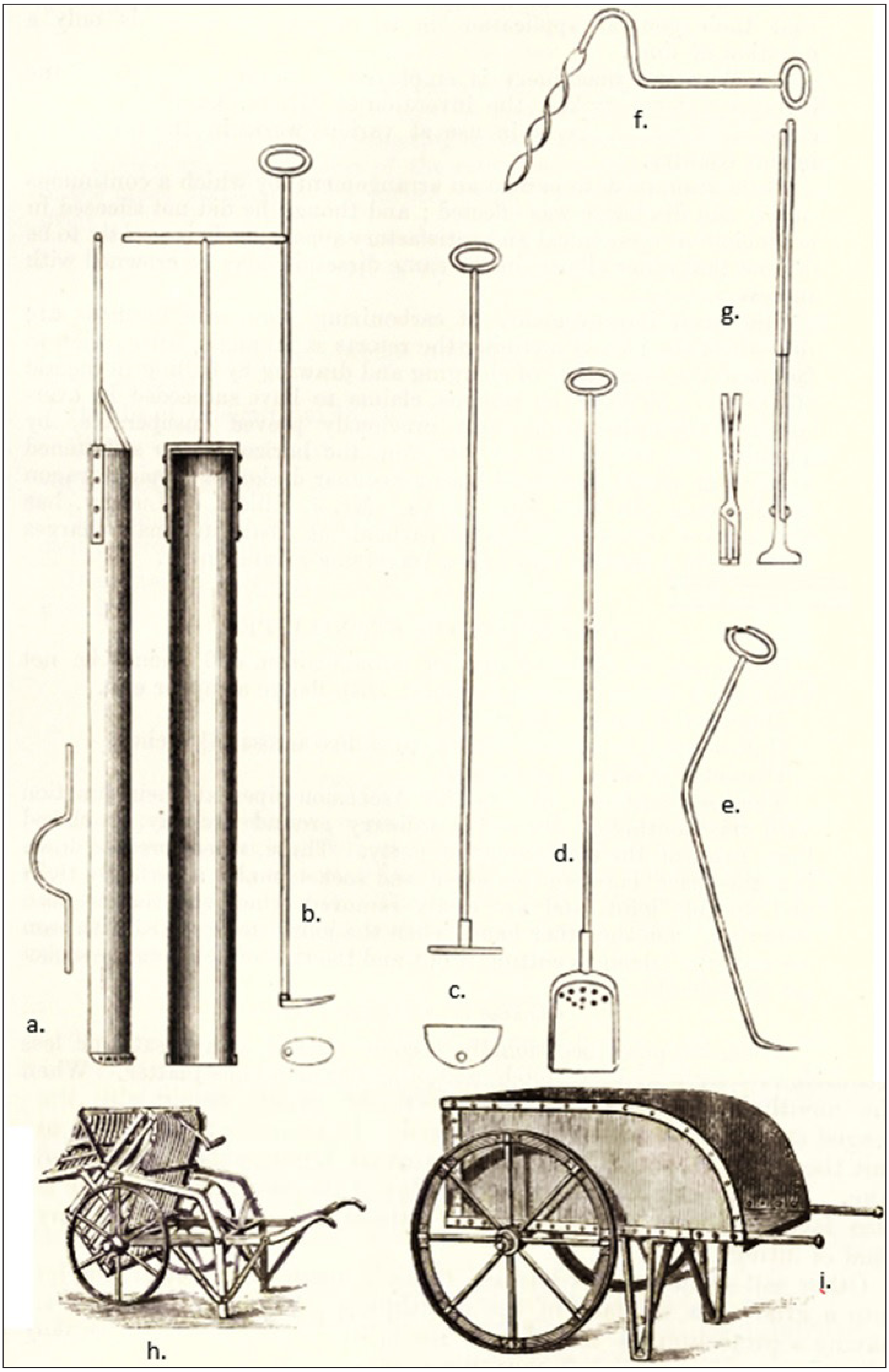


Figure 3.26 A Selection of hand tools used by the Stoker, including: a. The Scoop; b. Discharging rake; c. Ash-pan rake and d. Shovel; e. Pricker; f. Auger; g. Fire tongs; h. Price's coke and coal barrow; and i. Cockey's charging barrow. Source Newbigging 1889.

The increasing size of gasworks and retort houses in towns and cities allowed for further innovations in how operations could be undertaken more effectively and efficiently.

3.2.4.6 Mechanisation of Charging and Discharging Retorts

John Brunton devised a mechanised horizontal retort which could be operated continuously which he patented in 1835 (No. 6799). The retorts incorporated a piston powered screw mechanism and were sloped on their base to aid coke removal, he used this design at the gasworks in West Bromwich (Hunt 1900, Anon. 1860). Similar systems were patented by William Barnett (No. 7129) in 1836 and William Heginbotham (No. 7560) in 1838. Heginbotham's design used coal, which had been pre-crushed. In 1857 George Bower developed a continuous horizontal retort, which operated on the concept of an Archimedean screw which both removed coke and delivered fresh coal into the retort (Anon. 1960).

John Grafton patented (No. 7788) a system where a truck ran within the retort, loading coal at one end and then spreading it along the base of the retort, this system was not used elsewhere, but another aspect of having two ascension pipes, one at each end, was adopted and used by George Lowe on his through retorts (Anon. 1860).

Both Cruikshanks in 1839 (No.8141) and William Cartwright Holmes (No. 1405) in 1855 patented methods for the steaming of coal in a horizontal retort (Anon. 1860, Stewart 1960). The benefit of steaming was to increase the gas yield through producing water gas, a process which is described in detail in a later section of this report.

Alexander Croll whose name appears many times in this report patented (No. 8253) a process in 1839 where the heat held within hot coke was utilised by directly placing the coke in the furnaces after discharge from the retorts (Anon. 1860). This removed the requirement to quench the coke to cool it.

Prior to the use of producer gas for heating retort George Lowe and Frederick Evans patented the use of producer gas made from poor quality coal, peat or wood to dilute coal gas.

Although William Murdoch experimented with a variety of different designs and included vertical retorts at his first installation at the Salford Twist Mill of Phillips and Lee, the favoured design for most of the 19th century was the horizontal retort.

These retorts were originally designed as 'stop ended': closed at one end with an airtight iron door and ascension pipe at the other. A development by George Lowe in 1831 saw a change in design to a 'through retort' system. Doors on both sides allowed coal to be pushed into the retort at one end and, once the carbonisation process was completed, the remaining coke was pushed out through the back of the retort. An example of an early 20th century mechanical charger on a small gasworks is shown in Figure 3.27.

Figure 3.27 Loading a retort with a mechanical charger. Image courtesy of National Grid Gas Archive.

In 1825 George Lowe developed a scoop system of charging of retorts on the Curtain Road and Brick Lane gasworks (Stewart 1960).

John Grafton developed a retort charger with open bottom wagon and pusher front in 1838, Green had developed stoking machine with combined scoop and rake in 1858. From 1860 onwards, there was an onslaught in the development of retort house mechanisation, after which the mechanisation of the retort house gained real moment. A series of developments (Table 3.1) meant that the retorts could be charged (loaded) and discharged (unloaded) mechanically (Fewtrell and Newbigging 1878).

Table 3.1 Developments in the mechanisation of retort charging and discharging.

Year	Development
1869	Foulis retort stoking machinery
1973	West Manual stoking machinery
1874	Rowlands compressed air driven stoking machinery
1876	Tangye Hydraulic stoking machinery (Tried at Beckton)
1878	Taylor Stoking Machine Richards stoking machine
1880	Ross Steam Stoker - Coal projected into retort by steam jet.
1881	Wests Compressed air driven stoking machines
1883	Sommerville Stoking machinery – improved Best & Holden
1885	West Stoking machinery with revolving and opening scoops and rakes driven by steam, rope drives or compressed air.
1891	Arrol-Foulis Stoking machines with hydraulic operation.
1892	Green Retort charging machine on conveyor Principle
1900	De Brouwer Revolving belt projector retort charger.
1907	Fiddes-Aldridge Combined charger-discharger stoking machine.
1913	Guest Gibbons Combined retort charger-discharger.
1937	Fiddes-Aldridge Multiple Stroke charge-discharger

In 1867 Mann introduced a stoking machine with an opening scoop and rake at the Blackfriars gasworks in London, which was followed by a similar system developed by Best and Holden in 1868 (Stewart 1960).

The main driver for automating the loading and unloading of retorts was the London Stokers Strike of 1874. Following the strike, gas companies looked to reduce their dependence on stokers (Chester 1900).

Mr John West, the manager at the Maidstone Gasworks developed in 1873 one of the first and most notable systems for charging and discharging retorts, which is shown in Figure 3.28. This required modification of both retort mouthpieces. In this system, each retort had its own dedicated machine. The rod for working which was passed through a stuffing box in the retort door. Above each mouthpiece there was also a cylindrical coal hopper, fed from above, which supplied coal to the machine to charge the retort. A plate on the front of the charger, which ran on wheels, served to push the coke out of a sloping mouthpiece at the opposite end of the retort. This machine was therefore an early attempt of a combined charging and discharging machine.

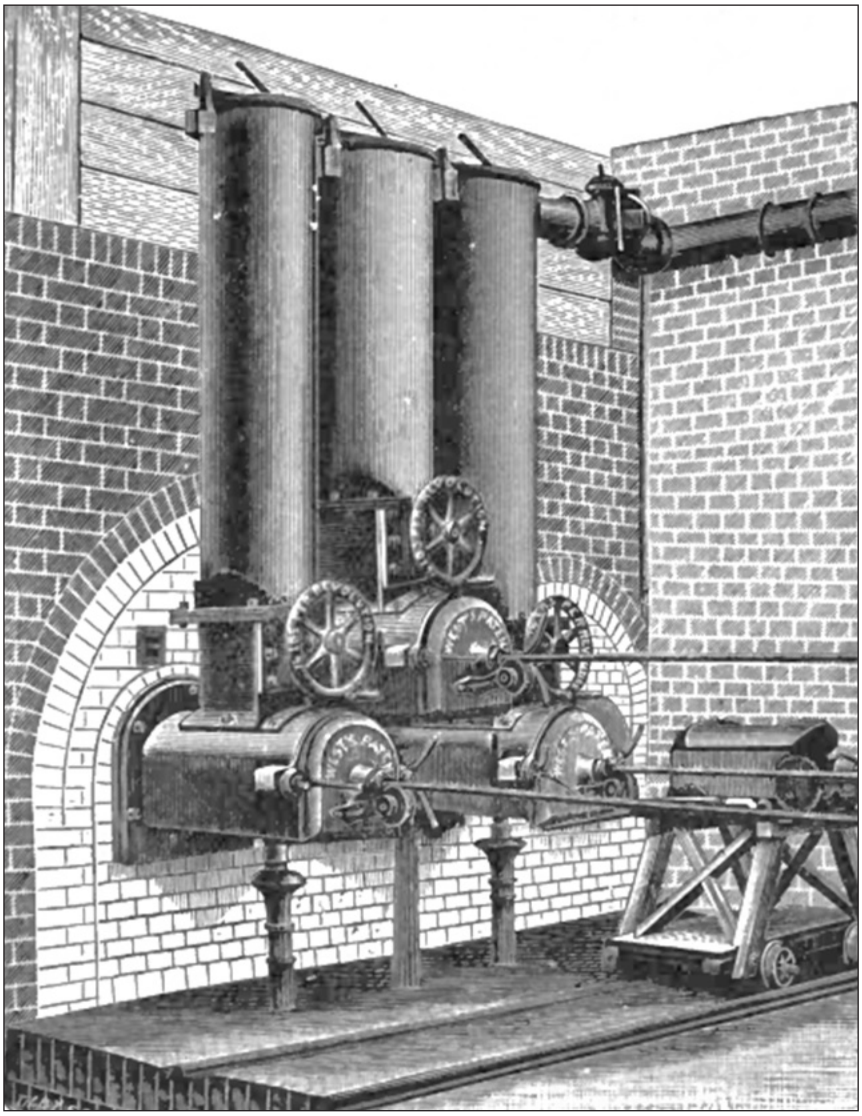


Figure 3.28 John West’s original stoking machine. Source Brackenbury 1901.

Whilst this device advanced the process it required further development. In “King’s Treatise” published in 1878 described no less than 16 different types of stoking machine, however (Fewtrell and Newbigging 1878). An issue found with many of the machines developed is that whilst they resolved the challenge of charging and drawing the retorts, they did nothing to aid the movement of coal from the store to the retort. Without the automated movement of the coal, the gas engineers were not convinced of the benefit of the new charging machines over traditional labour, which at this point was still cheap (Brackenbury 1901, Stewart 1958).

John West’s continued development of charging and discharging process involved using a trolley mounted on rails which moved up and down in front of the retort bench. It carried a coal hopper and the charging apparatus. West also introduced, for the first time, coal breaking, elevating and conveying machinery to work in conjunction with the stoking apparatus (Brackenbury 1901, Stewart 1958).

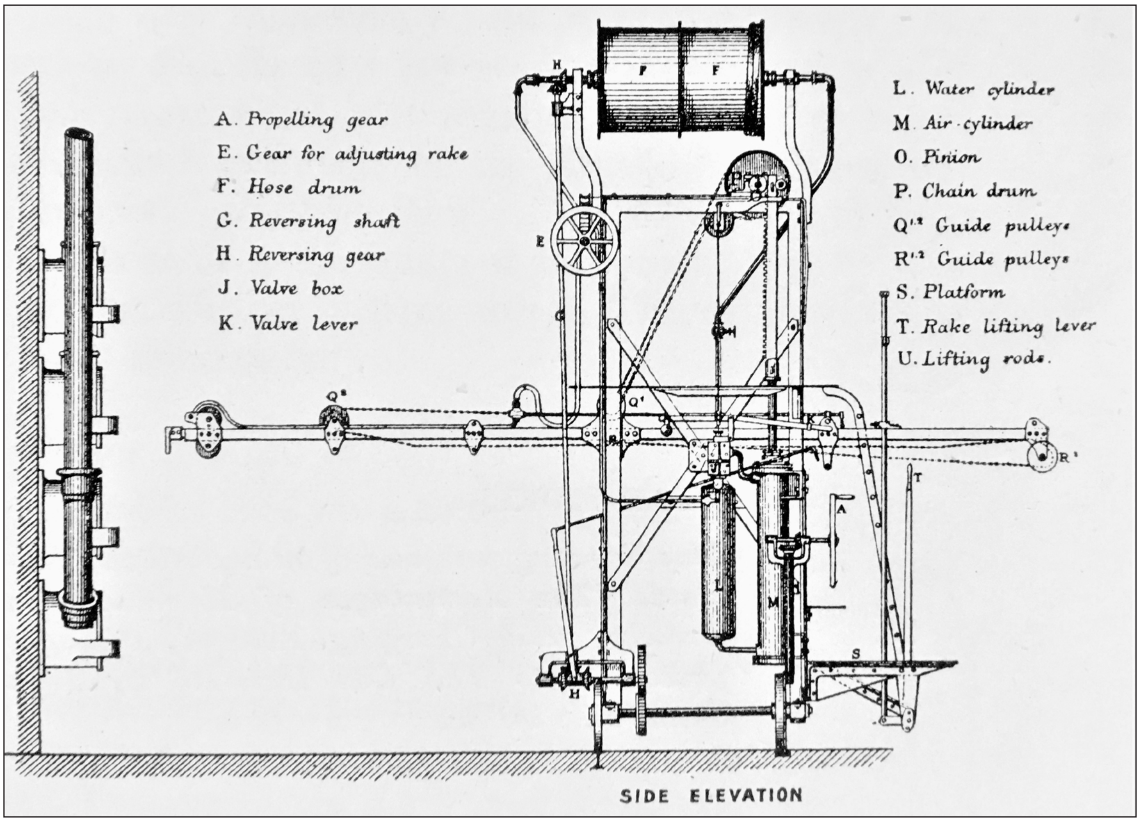


Figure 3.29 West’s compressed air drawing machine. Image courtesy of IGEM Archive.

West also applied power to this manual machine. Alterations were made to the machine with additional mechanisms added, and the device made more robust. By 1881 a compressed air powered machine (Figure 3.29) was being used at the Rochdale Road Gasworks of the Manchester built by West’s Gas Improvement Co. Limited, of Manchester. (Brackenbury 1901). A variant of the machine using rope driven machines were introduced in 1889. West’s Charging and discharging machines were very successful and by 1891 190 of these machines were in use in Britain.

Mr. William Foulis, the Gas Engineer of the Glasgow Corporation gasworks developed a hydraulically powered charging machine. His machine also ran on tracks along the retort house floor. This machine was greatly improved by Sir William Arrol working with William Foulis, which later employed water to cool the charging shovel and drawing rake (Brackenbury 1901).

Ross's Steam Stoker, shown in Figure 3.30 was a self-contained steam powered drawing and charging machine developed in the USA. It was used on the Nine Elms gasworks in London and the Windsor Street gasworks in Birmingham. They were manufactured in England by Messrs. Tangyes Ltd of Birmingham and contained their own boilers, which required skilled attendance, so they did not achieve wide spread use.

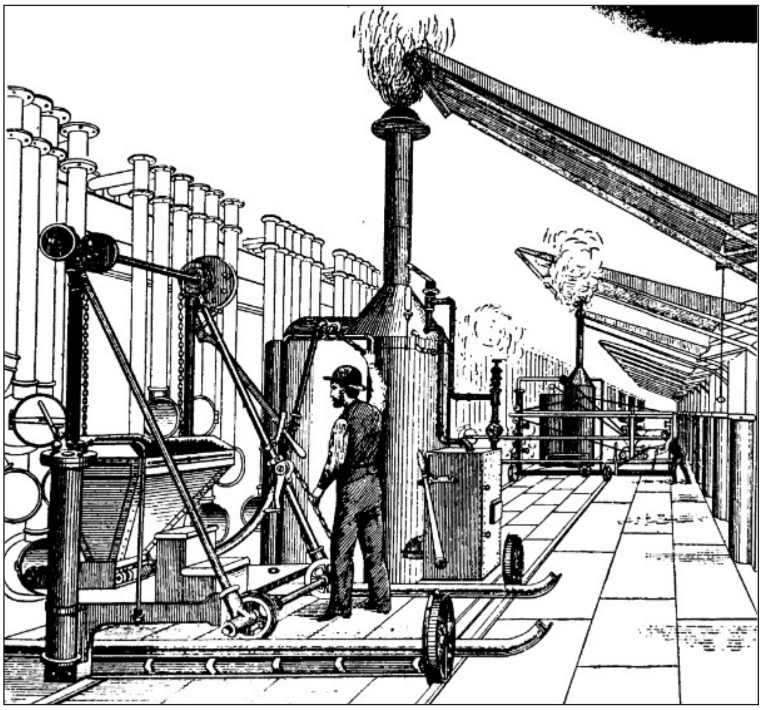


Figure 3.30 Ross' steam stoker. Source Chandler 1949.

The development of the through retort, had made charging and discharging much easier and allowed the process to be mechanised. The machines typically had mechanical pushers with an arm that could push all the way through the retort. The spent hot coke was pushed through the rear door of the retort, sometimes being collected on a conveyor or carriage. Another mechanical arm would then be inserted to load the retort with a new charge of coal, which would be levelled by another arm to give a consistent charge across the retort. (Brackenbury 1901).

The concept of a charging machine working on the projector principle and shown in Figure 3.31, was developed by Auguste de Brouwer, the Gas Engineer at the gasworks in Bruges in Belgium. It provided a considerable advantage over other equipment that it could fully charge a retort from only one side only. The system was quite simple that it used a large, grooved fly wheel. The flywheel and a belt held by three pulley wheels were powered by and electric motor. As coal fed between the fly wheel and belt it was projected through a telescopic feeding shoot into the retort (Ferguson Bell 1909, Meade 1916, Stewart 1958).

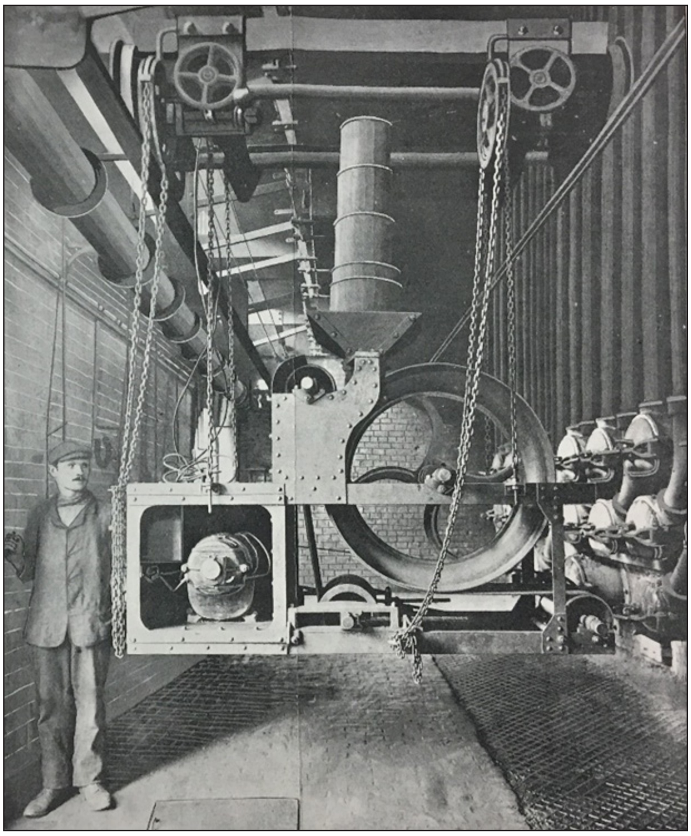


Figure 3.31 The De Brouwer Projector at Derby's Litchurch gasworks in 1909. Source Ferguson Bell 1909.

The Fiddes-Aldridge Charging and Discharging machine shown in Figure 3.32 used a similar method to that devised by Belgian engineer M. De Brouwer, which projected coal into the retort using the energy derived from the centrifugal force of spinning the coal in a large wheel (Meade 1916, Stewart 1958).

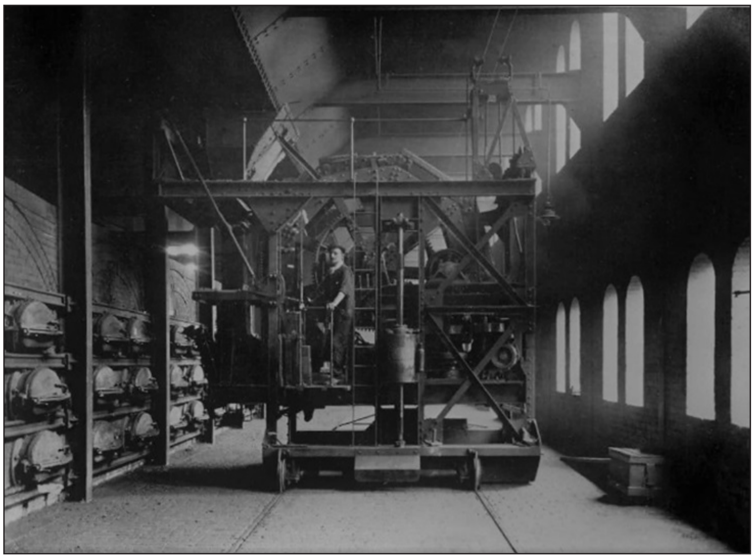


Figure 3.32 Fiddes-Aldridge charging and discharging machine at the Adderley Street gasworks in Birmingham. Image courtesy of National Grid Gas Archive.

The furnaces could also be loaded with coke (or coal) automatically. Such a mechanical device for loading coke into the furnaces of the horizontal retorts at Beckton is shown in Figure 3.33.

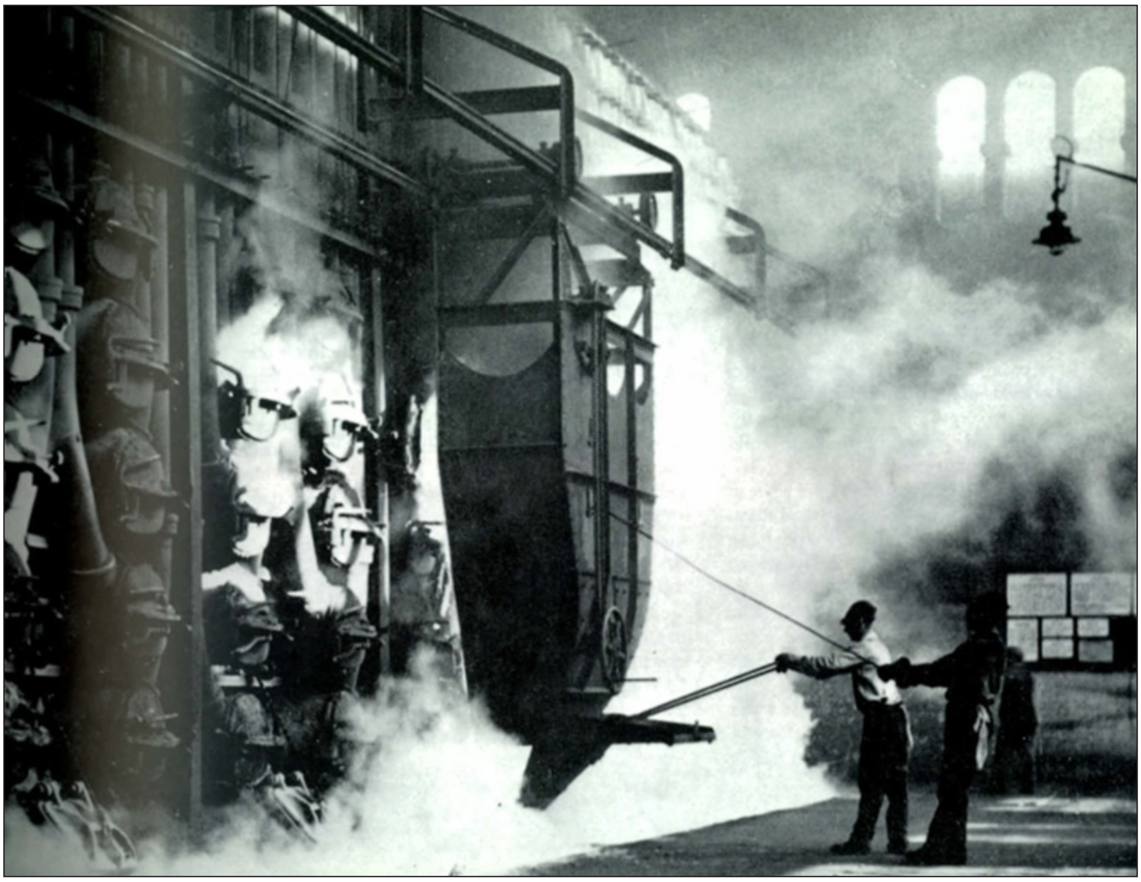


Figure 3.33 Loading coal into the furnaces within the retort house at Beckton. Image courtesy of National Grid Gas Archive.

At the front of the retort (above and behind the Retort Mouthpiece) was the ascension pipe. Some through retorts had a second ascension pipe on the rear mouthpiece. The role of the ascension pipe was to allow the gas and vapours to be removed from the retort and rise into the water-filled hydraulic main, which acted as both a water seal and primary condenser, removing a large portion of the tar and liquor from the gas. From the hydraulic main, gas would leave the retort house via the foul main (Meade 1916, Stewart 1958).

The retort house was controlled by the team of stokers under the guidance of the engineer. The stokers and engineers had very little equipment to measure the performance of the system, just a u-tube filled with water to measure gas pressure. Most judgments were made using knowledge and experience to check the colour of the flames. The retort house was subject to very harsh working conditions, with very high temperatures, smoke, dust and steam. To allow the hot air, dust and steam to escape a louvred clerestory was built into the roof and ventilation built into the walls above the height of the retorts to allow heat to escape in horizontal retort houses.

Initially, horizontal retorts were used on all sizes of gasworks. However as technology developed through the 19th Century, the gasworks serving towns and cities constructed ever larger horizontal retort houses with mechanised charging and discharging of the retorts. In the late 19th and early 20th-centuries, new types of retort were developed and started to become commercially available. These included inclined retorts, vertical retorts and chamber ovens, some of which could operate continuously (Stewart 1958). The small gasworks in small towns, villages and private establishments continued to use horizontal retorts.

3.2.5 The Inclined Retort

One of the disadvantages with horizontal retorts had been the considerable manual or mechanical effort required to load coal into the retort and discharge the coke from the retorts. One alternative approach was the use of inclined retorts, which could aid the movement of the coal and coke by gravity. Murdoch had experimented unsuccessfully with inclined retorts at Soho (see Figure 3.10 bottom right). However, this did not put off later engineers returning to the concept to make it viable. In 1818 John Grafton applied for a British Patent (No.4306) for an "Improved process or method of making carburetted hydrogen gas for the purpose of illumination." The design for the retorts were to be opened at both end and placed on an inclined position. He also introduced the use of fireclay for lining or casing the retorts. The retort was to be positioned on an incline held above the furnace (Anon, 1860, Stewart, 1960). Grafton's inclined retort design did not receive much further attention.

In 1854 Aristide Balthazard Berard applied for a British Patent (No. N° 1854), firstly, in the manufacture of "gas, coke, and other products from coal, by distilling the coal in masses of not less than one ton in a cylindro-conical fire-clay retort, having its axis inclined to the horizontal at an angle of not less than forty degrees, nor more than sixty degrees. This was followed in 1857 by Alexander Croll, who carbonised coal in a thin layer in an inclined retort (Anon, 1860).

The most significant development in the inclined retort came in 1885 when Emile Coze developed and later patented an inclined retort system at the gasworks in Rheims in France, where he was the engineer. The inclined retort system was promoted by the Coze Syndicate Ltd in Britain, a schematic from one of their adverts is shown in Figure 3.34.

These types of retort became popular in Britain after Frank Morris, the engineer of the Brentford Gas Company adopted it at their Southall Gasworks in 1892 (Figure 3.35). Other engineers soon followed such as George Winstanley at Coventry and Walter Herring at Huddersfield. By 1901 large inclined settings had been installed at the Meadow Lane gasworks in Leeds, Gaythorn gasworks in Manchester, the Saltley gasworks in Birmingham and the Rochdale gasworks (see Figure 3.9). Companies such as West's Gas Improvement Company focussed on improving the inclined retort and refractory brick manufacturers such as Gibbons Brothers in Dudley, manufactured retorts and firebricks specifically for inclined retorts, sometimes referred to as "slopers" (Stevenson 1901).

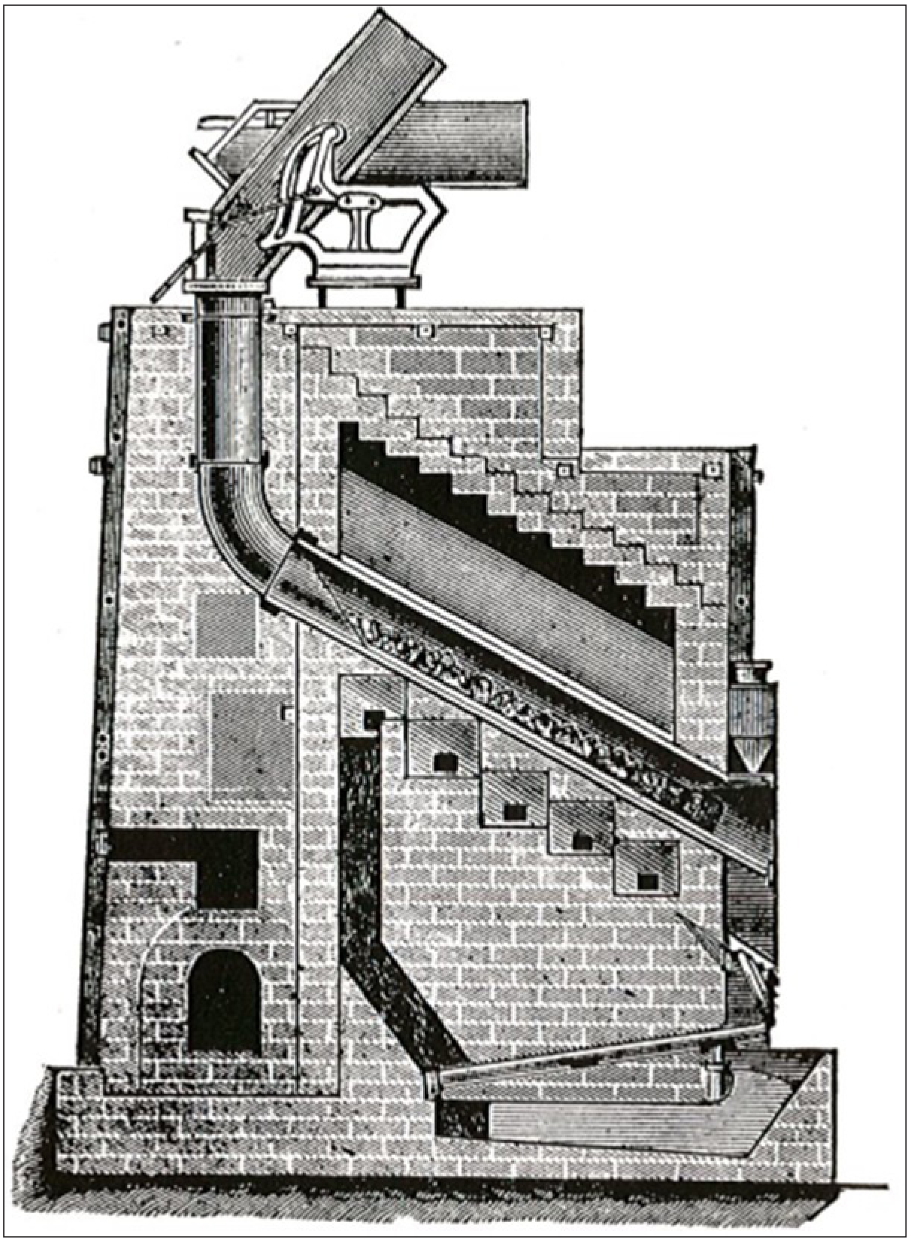


Figure 3.34 A schematic of the Coze inclined retort taken from an advertisement from 1890, by the Coze Syndicate Ltd for inclined retorts. Image courtesy of IGEM Archive.

The angle of the incline could vary from 28 to 34 degrees from the horizontal, however, they were generally set between 31 and 32 degrees from the horizontal in Britain, the theoretical angle of repose for most available types of British coals. The incline made it easier to load and unload the retorts. The length of the inclined retorts varied from 15 feet long in smaller installations to 20ft long in larger settings. Typically, they tapered from 24 inches by 15 inches at the bottom to 22 inches by 15 inches at the top. (Stevenson 1901).

The retorts were heated using regenerative furnaces, which heated the lower end of the retort with the heat rising to heat the higher portion of the retort. The inclined retorts developed such that they could be loaded mechanically from a charging device which could be moved along the retort settings, a mechanical conveyor being used to raise the coal up to the charging device. The carbonisation process within the inclined retort would take about eight hours (Stevenson 1901).

In theory, the system benefitted from less wear and tear and could be used without some of the charging and discharging machinery required on a horizontal retort. But it took skill to get an even charge within the retort and it was harder to get an even temperature. The coal was prone to creep down the retort when heated, so only certain types of coal were suitable for use in this retort. The coke could be hard to remove, even with the aid of mechanical pushers. Fuel consumption for heating was higher than for horizontal retorts and they were more difficult to operate and maintain, but some engineers preferred this form of retort (Meade 1921, Stevenson 1901).

With the development of the vertical retort they were eventually superseded, although the design was still popular in some gasworks and gas was still being manufactured using inclined retorts as late as 1948 (Stewart 1958).

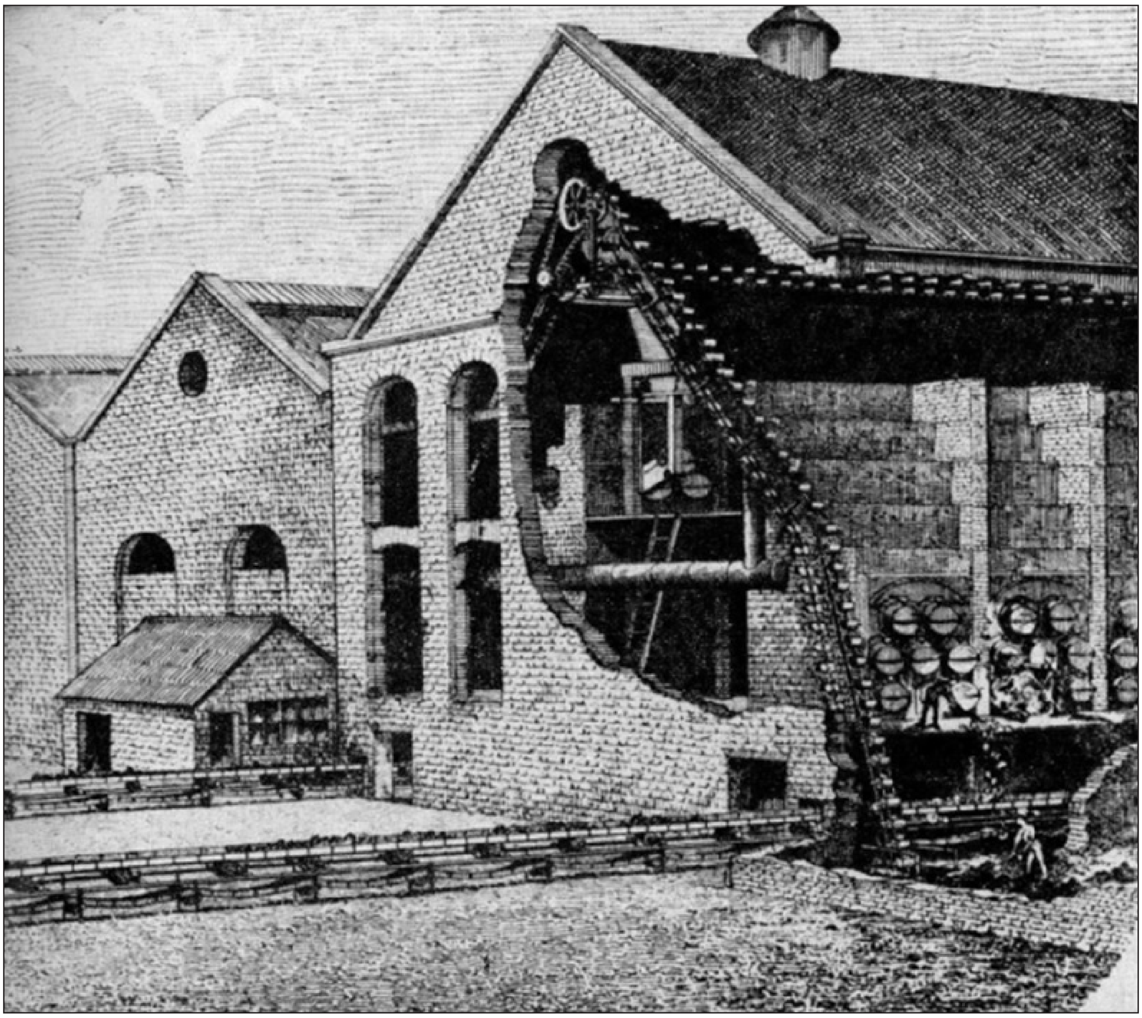


Figure 3.35 A sketch of the inclined retorts installed at Southall Gasworks. Image courtesy of National Grid Gas Archive.

3.2.6 The Vertical Retort

3.2.6.1 The Development of the Vertical Retort

An effective design for a vertical retort was not developed until the start of the 20th century. As the name suggests, the retort was rotated by 90° so that it was in the vertical plane. This design was first used unsuccessfully by William Murdoch in 1804. Murdoch used pot retorts with removeable internal cage, which proved very difficult to operate (Stewart, 1960). Others later attempted to improve the process. This included the Brunton intermittent vertical retort in 1828, the Radley intermittent vertical retort in 1845 and the Thomas intermittent vertical Retort bench in 1853 (Stewart, 1960).

James Young filed a patent for a continuous vertical retort in 1854 (No.326) which was entitled “Improvements in gas making”. Young was the son of a Cabinet maker, who grew up in Glasgow and gained an education through attending classes at Anderson College (a forerunner of the University of Strathclyde), a keen chemist he attracted the attention of Professor Graham, the chair of Chemistry. Assisting Professor Graham, Young later followed him to University College, London. Youngs attention was brought to an oil spring within a coal mine near Alfreton, Derbyshire by Sir Lyon Playfair MP whose brother in law owned the mine. Young started a small business to distil the oil from the mine, to make paraffin, whilst the venture was successful, the oil spring became exhausted and Young looked for other sources of oil.

As an alternative, Young then turned his attention to Scottish Torbanite, a fine-grained black oil shale found in Torbane Hill, near Bathgate in Scotland. Young developed and patented the continuous vertical retort which he operated at a low temperature to extract the mineral oil from Torbanite and later other Scottish oil shales, the paraffin oil produced was refined and the oil refining industry was born. Young's retort was designed such that minimal gas was made as his process was optimised for oil recovery, but it was an important step in the development of the vertical retort (Anon 1860 p304-305, Hughes and Richards 1880 p68, McKay 2012).

Another innovative development in the vertical retort occurred in 1871 with Porter and Lane developing a continuous vertical retort which incorporated and internal revolving screw to extract the coke. This design was demonstrated at the Great Peter Street gasworks of the GLCC. Andrew Scott the engineer at Musselburgh gasworks, built 4 large vertical retorts (figure 3.36). Unfortunately, these retorts failed due to the dilution of the gas produced by the formation of water-gas, the resulting gas having little illuminating power. The design also suffered from having inadequate heating (Korting 1906 p74-75, Stewart 1960, Glover 1906 p56).

Rowan patented a continuous vertical retort in 1885, which carbonised coal in a cupola, from the bottom of which the coke was withdrawn through a water seal (Lewes 1912).

It was not till the first decade of the 20th century, that commercially viable vertical retorts started to emerge. Several competing systems were developed. The first was the Dessau intermittent vertical retort developed in 1902 (see Figure 3.38). In the same year, the Settle-Padfield continuous vertical retort (see Figure 3.40) was developed. The Woodall-Duckham continuous vertical retort (see Figure 3.41) was developed in 1903 and the Glover-Young retort was developed in 1905 (see Figure 3.44).

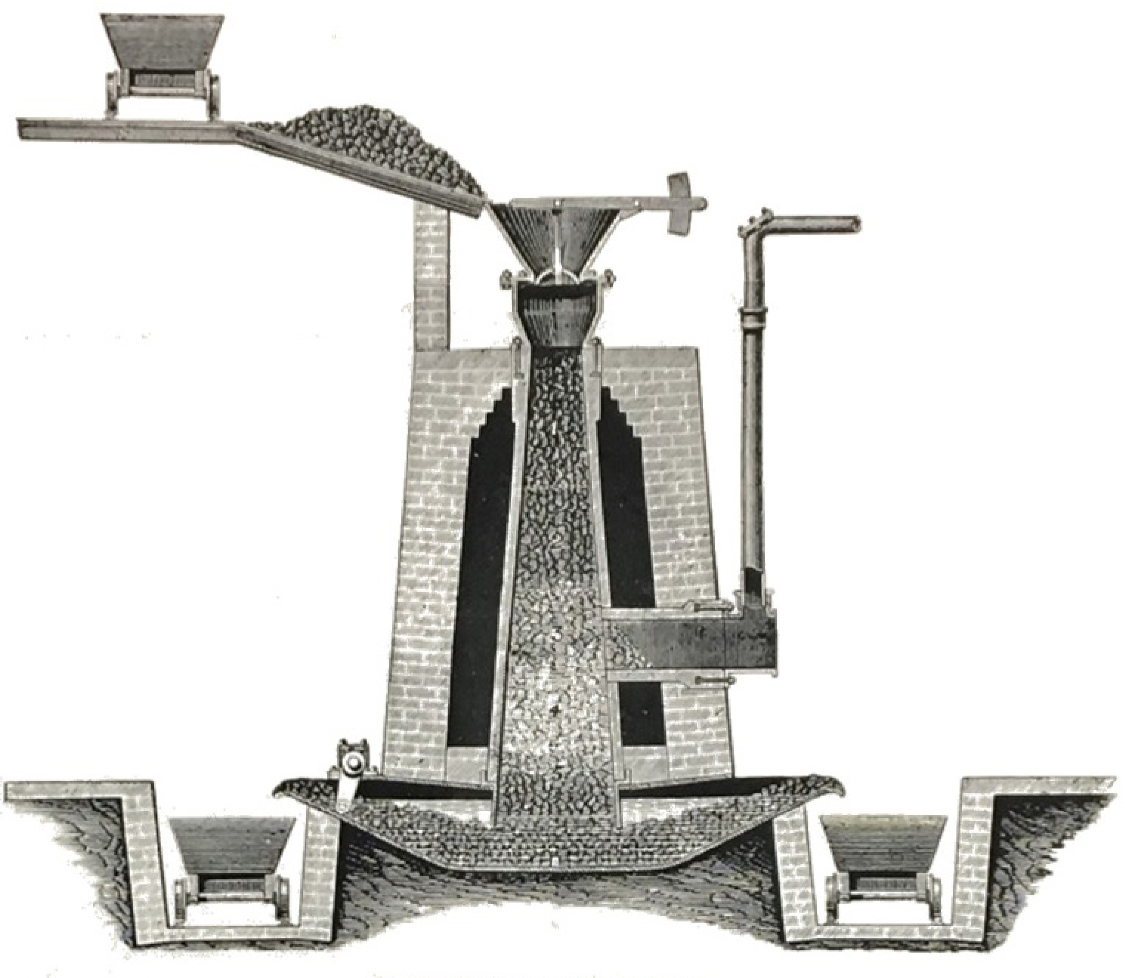


Figure 3.36 An engraving of the Scott Vertical Retort. Source Thomas Glover Transactions Institution of Gas Engineer, 1906.

3.2.6.2 The General Principal of the Continuous Vertical Retort

A general description of the continuous vertical retort follows. Coal of a suitable size was carried by conveyer to the top of the retort house where it was fed into a hopper, as seen in Figure 3.37. The hopper would feed coal down into a coal box on top of the retort, which held enough coal for an hour. Coal would then feed down into the top of the retort (charging). The hopper and the coal box were separated by a ‘coal valve’, which stopped the gas escaping. The valve would be opened once an hour to refill the coal box (Lewes 1912, Meade 1921, King 1948).

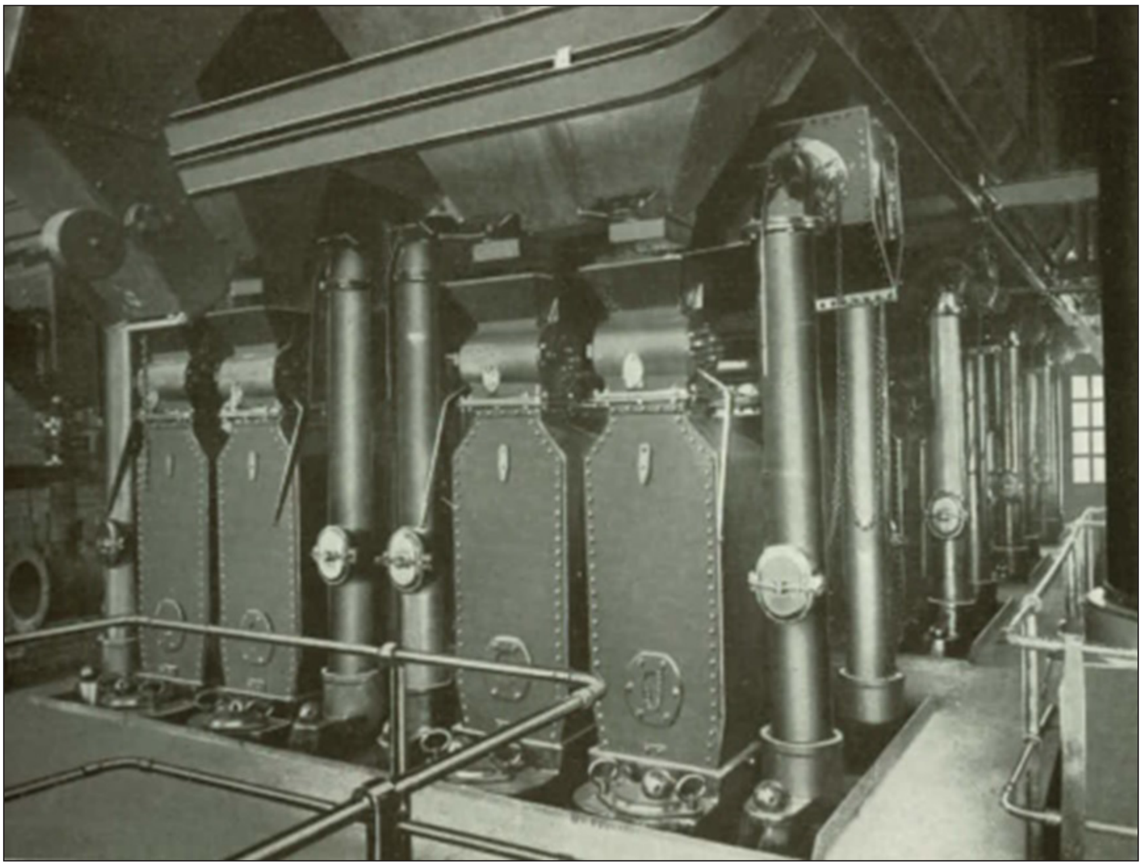


Figure 3.37 The coal feed hoppers, ascension pipes and hydraulic mains of the Glover-West Vertical Retorts, York 1924. Image courtesy of National Grid Gas Archive.

The coal passed down through the retort vessel by gravity. The retort was heated externally by a gas producer, either integrated into the retort house or separate. As the coal passed down the retort, it was gradually carbonised until it was removed as coke at the base of the retort, aided by extractor gear. The extractor gear ultimately controlled the rate at which the coal would pass through the vertical retort and therefore the extent to which the coal was carbonised (Lewes 1912, Meade 1921, King 1948).

From the base of the retort, the hot coke was discharged into a metal cart or hopper, removed and cooled by quenching it with water. Some vertical retort plants could also cool the coke in the retort. Vertical retorts were all heated using a gas producer, the operation of a gas producer is described in a later section of the report (Lewes 1912, Meade 1921, King 1948).

3.2.6.3 The Dessau Vertical Retort

The Dessau intermittent vertical retort was developed by Dr J. Bueb at the Dessau gasworks in Germany in 1902, the year it was patented in both Germany and Great Britain. Originally the Bueb design only heated three sides of the retort, with flues built into the unheated side to allow the gas to escape. This design had been abandoned in the 1904 plant built at Mariendorf, Berlin, where all sides of the retort where heated and the gas escaped through the coal stack. A new patent was taken out in 1904. The Dessau system had considerable advantages over previous horizontal or inclined retort system. It reduced labour, as coal could be moved by a mixture of conveyors and gravity once the plant was loaded. The plant also took up much less ground space, although the retort houses were much taller than their horizontal and inclined counterparts. It was operated as an intermittent process, so the coal was carbonised in batches and removed (Korting 1906).

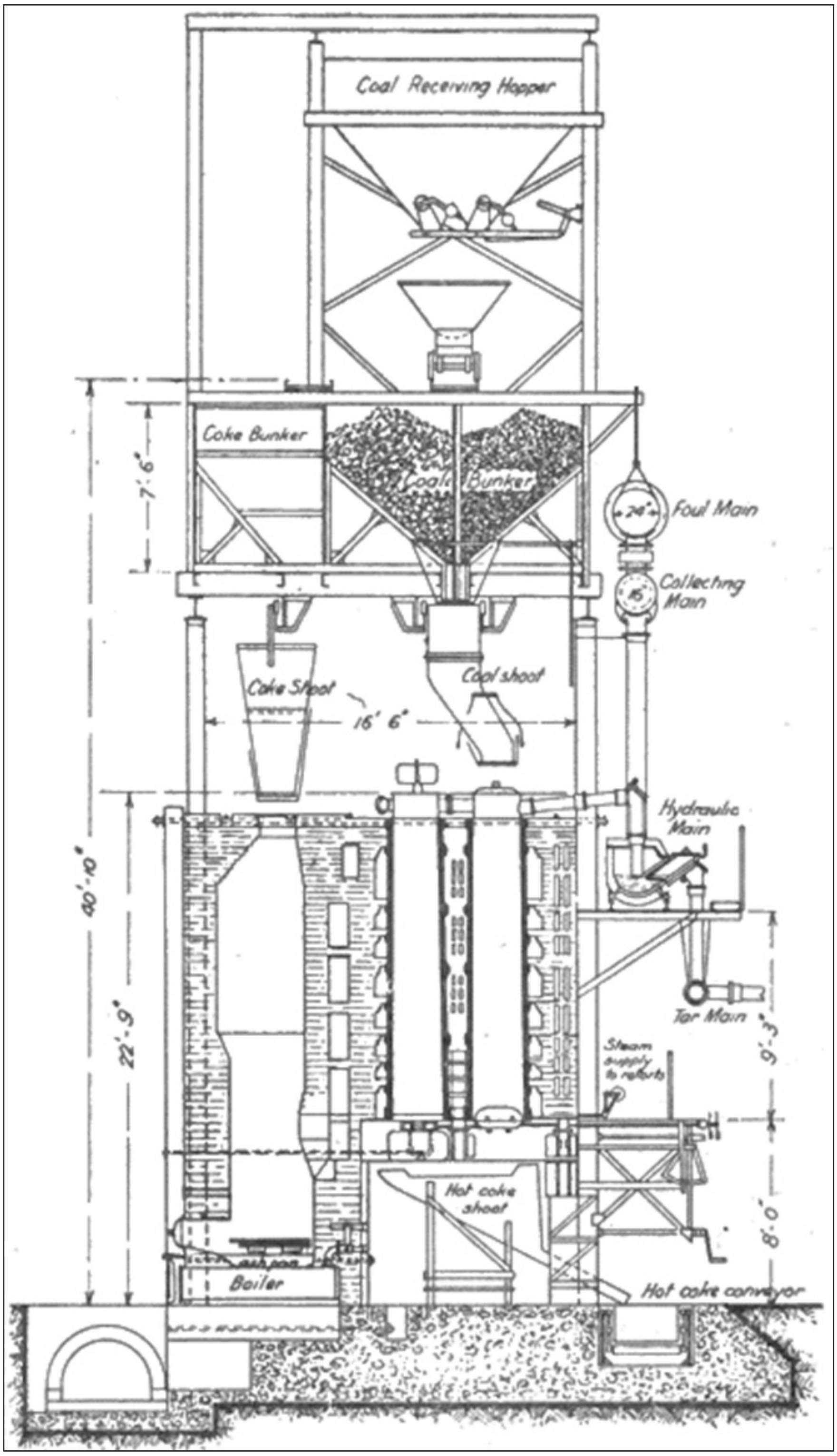


Figure 3.38 A cross section of a Dessau Vertical Retort. Source Lewes 1912.

The first major installation of the Dessau vertical retort was at the Ayres Quay gasworks of the Sunderland Gas Company in 1909 (Figure 3.39). The installation consisted of a bench of six beds of ten retorts each, the setting being in two rows of five. The retorts were 13 feet 1 ½ inches long and tapered from 9 inches by 22 ½ inches at the top to 13 ¾ inches by 27 ½ inches at the bottom. The installation could carbonise 400 tons of coal per week. The retorts were heated by an integrated gas producer (Lewes 1912).

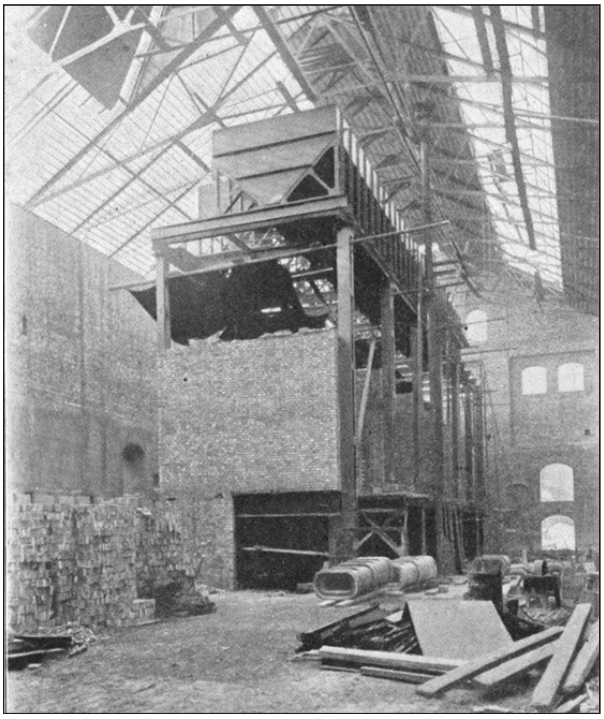
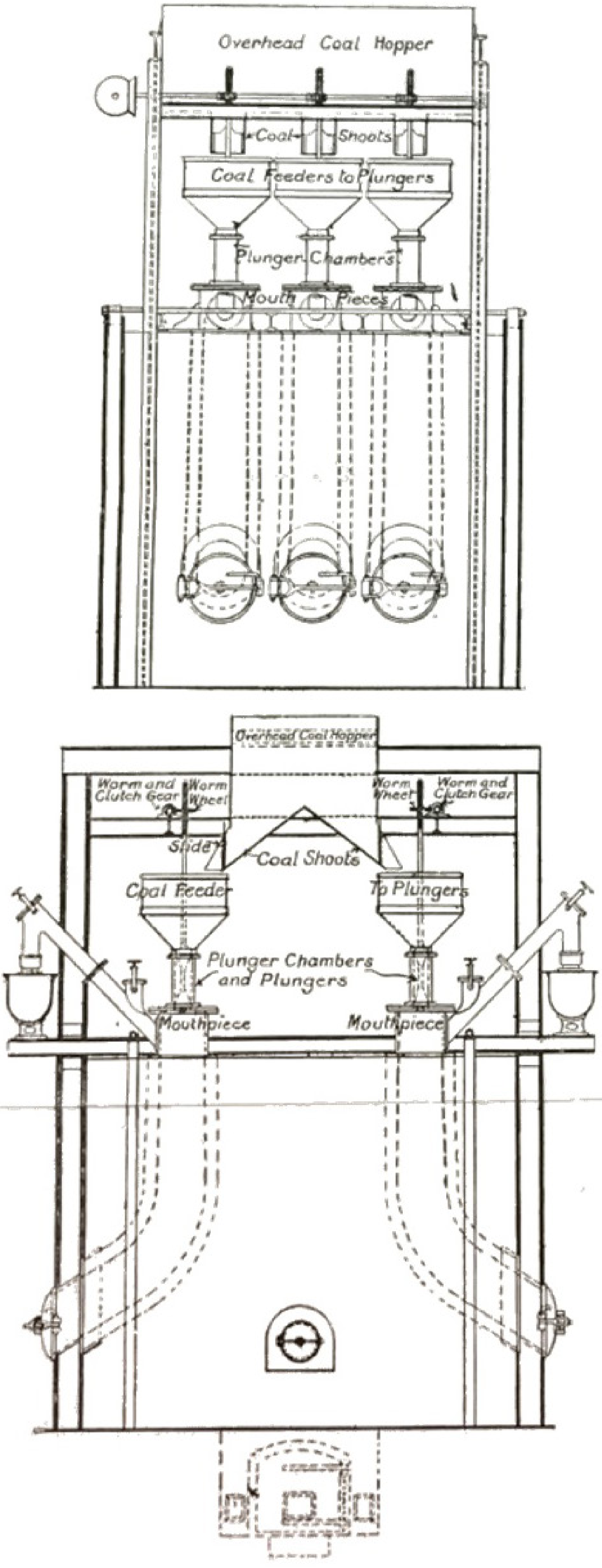


Figure 3.39 Installation of Dessau Vertical Retort at the Ayres Quay gasworks in Sunderland, the first installation in Great Britain. Image courtesy of IGEM Archive.

The intermittent operation of the retort in batches led to the build-up of carbon on the inner face of the retort, called scurf. This had to be removed on a regular basis or the coal would stick to the retort wall, this scurf removing process made the process more polluting than the continuous process, as the carbon would be emitted through the chimney, although it did make it easier to remove material adhered to the retort wall than the continuous process (Lewes 1912).

3.2.6.4 The Settle-Padfield Vertical Retort

The Settle-Padfield retort, was a semi-vertical retort developed in 1902, with the top part of the retort vertical and the lower part inclined. A schematic of the Settle-Padfield retort is shown in Figure 3.40. The original retort was built at the gasworks in Exeter. It utilised a partially empty retort with a large void space above the coal. The void space was used to gasify the tar vapours emitted during the carbonisation process (Korting 1906, Glover 1906). Although the plant gave good results there was an inherent weakness in the retort where the vertical and inclined sections overlapped, which led to fractures and a dilution in gas quality. The removal of coke was not mechanised and was done by hand which introduced variability into the process. Due to these failings in the design, the process was not more widely adopted by the gas industry (Lewes 1912).



The Settle-Padfield Vertical Retort.

Figure 3.40 The Settle-Padfield Vertical Retort. Source Thomas Glover Transactions Institution of Gas Engineer, 1906.

3.2.6.5 The Woodall-Duckham Vertical Retort

The Woodall-Duckham retort was developed as a collaboration between Harold Woodall and Arthur Duckham. Harold Woodall was the son of Sir Corbett Woodall, a leading figure in the gas industry and the engineer and general manager of the Bournemouth Gas and Water Company. Henry Woodall and Arthur Duckham took out their first patent in 1903. The original drawing of this vertical retort is shown in Figure 3.41. The key development they made over the Dessau model was the continuous operation which Settle-Padfield had attempted. Continuous operation being made possible through automatic charging of coal into the retort and the continuous removal of coke from the base of the retort.

They built three trial plants at the Bourne Valley works of the Bournemouth Gas and Water Company which sought to improve on the design and operation of the plant. After the three trial plants had been constructed, the first contract for a continuous vertical retort plant built by Woodall-Duckham was awarded in 1906, the plant was constructed at the Bourne Valley gasworks of the Bournemouth Gas and Water Company where Woodall was engineer and manager. The plant entered commercial operation in 1906 and was designed to carbonise 40 tons of coal per day. The key feature which Woodall-Duckham promoted was the regulated continuous decent of the coal through the plant enabling the coal to be converted to coke as it passed through the retort. Woodall-Duckham introduced a block construction of rectangular continuous vertical retorts in 1910 (King 1948).

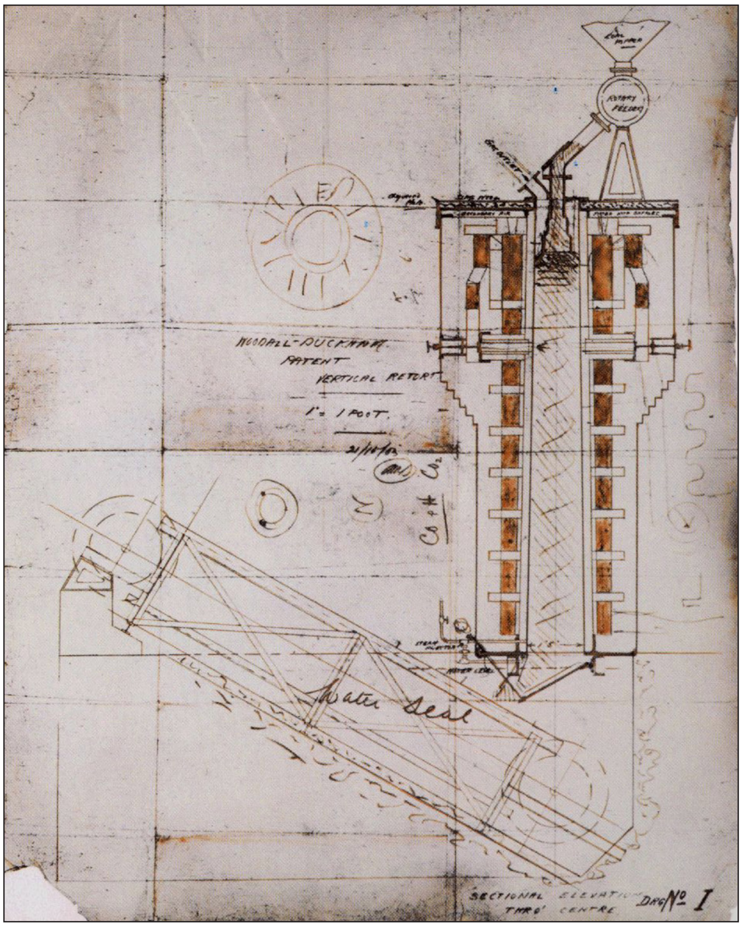


Figure 3.41 Drawing No.1, the first drawing of the Continuous Vertical Retort designed by Woodall-Duckham. Source Gas Journal 1945.

The Woodall-Duckham retorts were typically 25 feet long, they gradually tapered from 4 feet 3 inches by 8 inches wide at the top to 5 feet 3 inches by 20 inches wide at the bottom. They differed from other vertical retorts in being built up of grooved and tongued bricks, this reduced leakage at the joints and increased the available heating surface. The gas producer was integrated into the retort house (Lewes 1912).

In 1908 the water seal used to close the bottom of the Woodall-Duckham retorts was replaced by a better arrangement, and an ingenious helical coke discharger was added to remove the mass of carbonised material more regularly. The first order for their plant from a company other than Bournemouth Gas and Water company came from the GLCC for their Nine Elms gasworks (Lewes 1912, King 1948).

The ability to charge and discharge the retorts reliably and without incident was the key to the continuous vertical retort working effectively and had been the aspects which had caused the most problem. It took Woodall-Duckham five years to perfect the design. The mechanisms for the charging and discharging of the retort are shown in Figure 3.42 (Lewes 1912, King 1948).

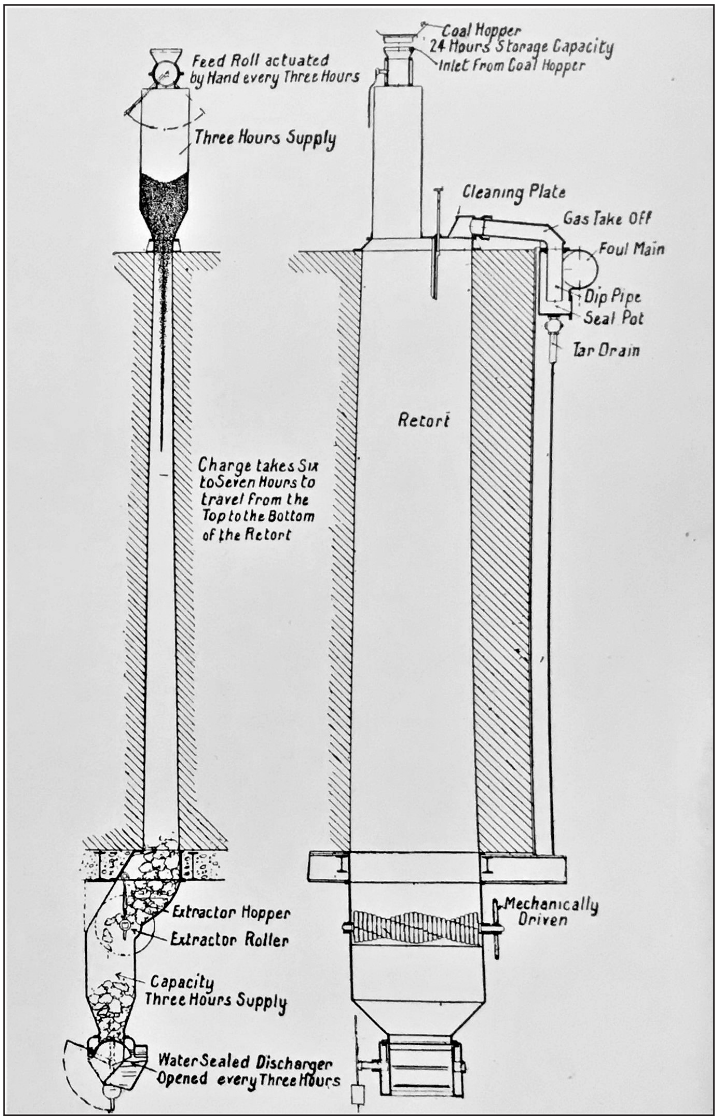


Figure 3.42 Woodall-Duckham retort, showing charging and discharging arrangements. Image courtesy of IGEM archive (Leather 1911).

As the coke was removed by the mechanically driven extractor roller, it fell into a cast-iron hopper or coke chamber which was attached to the bottom of the retort and would typically hold the coke generated over a period of three hours. This design evolved to include a water seal. The extractor consisted of a series of cast-iron cross pieces mounted on a shaft, each cross piece being arranged slightly in advance of its neighbour, to form helical blades. This extractor allowed coke to be gradually withdrawn from the base of the retort at a constant rate (Lewes 1912, King 1948).

The first order from an overseas gas undertaking for the Woodall-Duckham Continuous Vertical Retort came from Lausanne in Switzerland, the design of which can be seen in Figure 3.43.

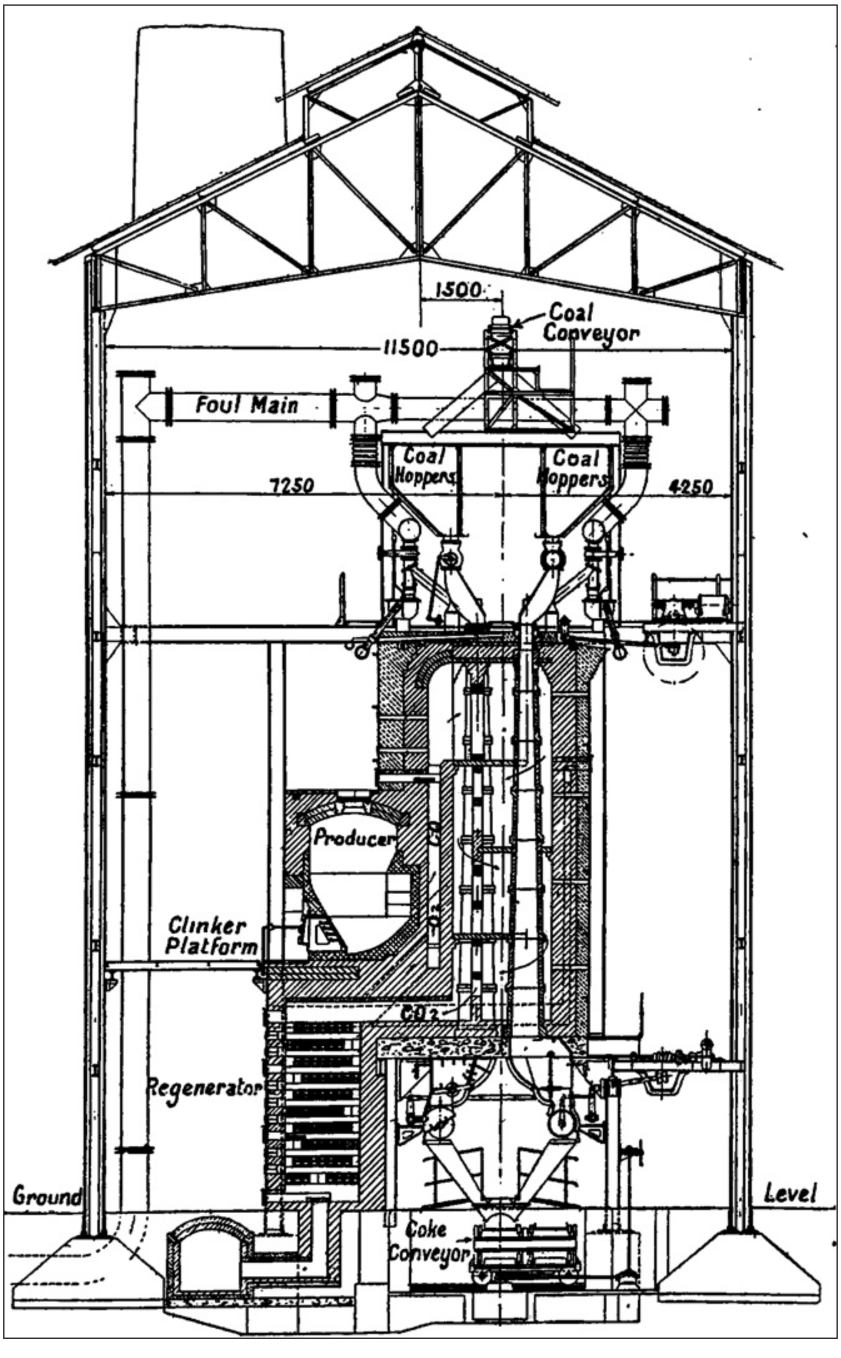


Figure 3.43 Woodall-Duckham vertical retorts built at Lausanne, Switzerland. Image courtesy of IGEM archive (leather 1911).

The coal was fed into the retort at the same rate as the coke passed through the retort. This was achieved through using a cast iron mouthpiece on the retort which facilitated both the gas exiting the retort and coal being loaded into the retort as a fine coal. The coal was fed from a gas tight hopper made of mild steel (Woodall-Duckham 1928).

Water gas could be produced in the retort by introducing steam through nozzles placed in the curved plate of the coke extractor box, which would react with the hot coke to produce water gas, this could greatly increase the volume of gas being made. The retorts were designed to have a long life, be relatively easy and cheap to maintain, required low capital cost and through the continuous nature of the process produce a gas of constant calorific value. Another benefit of the system was that it was enclosed, and this minimised the dust, steam and smoke that workers would be exposed to operating horizontal or inclined retorts (Woodall-Duckham 1928). Woodhall Duckham introduced the Block construction of rectangular continuous vertical retorts.

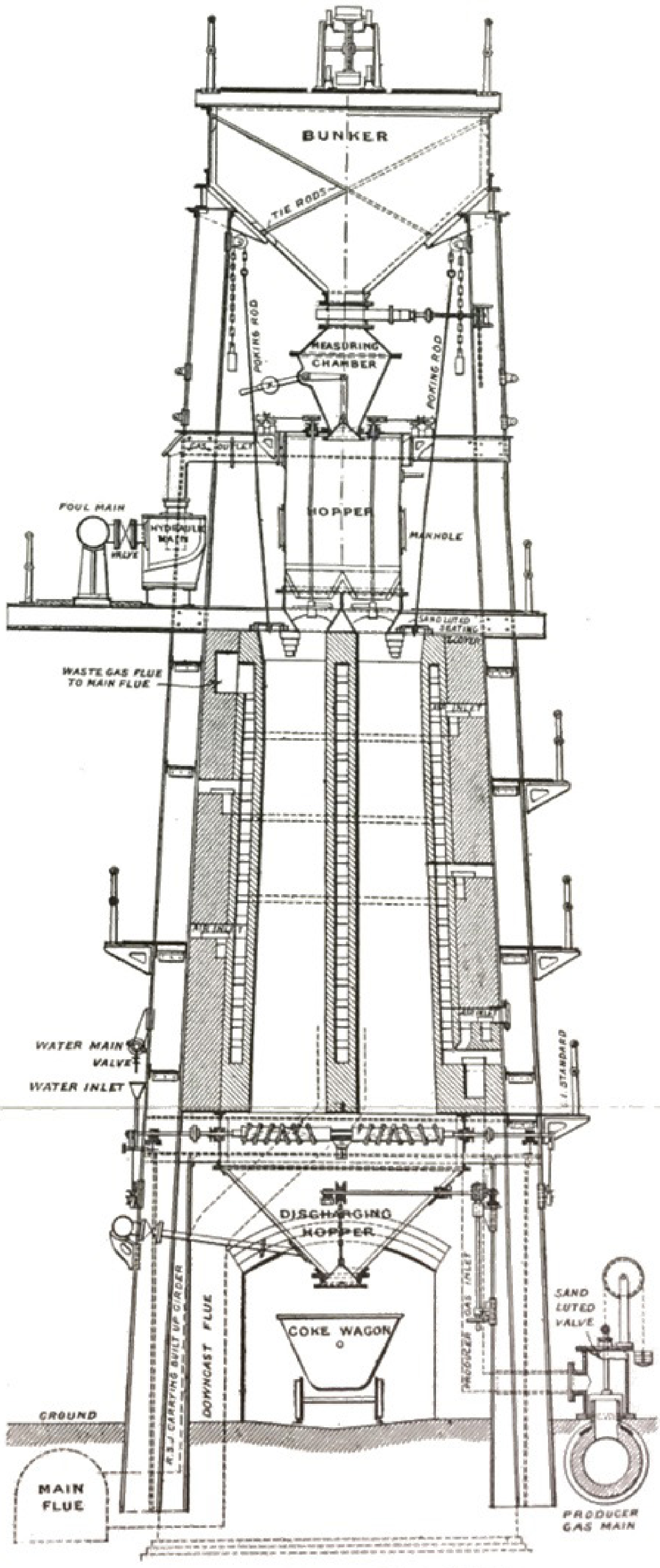
Woodall-Duckham also developed a semi-intermittent vertical retort in 1935 and static vertical retort in 1937, these however, never achieved the popularity of the continuous vertical retort (Stewart 1960). The company had broadened its range of carbonising technologies prior to this in 1923. When they had success with agreeing licenses to build the German designed Stettiner Chamotte-Fabrik intermittent chamber ovens and American designed Becker coke ovens within Britain and the Commonwealth countries (Woodall-Duckham 1928a, Woodall-Duckham 1953). These are both Discussed later.

3.2.6.6 The Glover-Young and Glover-West Vertical Retorts

The Glover-Young retort was developed in 1905 as a collaboration between Samuel Glover and William Young. Samuel Glover was the engineer at the St. Helens gasworks and at one time held the position as President of the Institute of Gas Engineers (Lewes 1912).

William Young developed a continuous vertical retort for the Scottish oil shale industry. He was the son of John Young, who had been the manager of the Selkirk and Dalkeith gasworks in Scotland. He became the manager of the small gasworks as Lasswade (Scotland), where he experimented with the extraction of oil and gas from colliery waste, obtaining support from the Leith and Clippens Oil company. This industry which was allied to gas making, extracted oil from oil rich shale rock through heating. Young's development of an improved continuous vertical retort improved the efficiency of the oil shale industry. Young had later developed the Peebles oil gas process, which Glover had witnessed at other gasworks and later used at St. Helens. Collaborating with Glover, Young helped develop the continuous vertical retort process shown in Figure 3.44, which was based on the form of the shale retorts of which Young had made a life-long study, this design was patented in November 1905. (Lewes 1912, Glover 1906, Stewart 1960).

The main difference between the Woodall-Duckham and Glover-Young system was that the coke discharge was independent of the coal feed, and that an empty space of constant dimensions was left above the coal, to form a cracking and fixing chamber for tar vapour (Lewes 1912).



Young and Glover's Vertical Retort Setting.

Figure 3.44 The Young and Glover Vertical Retort. Source Thomas Glover Transactions Institution of Gas Engineer 1906.

Williams Young's poor health and death in 1907, led to Samuel Glover later collaborating with John West in 1906. John West owned West's Gas Improvement Company who manufactured gas making plant. This collaboration led to the Glover-West vertical retort in 1909, which is shown in Figure 3.45. The main changes introduced in the Glover-West retort were the addition of a cooling chamber for the coke, in which the heat from the coke was transferred to the incoming air, by passing it through a jacket surrounding the coke cooler. The void space above the coal above the retort was removed from the design. The Glover-West retort also had an elliptical design, it proved very successful and was manufactured by West's Gas Improvement Company of Manchester (Wests Gas Improvement Company Ltd 1930, Special Correspondent 1954).

The first Glover-West continuous vertical retort plant was built at St. Helens in 1907. An example of the Glover-West vertical retort can be seen in Figure 3.45, which shows the customary vertical retort stack with coal being fed vertically down the retort from the hopper. The First commercial contract for a Glover-West continuous vertical retort was built at the Droylsden gasworks of the Manchester Corporation, entering service in 1910. In 1926 a Bell Bottom design was developed for the Glover-West continuous vertical retorts to provide improved efficiency for the steaming of the retorts to produce water gas (Wests Gas Improvement Company Ltd 1930, Special Correspondent 1954, Stewart 1960).

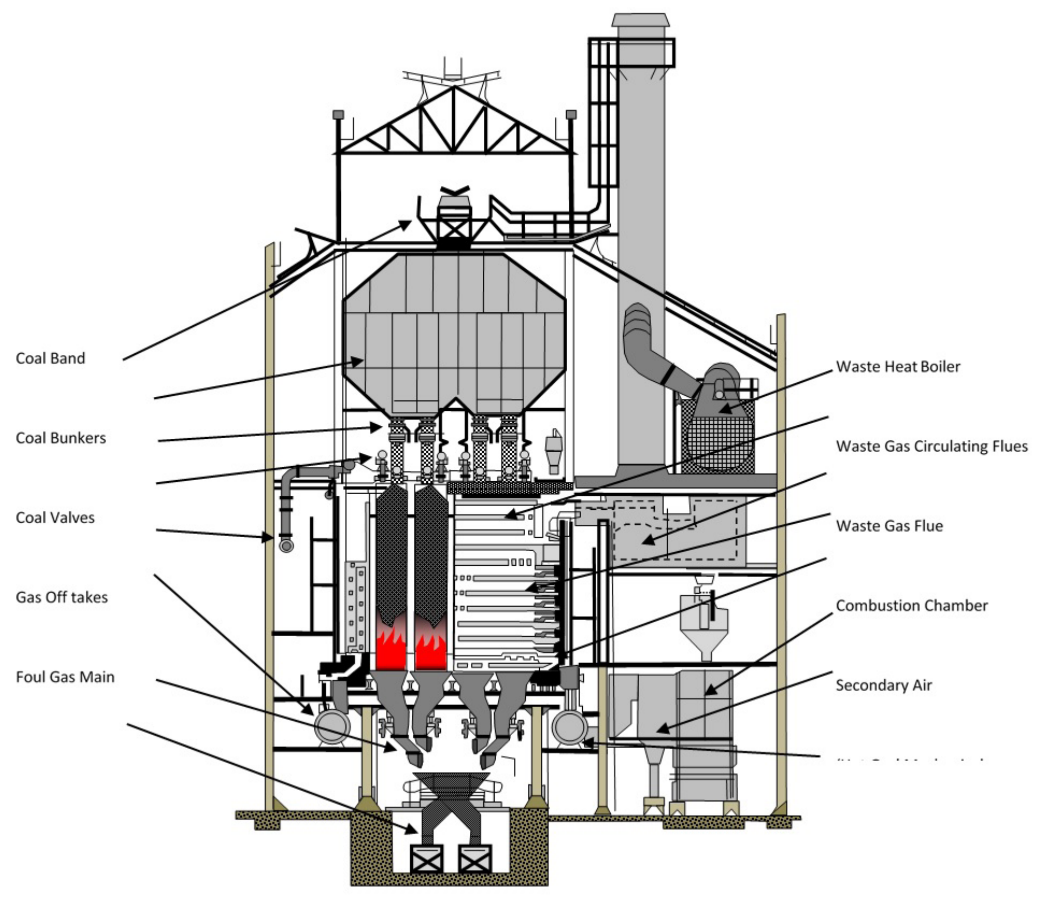


Figure 3.45 Cross section of Glover-West vertical retort house. Source R. Thomas.

Like Woodall-Duckham who introduced the "Static Vertical", West's Gas Improvement Company also introduced an intermittent vertical retort called the "Westvertical" in 1930. This system operated the vertical retort in a batch mode as was originally configured for the Dessau vertical retort. These retorts were configured into three zones, these were a: Carbonisation zone; Intermediate zone; and a Cooling zone. About just over half of the retort was taken up by the carbonisation zone, extending from the top to the middle of the retort, this was where the coal was carbonised, and coal gas made with the coal being converted to coke. The next zone, the intermediate zone (about 1/5 the length of the retort) was surrounded by the first two heating flues and maintained the coke at the correct temperature for water gas production. The final zone, the cooling zone consisted of a brick lined cooling chamber and the discharging chamber (Wests Gas Improvement Company Ltd 1930, Special Correspondent 1954).

At the end of each carbonising cycle, the valve at the top of the discharging chamber was sealed, the discharging door was opened, and coke removed. The discharging door was then closed, the valve at the top of the discharging chamber opened and the coke from the carbonisation zone fell into the discharging chamber and intermediate zone. New coal was then charged into the carbonisation chamber and the cycle repeated. Such plants were built at St. Albans and Sydenham, they performed better on low grade coal but were never as popular as continuous vertical retorts (Wests Gas Improvement Company Ltd 1930, Special Correspondent 1954).

3.2.6.7 The Drakes Vertical Retort

Drakes developed their own vertical retort plant in 1913. This was according to King (1948) the third most popular design behind the Woodall-Duckham and Glover-West. The Drakes retorts were rectangular in section with curved corners, constructed from tongue and grooved silica bricks. These bricks were not cemented with the surrounding firebricks of the combustion chamber to allow for expansion and contraction with variation in heat. The retorts were set in units of 1,2 or 4 (King 1948).

The combustion chambers were arranged horizontally around the retorts, and heating was from the bottom upwards. Heating provided by a step grate producer. The operation of the retort was like that described for the Woodall-Duckham and Glover-West systems (King 1948).

By the publication of Kings Manual of Gas manufacture in 1948, over 60% of the gas production on British gasworks was undertaken in Woodall-Duckham, Glover-West or Drakes continuous vertical retorts (King 1948).

3.2.6.8 Further Development of the Vertical Retort

As previously mentioned the yield of gas in the vertical retorts could be increased by a process called 'steaming'. Steam was introduced at the base of the vertical retort. The effect of the steaming process was twofold: it helped cool the coke by quenching it within the retort; and it also induced the water gas reaction, converting more of the coke to gas as carbon monoxide, carbon dioxide and hydrogen. It increased the amount of gas made but reduced its calorific value. Steaming was preferred in the winter to increase the amount of gas made at times of highest demand and was most popular between the First World War (about the time it was developed) and the Second World War. In some gasworks, steaming was used all year round and continued until production ceased (King 1948, Special Correspondent 1954).

Further vertical retort plants were built at many of the medium to large sized gasworks across the UK, and other manufacturers also entered this market. From 1910 onward, several other gas engineering companies devised their own vertical retorts, including the: Dempster-Toogood continuous vertical retort (1910); Wilson semi-continuous vertical retort (1910); Holmes-Winstanley Semi continuous vertical retort (1910); Herring's continuous and semi-continuous vertical retorts (which used a novel development, a separate gas producer); and Bate's internally heated vertical retort (1919) (Stewart 1960). Both the larger horizontal and vertical retort houses built in the 20th century were typically built using steel frames with panels infilled with bricks (Figure 3.46).

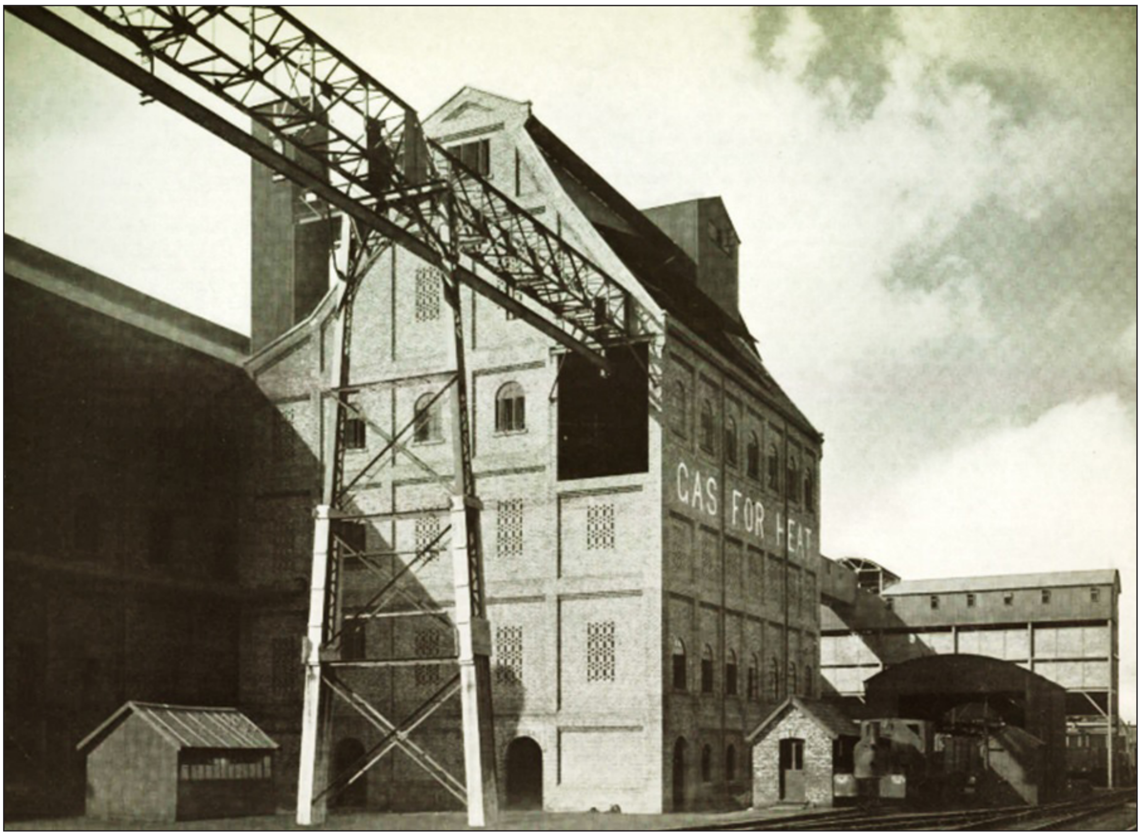


Figure 3.46 A typical example of a steel frames vertical retort house with Brick panelling at the former Garston Gasworks.

A photograph of a relatively late Woodall Duckham vertical retort house built *circa* 1950 at the Swan Village Gasworks, West Bromwich can be seen in Figure 3.47. A more detailed description can be found of the various vertical retort plants can be found in King (1948).

Figure 3.47 The rear of the vertical retort house and coke Screening plant, showing the Wagon tippers for discharging coal. Former Swan Village Gasworks, West Bromwich. Image courtesy of National Grid Gas Archive.

Whilst vertical retorts were used at many medium and large gasworks, some large gasworks such as Beckton chose to keep horizontal retorts because of the more saleable coal tars they produced. The type of retort chosen was often related to the types of coals available. The coals of the Durham and Northumberland coal fields were preferentially used in horizontal retorts and were shipped from ports such as Blyth and Newcastle all the way down the East coast of England and along the South coast as far as to Cornwall. Further inland, Midland, Lancashire and Yorkshire coals were more easily available by rail transport and there was a preference to carbonise these in vertical retorts, when they became available (King 1948).

Many small gasworks continued to operate manual horizontal retort houses until closure, often because they could not justify the expense or did not have the demand for gas to build mechanised horizontal plant or a vertical retort plant.

3.2.6.9 Rochdale Process

The Rochdale process developed in 1952 was a modified continuous vertical retort (CVR) process developed by the North-Western Gas Board at their Stretford Research Centre near Manchester.

The Rochdale Carrier Gas Process was designed to increase the efficiency of CVR by up to 100% through accelerated carbonisation. In the later use of the CVR, when it became practice to admit steam into the CVR to reclaim heat and generate water gas from the coke, to increase the volume of gas produced. In the Rochdale process, the steam was replaced by gas, either blue water gas or producer gas. These gases did not react with the char to any extent, all the available heat from the char was transferred to the coal charge for carbonisation. The Rochdale process was designed to produce a highly reactive coke for use in domestic grates, which would command a premium price (Nicklin 1957).

3.2.7 Coke Ovens and Chamber Ovens

Coke ovens were originally developed for the manufacture of coke for metallurgical purposes and predated gas manufacture. As coke oven technology developed, much larger charges of coal could be carbonised than by using retorts. When the recovery of gas and other associated by-products was developed on the continent, it became apparent that the greater volumes of coal being carbonised in coke ovens could be applied to improve economics of gas making on a gasworks.

The chamber oven was developed from coke making technology, which is described in the next section. One of the biggest challenges with making gas in either a chamber or coke oven was the loss of gas due to design of the brick-built ovens where gas could escape between the bricks (Lessing 1909, p115).

3.2.7.1 By-Product Coke Ovens

Coke ovens were not originally designed to produce either gas or by-products such as tar. Their sole purpose was the production of coke primarily for the metallurgical industries. It was not until it was realised that there was some economic value in these by-products, that the process was adapted to capture them, and the by-product coke oven was born. There was considerable hesitance to this adaptation at first because coke manufacturers believed the production of by-products would be at the expense of the quality of coke manufactured (Lunge 1909).

Early coking operations were very simplistic, they involved constructing a large circular mound of coal built up around a central chimney with open vents into the stack. The mound was covered with a layer of wet coke dust. This method was only suited to round coal rather than slack as it was necessary to have space between the coals, for the coal to carbonise. The process took about 5 or 6 days and required a lot of skill to ensure you did not end up with a pile of ash (Armstrong 1929).

The first engineered coke ovens were the ‘beehive coke ovens. These were either square or conical structures with a domed roof which gave rise to the “beehive” name. The by-products were primarily burnt above the coal and it was the heat from burning these by-products which coked the coal, with the process moving down through the fuel bed. Some by-products and combustion products were released through the top of the oven and these were deposited on the chimney and surrounding land from the smoke produced. The date of origin for the coke oven is uncertain but it is likely to have evolved from apparatus used to make charcoal (Armstrong 1929).

The early history of the development of by-product coke manufacture was described in part in the earlier section “Origins, Scientific Experimentation and Pneumatic Chemistry to 1800” in Volume 1. A brief recount and additional information not covered in that section is included within this section as well as later advances.

By-product coke ovens were described by the French metallurgist, de Gensanne, at Sulzbach, near Saarbrucken around 1768 (Hunt, 1907). The ovens produced a form of oil which was burnt in lamps used by peasants and miners (Lunge, 1916). The Earl of Dundonald produced tar from his coke ovens, George Dixon and John Champion, both operated coke ovens which produced tar as a by-product, described earlier in Volume 1 (Stewart 1958).

In 1838 Frederick Neville took out a British Patent (no.7898) for an “Improved method or process of manufacturing coke, whereby the sal ammoniac, bitumen, gases and other resideous products of coal are at the same time separately collected, and the heat employed in the process is applied to other useful purposes”. This was a beehive type oven, but above the oven several retorts were installed to make use of the heat generated from the coke making process (Anon, 1860). The method was not further adopted by the industry.

In 1850 Antoine Pauwels and Vincent Dubochet patented (No. 13057) for “Improvements in the production of coke, and of gas for illumination and also in regulating the circulation of such gas". The patent described a horizontal chamber retort made from bricks and metal, which had a system of flues and valves that allowed the gases to be collected and by-products recovered, the patent also included an extractor like the exhauster used on a gas works to extract the gas (Anon 1860 p207-208). This design had met with some success on the continent as there were 50 such ovens in use in Saarbrücken in 1854, although these did not include recovery of the tar, but the gas was burnt instead. A later installation at the La-Villette gasworks of the Paris Gas Company, produced high grade coke and a poor-quality gas from which by-products had been removed (Lunge 1909 p59).

It is contested whether Pauwels and Dubochet first developed this advancement or Knab, another French engineer from St. Denis, who built coke ovens at Commentry in central France in 1856. Knab’s ovens were externally heated and gave a much greater yield of coke as the coke was not being burnt in the process.

In 1852 William Edward Newton filed a patent (No.13,974) which adapted the beehive oven through the inclusion of a flue to draw the gases produced to a separate chamber. In this chamber the gases were cooled, and tarry by-products removed (Anon 1860 p233, Stewart 1960). Similar patents were also filed by the French engineers Charles Alexandre De Fonbonne (1856) and Claude Laurent Victor Maurice (1855) and Joze Luis of London (1858) applied for a British patent (No. 2082) for a Horizontal By-product Coke Oven (Anon, 1860).

The French engineer Pernolet patented a by-product coke oven which was like that of Knab, with the exception that higher temperatures were used (Lunge 1909 p61).

It was the adaptation of Knab's coke oven by Haupart and Carvès, which developed an effective by-product coke oven. Francois Carvès, at Commentry, first introduced the heating of the ovens by side flues in addition to the bottom flues. The gases and vapours generated by the coal during the coking operation were passed into a hydraulic main and then cooled by air, where tar and ammonia was condensed. The gases were continually drawn off by exhausters and then used for heating the coke-ovens (Lunge 1909 p60).

Whilst these types of ovens were gradually introduced elsewhere in France, there was not a dramatic uptake of the design. Between 1866 and 1873, 53 such ovens were erected at Bessegès, and a further 100 ovens were built at Terre-Noire, near St Etienne in 1879. The coke ovens attracted numerous visitors who detailed their operation, which included Dr Angus Smith and Henry Simon, both of whom thought the process had merit in Britain. Henry Simon originally from Silesia, had trained as an engineer in Zurich, he moved to Manchester in 1860 and had established himself as a consulting engineer by 1867. Having already improved flour milling processes, Simon had turned his focus on coke making. He read a paper entitled 'An improved System for the Utilisation of By-Products in the Manufacture of Coke' after his visit to the coke ovens at Bessegès to the Iron and Steel Institute in 1880. After securing the British patent rights to Carvès coke oven design, it still took the strength of support from Henry Simon which gradually got the attention of the iron and steel industry in Britain, he even modified the process with an improved recuperator (Lunge 1909, Brewer 1981). A vast number of patents for by-product coke ovens followed which are described in George Lunge's book, "Coal Tar and Ammonia" (Lunge 1909).

Three main types of coke oven developed, the first was based on the traditional beehive coke oven, where some of the coal used was burnt in the coke making process, however the off gas was collected, and by-products were recovered.

The second type of oven was the Coppee oven and the third type was the Knab-Carvès and Pauwels-Dubochet coke-ovens. The second and third type belong to that class of coke-ovens called horizontal closed ovens. Both were constructed so that the gases evolved during the carbonisation were collected and used for heating the ovens. Unlike the beehive ovens no air was admitted into the carbonisation chamber (Lunge 1909).

The coke oven was effectively a long rectangular box constructed of refractory (heat resistant) material, they were typically 42 feet long and 14 feet high, but only between 12 and 18 inches wide. Such an oven would hold 16 tons of coal (Stewart 1958). The oven had large iron doors at both end, which were removed when carbonisation had finished, and a mechanical pusher would push the hot coke out of the oven, where it would be collected and cooled (Stewart 1958).

Ovens were lined up into a battery (often comprising over 100 ovens) and heated by a system of flues built into the oven walls. The design of the flues was the main difference between the Coppee and knab-Carvès ovens. Coppee oven differed from the Knab-Carvès oven in that they had many openings in the upper part of their side-walls, connected with an equal number of parallel heating-flues running perpendicularly downwards between each two ovens, and into these flues air was admitted, the flame ultimately passing below the sole. The Knab-Carvès ovens, as well as the later Semet-Solvay ovens, were heated by flues running horizontally in a zig zag form, also between each two ovens (Lunge 1909).

With horizontal closed ovens the combustion of the gas to heat the retorts typically used recuperators to preheat air in a series of vertical flues adjacent to one side of the oven. The hot gases are channelled through crossover flues across the top of the oven and down the opposing side wall. The flow of gases through the flues was regularly switched to ensure even heating throughout the oven and reduce the deterioration of the refractory materials. Coke ovens are kept hot continuously; if they cooled down, the refractory material could be damaged, requiring a costly replacement (Stewart 1958).

Henry Simon built his first by-product coke ovens at Bankfoot Colliery in Crook, County Durham in 1881-1882. Although successful in attracting a few more orders, Simon did not receive the approval of iron masters despite being awarded a gold medal and diploma at the Inventions Exhibition in London in 1885 (Brewer 1981). In 1892 Henry Simon and the Société Francois Carvès formed a company to build and operate two batteries of ovens at a small colliery in Lanchester, County Durham, this company eventually became Simon Carvès Ltd, a key player in the coke oven industry in Britain. Although more coke ovens were ordered Simon Carvès struggled against German competition, where the German iron and steel industry had been more supportive of the technology (Brewer, 1981).

Such an example of German competition was observed when the German Otto Hillgenstock company bought the Crigglestone Colliery (Near Wakefield) and built a by-product coke oven plant at the site to demonstrate their technology, the Crigglestone colliery had closed previously as it was unprofitable purely as a coal mine, but Otto-Hillgenstock proved the colliery could be worked profitably in conjunction with the by-product coke ovens. Otto-Hillgenstock also imported coals from other collieries so they could demonstrate the value to the mine owners of their process prior to building new coke oven plants for them (Anon 1912a p414 & 443). Crigglestone coke ovens latter provided a gas supply for the town of Ossett. A schematic of a Woodall-Duckham Becker Combination Underjet Coke Oven is shown in Figure 3.48. Coke ovens used coal in a different form to gasworks: crushed to a fine powder for the coke oven compared to solid lumps (e.g. nuts or cobbles) in a gasworks. The coal used was often a blend of various types of coal. It was stored in a large bunker in the middle of the coke battery prior to being dispensed into the charging car in measured quantities. The charging car moved along the top of the battery charging ovens as required. Prior to charging the oven with coal, both iron doors on either end of the oven were closed. The stoppers in the top of the oven would be removed and the crushed coal would be poured in. Once sufficiently full, the coke was levelled off using a levelling arm, leaving a void at the top of the oven. The coal was then carbonised for about 16 hours (Meade 1916, Stewart 1958).

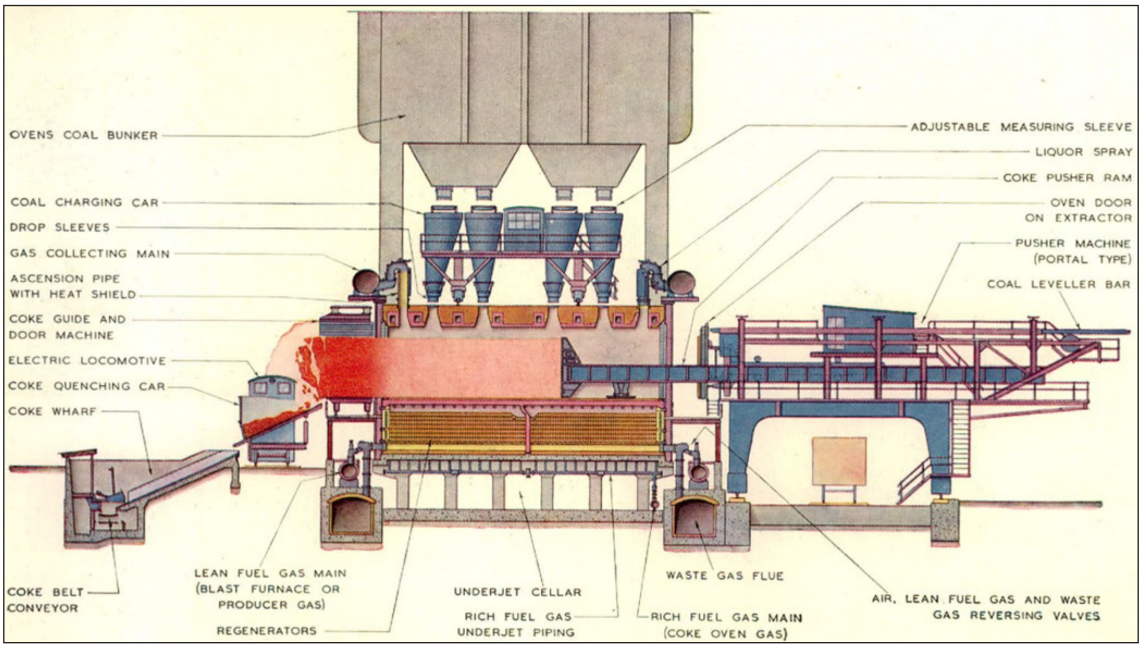


Figure 3.48 A cross section schematic of a battery of Woodall-Duckham Becker Combination Underjet Coke Oven. Source Woodall-Duckham 1953.

Coke ovens were rarely used on British gasworks, only three gasworks sites operated coke ovens in England. These were Koppers Coke Ovens constructed at the Saltley gasworks site in Birmingham in 1911, shown in Figure 3.49. Two batteries of Koppers Coke ovens were first built by Woodall-Duckham at Beckton in 1931, with three more batteries built between 1948-56, Shown in Figure 3.50. Simon Carvès coke ovens (1950) and low temperature Coalite plants built at gasworks such as East Greenwich in London and Plymouth. Due of their large size, coke ovens could produce large amounts of gas on a continuous basis as the ovens were continually charged and discharged, they also produced coke which was important for the metallurgical industries (Woodall-Duckham 1953, Stewart 1958).

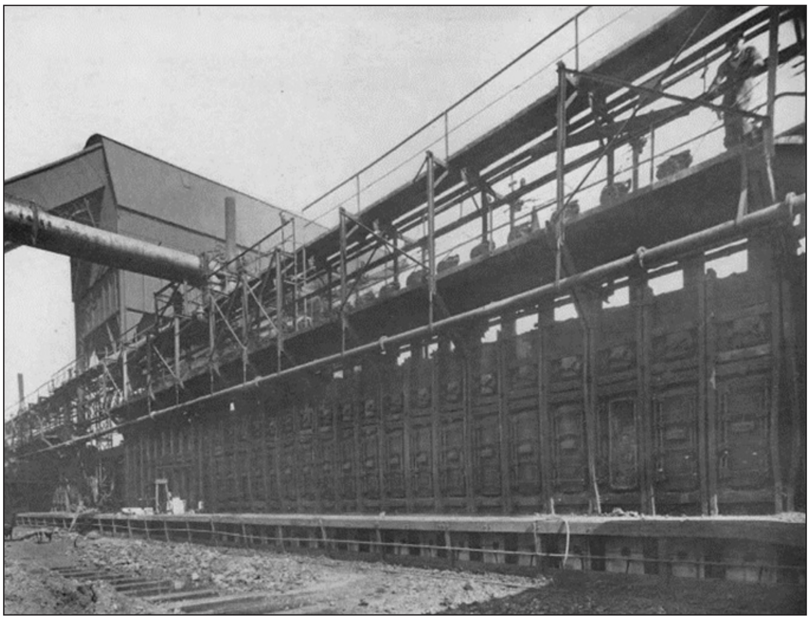


Figure 3.49 The former Koppers Coke Ovens at the Saltley gasworks, Birmingham. Image courtesy of National Grid Gas Archive.

Even by 1915 gas from by-product coke ovens was generally only being used for heating the coke oven. With only a limited supply of surplus gas being distributed to public gas undertakings. The application of gas producers to coke ovens, allowed the richer coke oven gas being made available for public supply and poorer quality producer gas being used to supply the coke ovens. In 1915 several Acts of Parliament, put forward by large city corporations, were passed, which would allow them to use by-product coke oven gas. Notable amongst these early adopters were Middlesbrough and Leeds, both of which had several large coke ovens in their areas. In the case of Leeds, a supply was taken from the coke ovens of the Middleton Estate and Colliery Company which was delivered to the Dewsbury Road Gasworks (Anon 1915a, Golisti 1993). By 1921, there were a total of 8146 by-product ovens in Britain, the most popular being Otto-Hilgenstock, Koppers and Simon-Carves (Edwards 2001).

Coke ovens had a big impact on the gas industry in Britain as they did in other parts of the world. Coke oven gas was taken by many gas undertakings which had coke ovens in their district. The supply of coke oven gas in some areas was so great that the gasworks stopped manufacturing gas, apart from Carburetted Water Gas (CWG) which was only produced at times of peak demand. Separate gas distribution grids were built in areas such as South and West Yorkshire which collected gas from the coke ovens and distributed it to the public gas undertakings (Golisti 1993).

Figure 3.50 The Koppers Coke Ovens at the former Beckton Gasworks, London. Source Woodall-Duckham 1953.

The by-product coke oven had a different design from a retort, although the principles of operation were similar, especially compared to the horizontal retort. The by-product coke ovens were larger than gasworks retorts and designed to produce metallurgical coke for iron and steel manufacture rather than specifically for gas or by-product manufacture (Stewart 1958).

Coke ovens were the only remaining operational coal carbonising plant in Britain in 2019, with coke ovens at the steelworks at Scunthorpe and Port Talbot.

Once the process was complete, the oven doors at the side of the oven were removed and a mechanical arm pushed the red-hot coke into a hot coke car. Once full, the hot coke car was taken to the quenching machine to be cooled by spraying with water. The plant used to purify coke oven gas and recover the by-products was very similar to that of a gasworks, although larger in scale. The main plant involved is described in the section on condensers (Lewes 1912, Brewer 1981).

Whilst most coke ovens in Britain operated at high temperatures, there were a few examples of low-temperature coke ovens, the most notable being the former Coalite works at Bolsover in Derbyshire. The Coalite process was developed by Thomas Parker in 1904, this was a lower temperature coking process which operated at 420°C (later increased to 650°C) and produced a more brittle coke which burnt easier than higher temperature coke and made it suitable for domestic fires. The process also produced by-products (coal tar and ammoniacal liquor) of a different composition due to the lower temperatures used which made them less thermally degraded (Lewes 1912, Brewer 1981).

3.2.7.2 The Development of the Chamber Oven

The Appolt intermittent vertical Chamber oven was one of earliest chamber ovens, it was developed in 1853, it consisted of a rectangular structure containing twelve coking chambers built in two sections, the top being narrower than the bottom, and between the chambers, the flues varied with the taper of the retorts. The vents in the side walls of the retorts allowed the gases and vapours to pass into the flues, where, meeting the air supply, they burned heating the chamber. The retorts were fitted with doors at top and bottom, so that they could be fed and discharged by gravity. These ovens were used as early as 1857, at the collieries in the Pas-de-Calais region of France (Lewes 1912).

The type of chamber oven which became popular in the early 20th century across Europe was developed in Germany, first being proposed by the German Scientist Dr Hans Bunte. Dr Bunte had identified that the economics of gas production were restricted by the relatively small size of the retort and on large gasworks they were restricted to just multiplying the number of retorts. Dr Bunte identified that if gas was manufactured in larger chambers like coke ovens then the poorer gas quality produced could be enriched by benzol. His idea was taken up by Mr. H. Ries, the Engineer and Manager of the Munich Gasworks in collaboration with Dr E. Schilling, who together constructed the first large spaced chamber ovens on the gasworks at Munich. Ries converted an old inclined retort setting to a set of three inclined chamber ovens each with a capacity of 1 ton and set at an angle of 35° (Lessing 1909, p116).

Whilst the gas produced was not of the desired quality, encouraging results were obtained and experimentation continued with the chambers enlarged to a capacity of 2.2 tons. The new chambers produced such good results that a new large plant was constructed on these principles (Lessing 1909, p116).

The new plant which included a bench of fifteen inclined chambers in five settings of three chambers each, was built at the Kirchstein gasworks of the Munich Corporation (Lessing 1909, p117). The advantage of the new settings was where a considerable reduction in labour, with the chamber ovens requiring charging only 123 times in 24 hours as opposed to the horizontal retorts previous operated by the corporation which would have had to be charged 2376 times in the same 24 hr period to make the same volume of gas (Lessing 1909, p117).

Other inclined chamber ovens were built, the next being constructed at Hamburg and then in Leipzig, Paris, Rome and Berlin (Lessing 1909, p121). The coke oven manufacturer Koppers later developed an inclined chamber oven process at gasworks in Bochum and Vienna (Figure 3.51) in 1908.

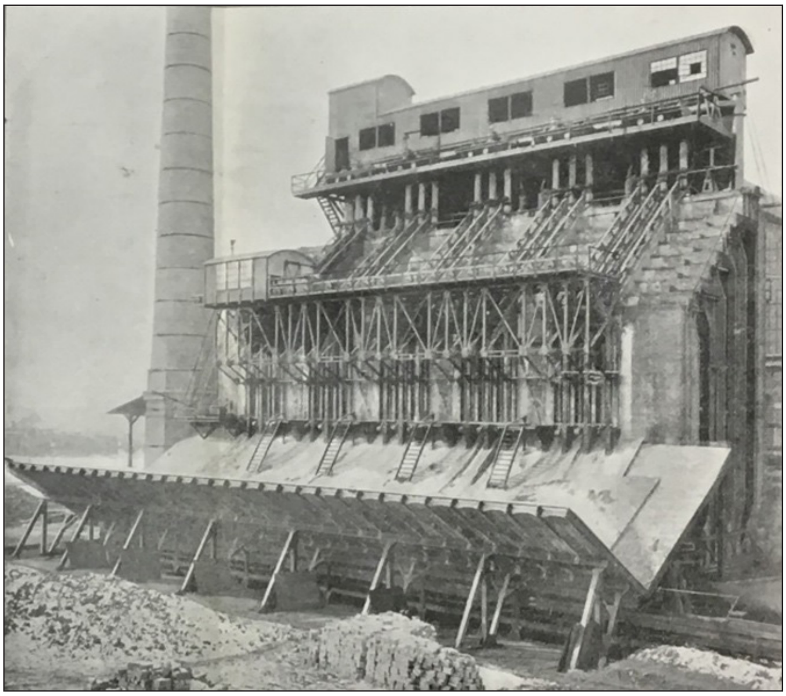


Figure 3.51 Koppers Inclined Chamber Ovens, Vienna, Austria, 1906. Source Lessing 1909.

Other German engineers also started to manufacture chamber ovens, these included Messrs Knoch who built an inclined chamber oven plants with vertical flues at Halberstadt in 1908. Messrs Klönne who had unsuccessfully tried to build chamber oven settings at Schalke in 1892. Returned to the construction of these settings in the first decade of the 20th C, building inclined, vertical and horizontal chamber ovens. The inclined chamber settings built at Konigsberg can be seen in Figure 3.52.

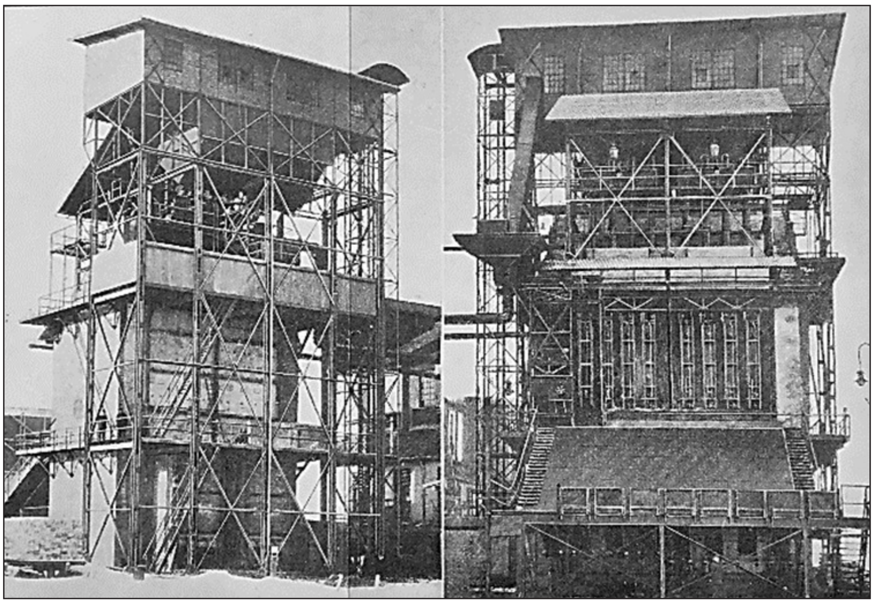


Figure 3.52 Klönne Inclined Chamber Ovens, Konigsberg, Germany. Source Lessing 1909, Image courtesy of IGEM Archive.

The horizontal chamber settings were first built by Klönne at Rotterdam in 1908 and operated in a similar fashion to coke ovens with coal loaded through the top and pushed out horizontally. The horizontal settings were about 30% cheaper to build than the inclined settings. Klönne also built a vertical chamber oven plant at the Dortmund Gasworks (Lessing 1909, p123).

Stettiner Chamotte Fabrik developed a vertical chamber oven from the Dessau vertical retort. This system modified the by building one larger Chamber in place of three smaller chambers and introduced the use of more robust Silica retorts to allow faster carbonisation. The use of improved retort fittings and mechanical gear also increased the efficiency of the plant. The vertical and inclined chamber ovens became very popular across the wider European continent and chamber ovens were in use from Finland to Spain.

3.2.7.3 The Application of Chamber Ovens in Britain

The development of chamber ovens in Britain was slower than on the continent, in part due to the success of the vertical retort and the availability of better-quality gas making coals. Chamber ovens were pioneered by Thomas Glover, the engineer and manager of the Norwich Station of the British Gas Light Company. Thomas was the brother of Samuel Glover, one of the developers of the Glover-West vertical retort.

Thomas Glover developed his chamber ovens at the St. Martins at Palace gasworks at Norwich, they can be seen featured in the advert in Figure 3.53. Glover's chamber ovens were horizontal and able to be installed in the same settings as conventional horizontal retorts. They were larger than horizontal retort, at 21 feet long, 3 feet high, and 1 foot wide and held about a ton of coal. They were also referred to as chamber retorts and produced a richer gas than the continental chamber ovens. They were fully charged by means of a de Brouwer projector (Meade 1916).

Their cost effectiveness was somewhere between the horizontal retort in use at that time (circa 1908) and the continental chamber ovens. The biggest advantage of the process was that it could be installed in smaller gasworks in any suitable horizontal retort setting (Lessing 1909 pp123-124).

It was later realised that using fully charged horizontal retorts, was just as effective as Glovers chamber ovens, and the system was ultimately abandoned (Meade 1916).

Figure 3.53 An advert from the Gas Journal for Thomas Glover's Norwich Chamber Ovens circa 1910.

Woodall-Duckham introduced the German designed Stettiner Chemofabrik Intermittent Vertical Chamber plant into the British market from 1923. They had built an earlier Stettiner Chemofabrik Inclined Chamber Oven plant in 1915 at the gasworks in Darwen, a second Woodall-Duckham Inclined Chamber Oven Plant was built at the Lancaster gasworks in 1927 and is shown in Figure 3.54. This design was not widely as adopted in the UK, as it had been on the continent.

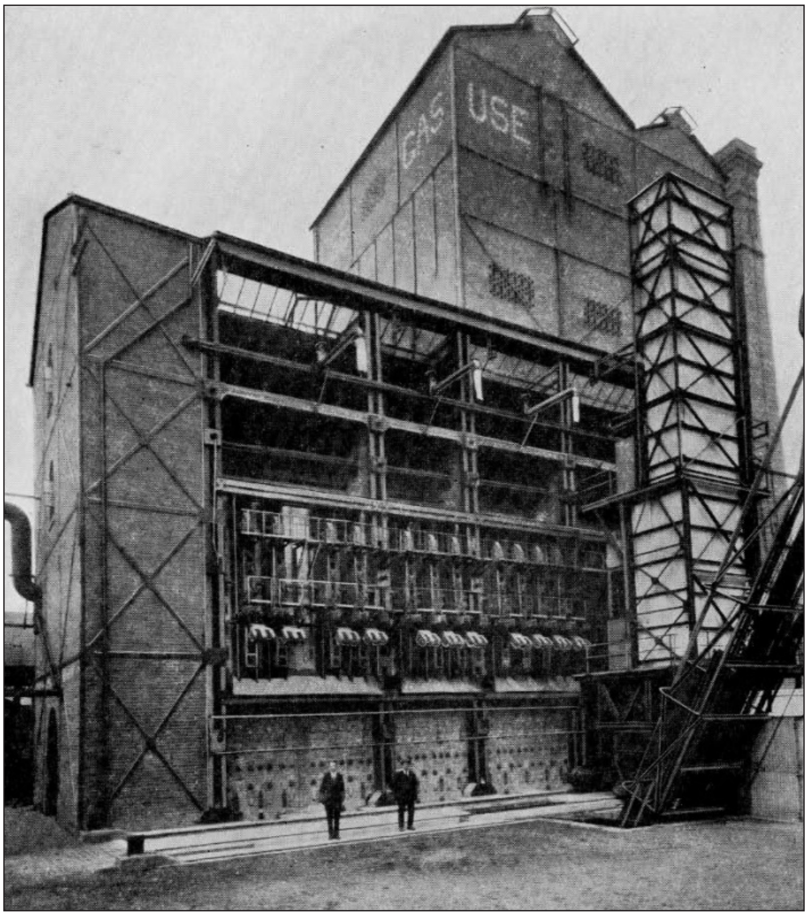


Figure 3.54 Inclined Chamber Oven Plant built at Lancaster Gasworks c1927.

There was a more significant uptake of the Intermittent Vertical Chamber Oven (IVCO), by 1928 plants had been or were being constructed by Woodhall-Duckham at gasworks in Croydon, Glasgow, Ramsgate and Taunton. These plants continued to be built in the UK post nationalisation in 1949 and the last traditional coal gasworks to be built in England, at White Lund near Morecambe was an IVCO plant. A diagrammatic cross section of a Woodall-Duckham IVCO plant is shown in Figure 3.55.

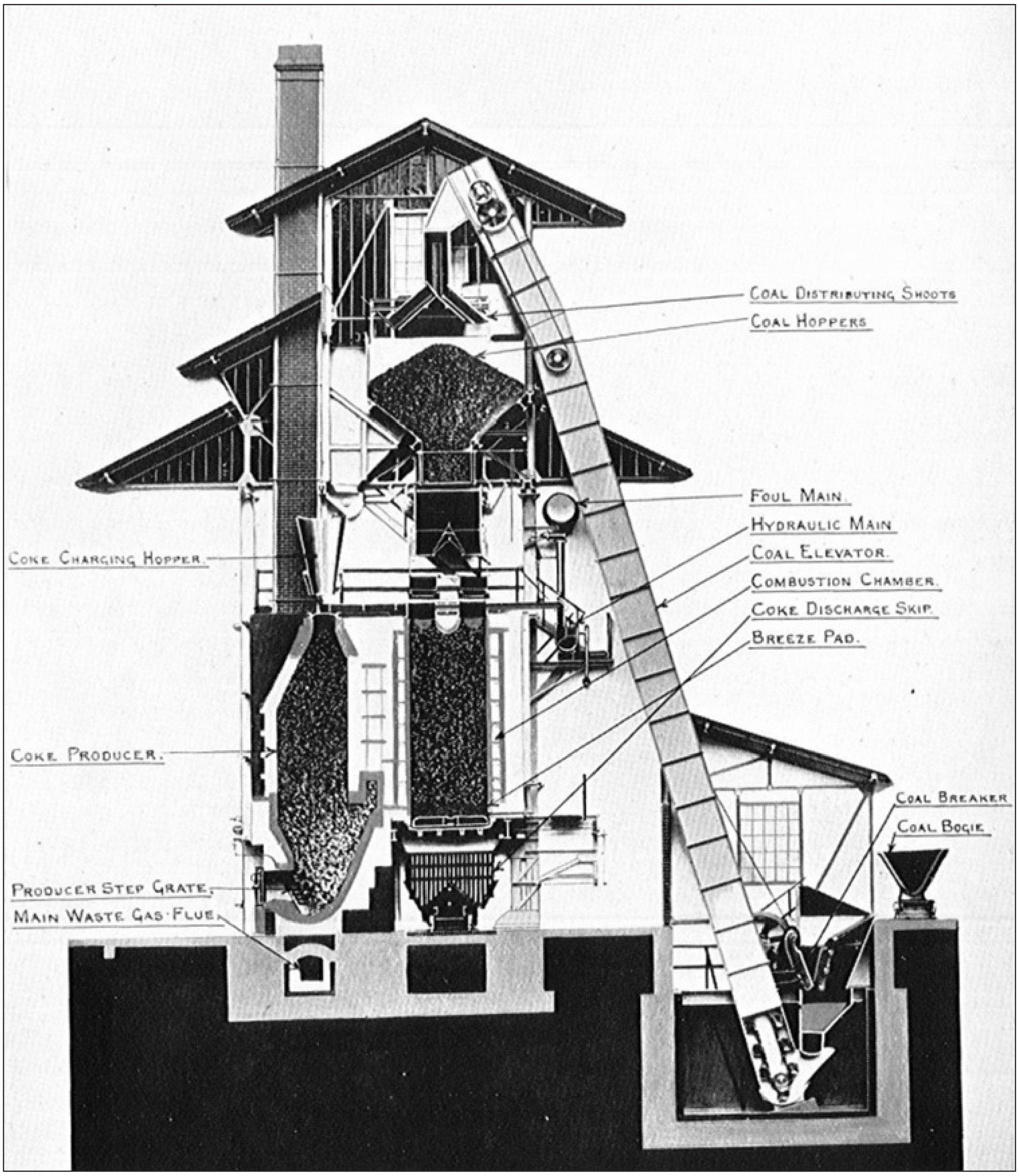


Figure 3.55 A Diagrammatic Cross Section of a Woodall-Duckham Intermittent Vertical Chamber Plant. Source Woodall-Duckham 1928.

The IVCO operated in a batch process. The ovens within the IVCO were rectangular and constructed to hold a mass of 1 to 7 tonnes of coal. They were also heated by external gas producers. The process differed as coke breeze (fine coke) was added to the base of the vertical chamber oven prior to the coal being loaded. This kept the oven door cool and ensured the coal was fully carbonised. A benefit of the IVCO system was that it could be used to carbonise poor quality coals (Slacks) or blended coals which had not typically been suitable for use in retorts. The process could also produce higher quality coke for the poor-quality coals used (Woodall-Duckham 1928).

Towards the end of the carbonisation process, the chamber would be steamed. This would allow the IVCO system to produce water gas. The water gas produced had a lower calorific value than the coal gas and would effectively dilute the calorific value of the coal gas. By controlling the length of the steaming, the calorific value of the gas could be varied. The IVCO system had relatively low labour costs and as the retorts were constantly heated and operated in a similar fashion to a coke oven, maintenance costs were relatively low (Woodall-Duckham 1928).

3.3. Gas Processing, Purification and Supporting Activities

The hot gas leaving the retorts or ovens was laden with impurities which made it unsuitable to burn. The gas required processing and purifying to make it suitable for use. These processes cooled the gas to atmospheric temperatures to remove tarry matter, washed and scrubbed the gas to remove residual tar and impurities and then purified to remove noxious substances. Later processes were also developed to remove useful substances such as benzol or remove problematic substances such as naphthalene or moisture. These processes were aided by a pump called an exhauster and are described in the following section. The first process was to cool the gas, which was undertaken using condensers (Stewart 1958, Meade 1921).

3.3.1 Condensers

Once the gas left the retorts via the ascension pipe, it entered the hydraulic main and foul main. Both aided the cooling of the gas, helping to remove tar and some of the ammonia and phenol from the gas. From the foul main, the gas would pass to the condenser, the role of the condenser was to cool the gas and remove coal tar and liquor from the gas, draining it to a below-ground tar tank or well (Stewart 1958).

From the earliest experiments on gas by Murdoch it was realised that some form of purification of the gas would be required. The tar which accompanied the gas would foul and block the pipes which transported the gas, it would also produce a foul odour when burnt. According to Creighton, the first attempts to purify the gas consisted on washing the gas with water (Newbigging and Fewtrell 1878, Stewart 1958).

Matthews describes that Murdoch was able to rid the gas of the odour, during his experiments, but the resulting gas then only gave very little light (Matthews 1827).

The Development of the condenser is described in the context of the different types which evolved, some of which were developed concurrently. Many different designs were employed.

3.3.1.1 Water Cooled Condensers

The first dedicated condenser was described by John Perks in his patent (No. 4154) of 1817. Condensers of Perks design featured in the very early gasworks built by the Neath Abbey Iron Company, who plans can still be found in the West Glamorgan Archives. This simple design consisted of a long water-filled trough through which water passed and in which the gas pipes were placed and cooled. John Malam was also heavily involved in the early development of the condenser. He developed a water-cooled condenser in 1818 which also included a device to wash impurities from the gas (Anon 1860, Stewart 1958).

From the 1870's great developments in the water-cooled condenser were made. George Livesey developed in 1870 a condenser based on the same principles as that described above, using serpentine horizontal pipes located in shallow water at the Old Kent Road Gasworks of the South Metropolitan Gas Company (Newbigging 1889, Stewart 1958).

Cleland's Low Speed Condenser consisted of a series of vertical pipes, connected at the top by a tubular cornice, which served as the common inlet to the whole series of pipes. The hot gas was divided equally amongst the several pipes, where it travelled downward at a comparatively slow speed. In the lower fifth of each column, a "bottle brush" of wood or other material, with a drip ledge above it to divert the descending liquor on to the centre of the brush, creating a scrubbing action. This created a very effective condenser which yielded of a high strength ammoniacal liquor (Newbigging 1889, Stewart 1958).

Another more advanced design was the water tube condenser. This worked by passing the gas through a vessel containing many water-filled tubes. The cold water in the tubes flowed in a counter-current direction to the gas, cooling the gas and condensing out tar. The tubes could be mounted in a vertical or horizontal direction. The Morris and Cutler Crossflow (1874) and Clapham Vertical Tube Water Cooled condenser (1884) worked on this principle (Newbigging 1889, Stewart 1958). A relatively late example of a Water Tube Condenser is shown in Figure 3.56.

Cutler's Horizontal Condenser had one or more small tubes passing through the interior of the larger pipes. A stream of water was passed through the tubes counter-current to the direction of the gas. With this arrangement by the time the cooling water had reached the inlet of the Condenser, it has absorbed sufficient heat to become a moderately high temperature, this prevented sudden cooling and ensured more gradual cooling of the gas throughout the condenser (Stewart 1958, Newbigging 1889).

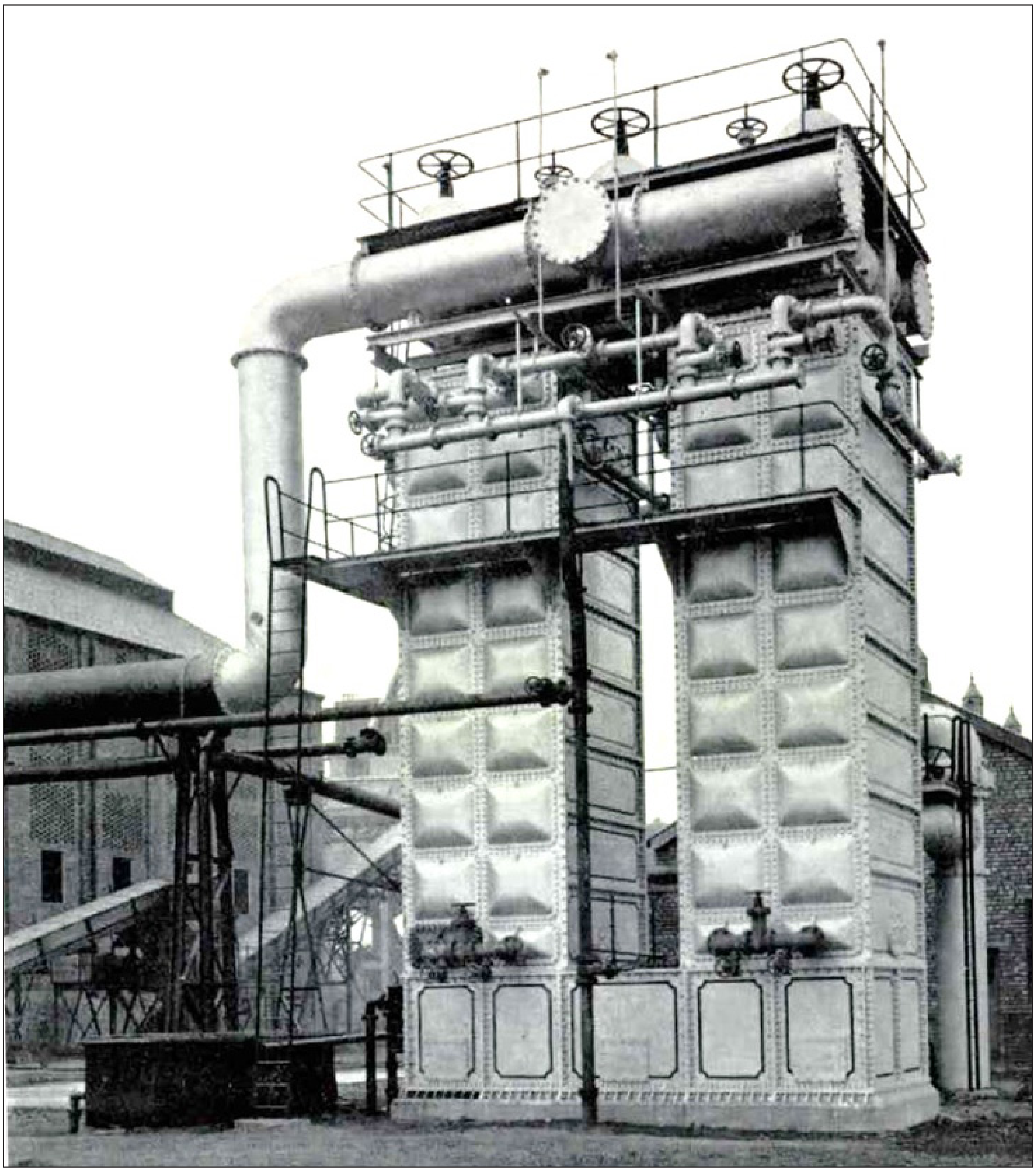


Figure 3.56 Two “Super” type Horizontal Water-Tube Condensers. Image courtesy of National Grid Gas Archive.

3.3.1.2 Atmospheric Condensers

On small gasworks, gas would generally be cooled using an atmospheric condenser. These came in a variety of formats and could easily be built using spare pipework and connections which the manager may have available on the gasworks (Meade 1921).

The atmospheric condenser relied on the temperature differential between the cooler ambient air and the hot gas, to cool the gas; this process was more successful in the winter, when the outside air temperature was lower.

One of the earliest forms of the atmospheric condenser was the horizontal atmospheric condenser as shown in Figure 5.57. These were often attached to the outer wall of the retort house or other convenient building. They were later placed a short distance from retort house.

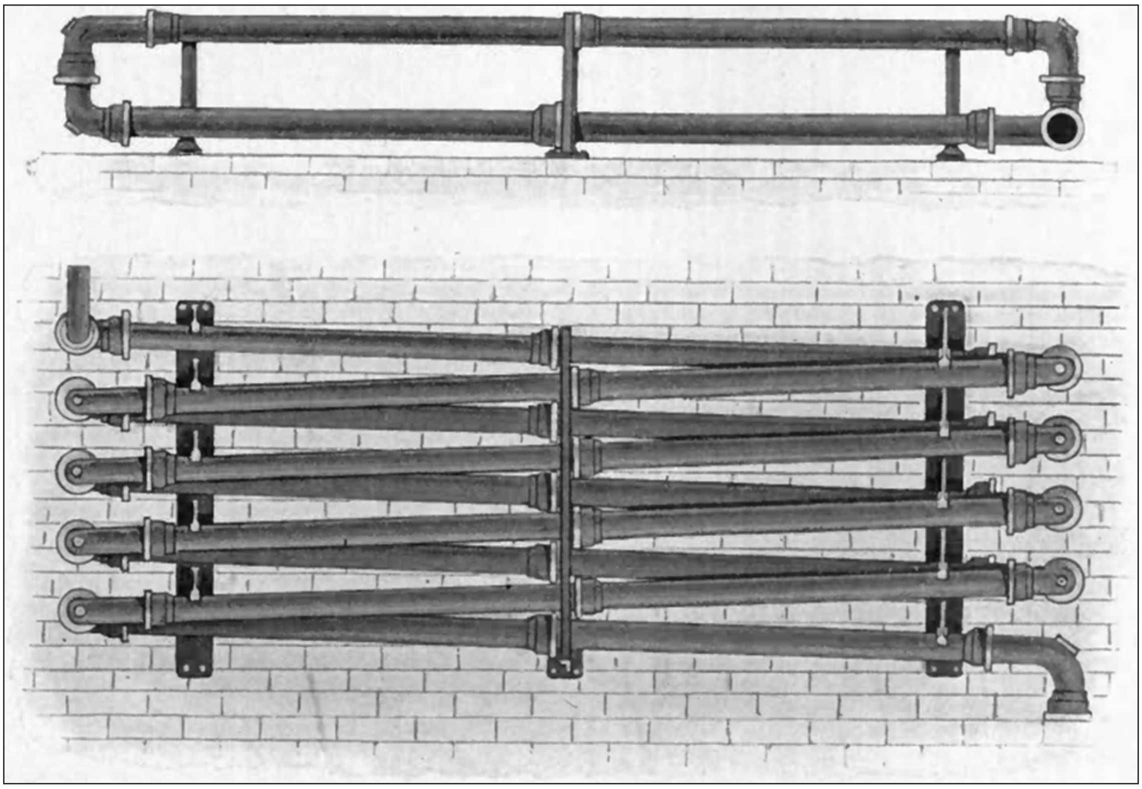


Figure 3.57 A Drawing of Horizontal Atmospheric Condensers. Source Meade 1921.

The pipes forming the horizontal condenser ran side by side, slightly inclined to the horizontal, and were commonly from 50 to 80 feet (15 to 24 meters) in length. There were often 8 to 12 rows of pipes. The condensed tarry matter would drain down the gradient of the pipe to an outlet which drained to the tar tank. In hot weather water was sometimes sprayed on to the pipes to improve the cooling (Newbigging 1889, Stewart 1958, Meade 1921).

The Zig-Zag condensers (Figure 5.58) were developed by James Malam in 1854 and improved by R. P. Spice in 1864 and D. A. Graham in 1867, it became a popular 19th Century condenser design. Graham's design consisted of two series' of ten 16 inch (0.4 meter) cast-iron pipes, 65 feet (19 meter) long, arranged in pairs side by side, and supported on framework. The end of each length of pipe was joined to that of the next, so from the inlet at the top, through the entire run of the condenser to the outlet at the bottom, there was a gradual inclination, so gave it the effect of a spiral, this aided the removal of the tar. Each length had a flange which allowed access to clean the condenser as required (Newbigging and Fewtrell 1878, Newbigging 1889, Stewart 1960).

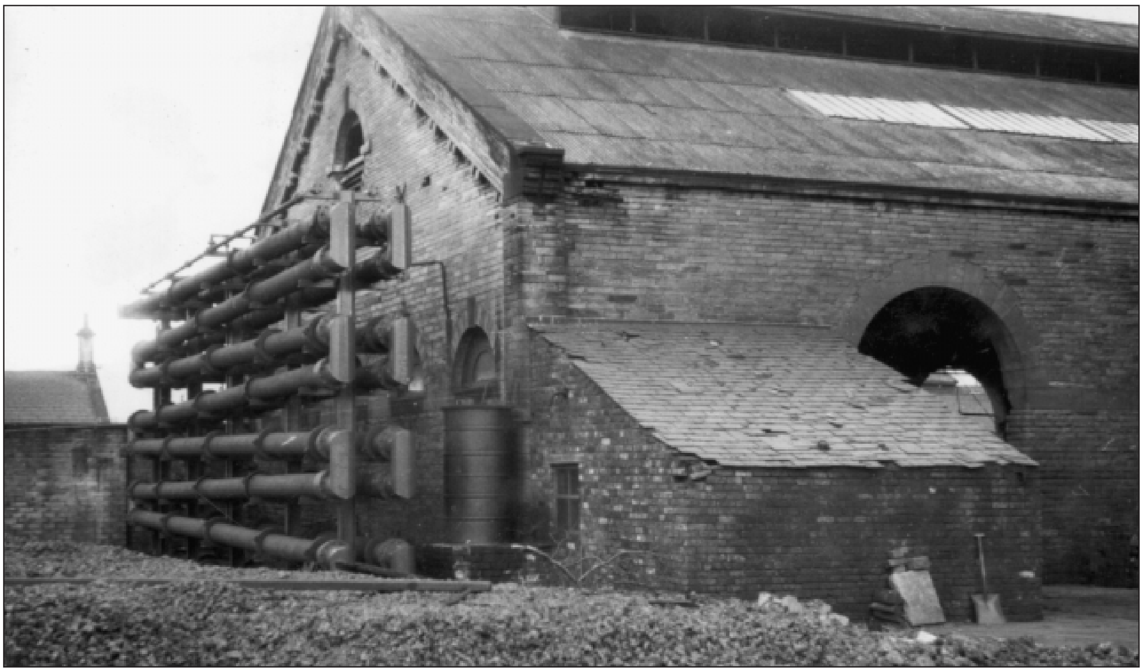


Figure 3.58 A Zig-Zag Horizontal Atmospheric condenser positioned next to the retort house. Image courtesy of National Grid Gas Archive.

Butterfield (1904) identified that vertical atmospheric condensers were less efficient than the horizontal forms. They consisted of several pipes, 20 to 30 feet high, placed vertically side by side. The gas passing up one pipe and down the next throughout the series. The condensed tar would drain from the lower ends of the pipes into the tar tank (Butterfield 1904).

The vertical atmospheric condenser later evolved to the following format. Consisting of a series of vertical pipes, usually 18 feet long, put together in two lengths, through which the gas passed up and down alternately. The gases entered a rectangular cistern at the base of the condenser, in which the coal tar and liquor are deposited, and flowed to the tar well. At the top was another cistern, containing water to seal the movable hoods covering each pair of pipes, and for further cooling could be applied in warm or sunny weather; by trickling small streams of water down the exterior surface of the pipes.

3.3.1.3 Annual Condensers

The Annular Condenser became a very popular choice for gasworks and was regarded by Newbigging (1889) as one of the most efficient atmospheric condensers. The annular condenser was a more advanced design, with the condensing apparatus formed from two concentric cylinders as shown in Figure 3.59. Both the internal and external faces of the condenser were cooled by air. The hot gas passed through the annular space between the two cylinders and the tar would condense over the surface of the condenser in a thin layer, draining to the well. Multiple annular cylinders formed the condenser, these were connected by either diagonal pipes or horizontal pipes. The diagonal pipes would join the bottom of the first cylinder to the top of the next. The horizontal pipes joining the cylinders would be placed alternately connecting either the top or bottom of the cylinders together, so the gas travelled the longest route possible through the condensers.

This design became popular from the 1860s, the annular condenser being developed by Kirkham (1860) and improved upon by Wright (1865), Walker (1865) and Paddon (1865).

Wrights modified version of Kirkham's Condenser was designed as described above with pipes, placed diagonally, connecting the top and bottom of the annular cylinders. This arrangement allowed the gas to pass through the annular space in the downward direction. The cooling current of air passed up through the interior ventilating pipe could be regulated by opening valves at the top or bottom of the interior ventilating pipe. A small pipe was connected to the bottom of each annular cylinder to allow the deposited tar and liquor to drain into the tar well (Newbigging 1889, Meade 1921).

3.3.1.4 The Tubular or Battery Condenser.

The Tubular or Battery Condenser was an oblong vessel, it was divided into sections by internal baffle-plates, placed at distances, equal to the width, apart. It was typically built to be 2 feet wide (0.6 meter) and 12 to 18 feet (3.6 to 5.4 meters) high. Its length was dependent on the requirements of the gasworks. Across each section 2-inch diameter tubes passed from side to side through which cooling air could pass. The gas passed from the inlet, up and down each section where the tubes served a double purpose of cooling the gas and retarding the passage of gas whilst forming an increased surface for the natural settlement of the tar. A relatively late multi-pass vertical tube condenser is shown in Figure 3.60.

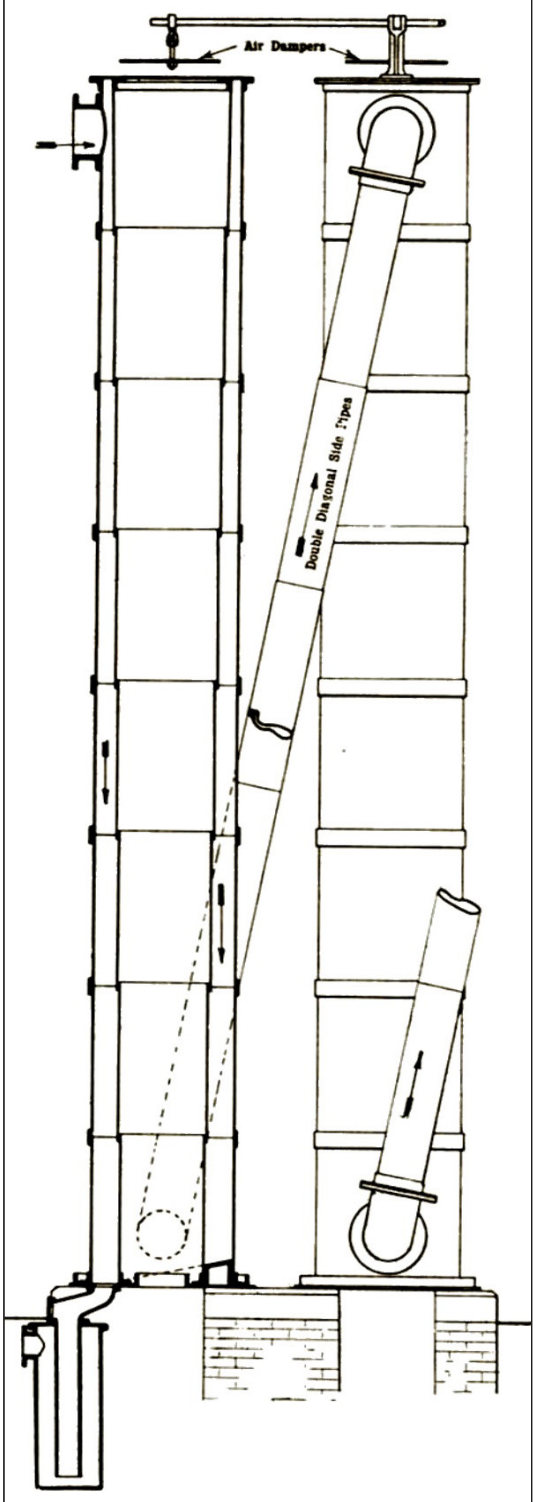


Figure 3.59 Schematic of Annular Condenser. Source Meade 1921.

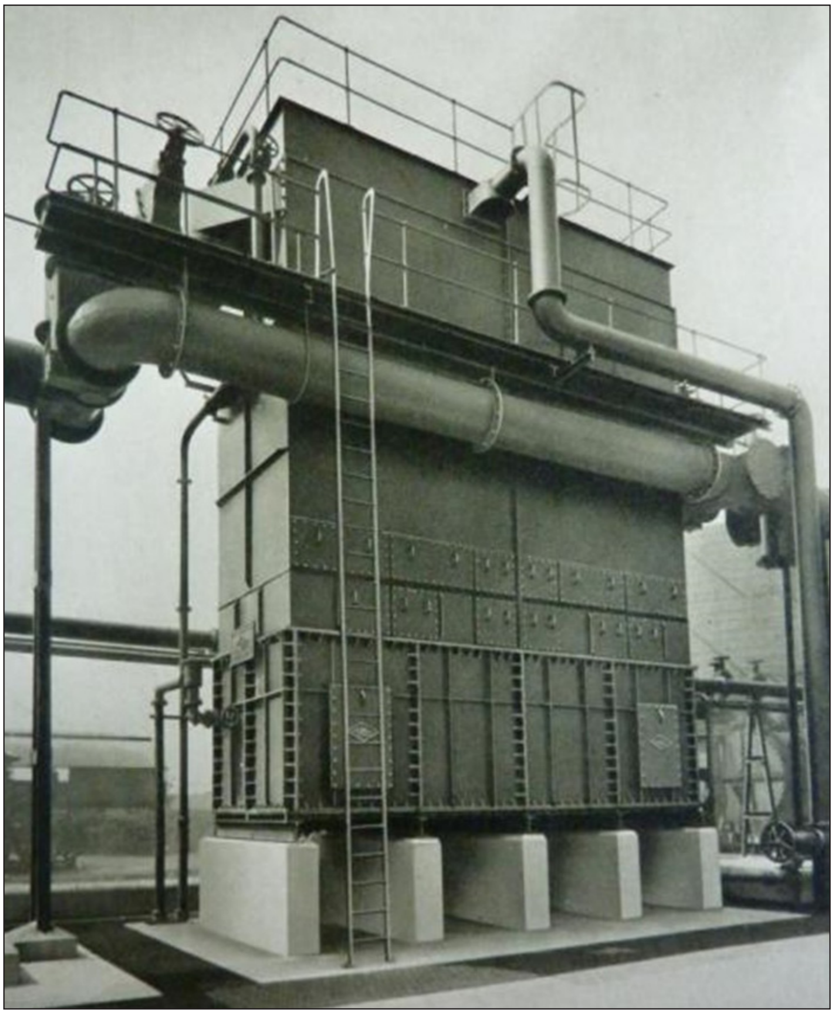


Figure 3.60 A multi-pass vertical tube condenser mounted on a tar and liquor separator at the former Romford gasworks. Image courtesy of National Grid Gas Archive.

3.3.1.5 Underground Condenser.

This variant of the condenser consisted of an array of pipes placed below ground, where the temperature would typically remain constant all year round. This system, required a much longer length of piping, owing to the small amount of radiant heat escaping from the surface of the buried pipes. It could provide more gradual condensation, but still required a further above ground condenser for a final condensation step (Newbigging 1889)

3.3.2 The Exhauster

The exhauster was not used in the first gasworks which were constructed, but developed a few decades later in the early 19th century. The exhauster was a form of pump which kept the gas flowing from the retort to the gasholder. It was often referred to as the heart of the gasworks, as it became of vital importance to the effective manufacture of gas (Stewart 1958).

The exhauster would draw the crude gas away from the retorts at a slightly negative pressure of approximately 10 inch water gauge pressure which was equivalent to 0.024 bar. Without an exhauster, the processing plant and gasholder would push against the retorts causing significant back pressure. The exhauster would prevent the build up of pressure and prevent the thermal degradation of the gas and coal tar, which would lead to the build-up of carbon deposits in the retorts and pipework. It also prevented the loss of gas through the retort walls, caused by the slightly porous nature of the fireclay and silica from which the retorts were constructed. The earlier cast iron retorts were much less porous and therefore this function of the exhauster was not required (Meade 1921, Stewart 1958).

The exhauster pulled the gas through the condenser and pushed it through the washer, scrubber and purification plant into the gasholder. This could require a pressure of 50 inch water gauge pressure or 0.12 bar (Stewart 1958, Meade 1921).

If primary and secondary condensers were used, the exhauster would normally be positioned between the two. An example of gas exhausters on the large Windsor Street gasworks in Birmingham can be seen in Figure 3.61.

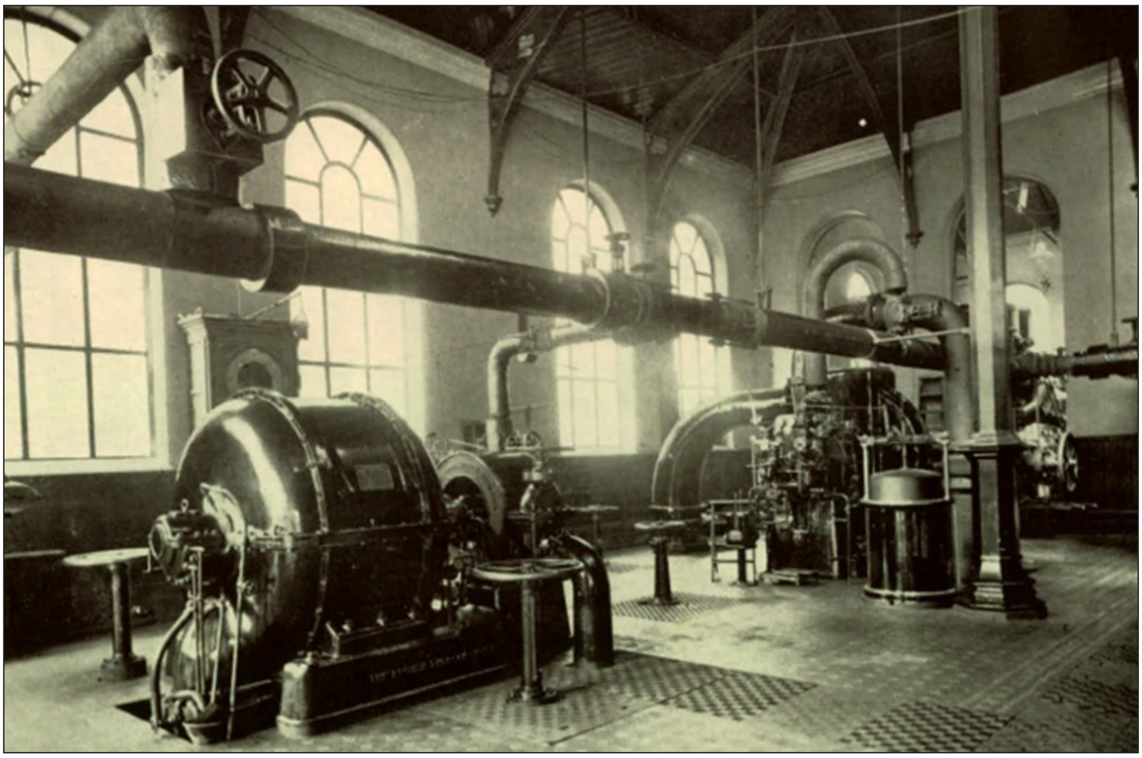


Figure 3.61 Gas exhausters at Windsor Street gasworks, Birmingham. Image courtesy of National Grid Gas Archive.

The need and benefit of an exhauster was first identified by the engineer Mr Simeon Broadmeadow of Abergavenny, who included it in has patents of 1824 (4893) and 1825 (5146). His first design was a double bell oscillating pump. It was composed of two gasometers attached to a beam (Anon 1860, Stewart 1958).

In 1830 Broadmeadow developed a new design using an inclined tube with archimedean screw and water seals (Stewart 1960). At this time the type of retorts in use were cast iron which were airtight, however as fireclay, a more porous materials was introduced *circa* 1840, the need to draw gas from the retorts to prevent leakage became apparent.

Exhausters were used on all but the smallest gasworks. They were classed as either rotary or reciprocating depending on their mode of action.

The reciprocating form was developed from Broadmeadows design. The reciprocating exhausters used a mechanism similar in appearance to a gasholder, where a vessel suspended in a tank of water was raised and lowered as it received and expelled gas in a cyclical fashion. Gas inlet and outlet pipes were connected to the inside of this vessel. When the vessel was raised, a vacuum was created and gas was pulled in through the inlet (a flap on the outlet closed to prevent back flow). When the vessel was lowered, gas was pushed through the outlet (a flap on the inlet closed to prevent back flow). By repeating this action, gas was drawn out of the retort. The vessel was raised and lowed by a simple mechanism. This consisted of a lever, one end of which was connected to the top of the vessel, the other to a shaft connected to a rotating cam (Meade 1921, Stewart 1958).

John Grafton's exhauster was the earliest reincarnation of Broadmeadows exhauster, developed ***circa*** 1841, it had a three-bell pump with hydraulic valves driven by a steam beam engine. In 1843 John Methven further improved the Grafton exhauster by fitting flap valves on his exhausters at Fulham and it received widespread use, it was, however, inefficient due to the problem of fluid friction. The French engineers Pauwels and Debouchet also adopted this type of exhauster in 1850 (Stewart 1958, Stewart 1960).

Around this time other types of exhauster were developed, in 1840 James Malam used a reversed wet drum gas meter, as an exhauster which also acted as a gas washer. George Anderson produced the reciprocating piston-type exhauster in 1841, this system was later improved by Dempster and was in use up to about 1900 (Stewart 1958, Stewart 1960). Piston based gas pumps became popular again in the mid 20th Century for the pumping of gas at high pressures in gas distributions systems.

In 1847 Jones patented a twin double-lobed impeller exhuster, the design was ahead of its time, it was not adopted until later in the UK. It was received favourably in the USA and 1866 Roots improved the lobed impeller exhauster. This developed into the Roots-Connersville exhauster and was reintroduced into Britain by W.C. Holmes as a double lobed impeller driven exhauster, which became very popular (Stewart 1958, Stewart 1960).

Cleland of Liverpool developed a very simple steam jet exhauster, which projected a high pressure jet of steam, through an arrangement of pipes to push the gas without any other mechanical aid. A schematic of this type of exhauster is shown in Figure 3.62. The system was improved in Germany by the Körting Brothers, and achieved some popularity, but was ultimately unsuccessful because of the cost of condensing the steam which otherwise diluted the strength of the ammoniacal liquor formed (Stewart 1958, Stewart 1960, Newbigging 1889).

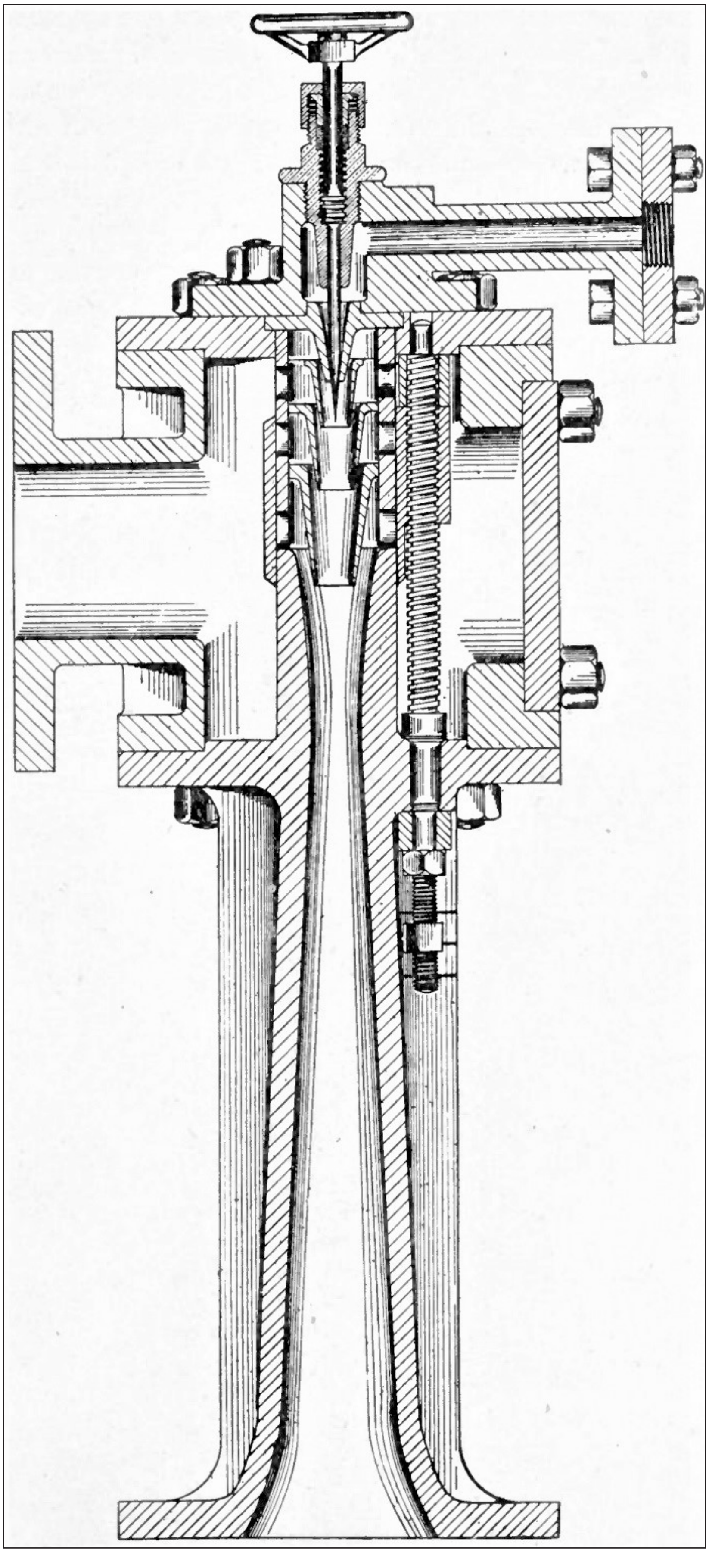


Figure 3.62 A Schematic of Clelands Steam Jet Exhauster. Source Meade 1921

In 1848 Joshua Beale developed the internal drum exhauster from his rotary steam engine. This gas exhauster comprised of an eccentric drum resting within a larger cylinder and carrying protruding vanes which swept the gas in and out of the cylinder. The drum exhauster proved popular in the gas industry due to its reliability, robustness and ease of operation and became the industry standard. It was progressively improved by his son in 1865 (sliding blade and drum exhauster) by Donkin in 1873 (4 blade exhauster) and 1877 (drum exhauster, 4 blades and centre block) and by Waller in 1873 (three blade exhauster), in respect of the absence of pulsation, less slip, less rubbing friction and in ability to deal with higher outlet pressures (Stewart 1958, Stewart 1960).

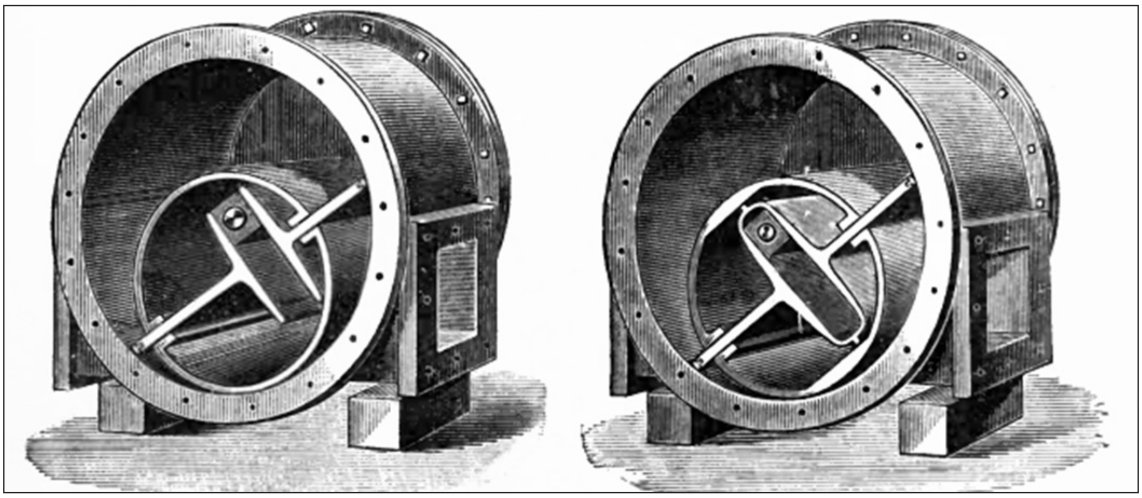
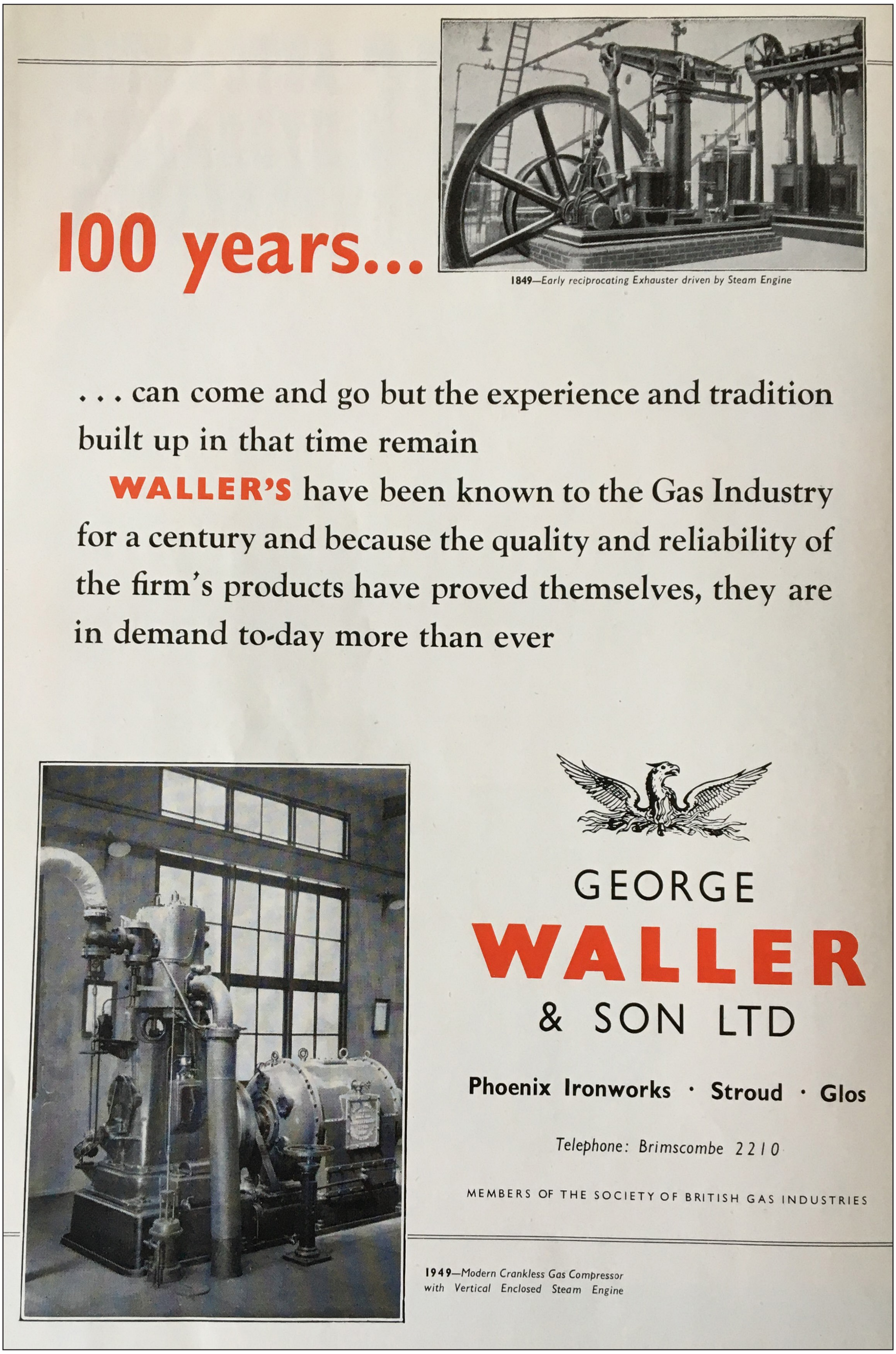


Figure 3.63 Beale's gas exhauster, patented in 1877 (left), Donkin's improved Beale's gas exhauster, patented in 1892 (right).

The exhauster required some form of control, this was achieved using a retort house governor. This governor had a different purpose to the Station Governor, being used for reducing and controlling the intensity of vacuum created by the exhauster (Meade 1921). The exhauster governor controlled the speed of the exhauster through controlling the throttle valve of the engine or the steam supply to steam engines (Newbigging 1889, Meade 1921).

One of the most popular manufacturers of exhausters was George Waller and Sons of Stroud, who manufactured these devices for over 100 years and feature in Figure 3.64.

The concept of the exhauster was later adapted to increase the pressure of gas within the mains and provide gas to outlying districts, in which case the pumps would be referred to as Booster Pumps. Whilst this was originally achieved with Beale exhausters up to a pressure of 5 lb per square inch, for higher pressures up to 250 lb per square inch, turbine fans such as the Rateau Star Wheel high speed centrifugal pumps, British Thomson-Houston Co. Ltd. Turbo exhauster (1921), Reavell Turbo exhauster and boosters (1920) or the aforementioned Connersville systems were used (Stewart 1958, Stewart 1960).



100 years...

1849—Early reciprocating Exhauster driven by Steam Engine

. . . can come and go but the experience and tradition built up in that time remain

WALLER'S have been known to the Gas Industry for a century and because the quality and reliability of the firm's products have proved themselves, they are in demand to-day more than ever

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1949—Modern Crankless Gas Compressor with Vertical Enclosed Steam Engine

Figure 3.64 An advert for Exhausting Machinery by George Waller, Gas Engineers of Stroud. Source Gas Journal 1949.

The booster pumps shown in Figure 3.65 were Bryan Donkin and Company electrically driven boosters installed at the Partington Gasworks. The Partington gasworks which supplied Manchester, was located in Cheshire when constructed and boosters were required to drive the gas to the Gaythorn gasworks from where the gas was distributed.

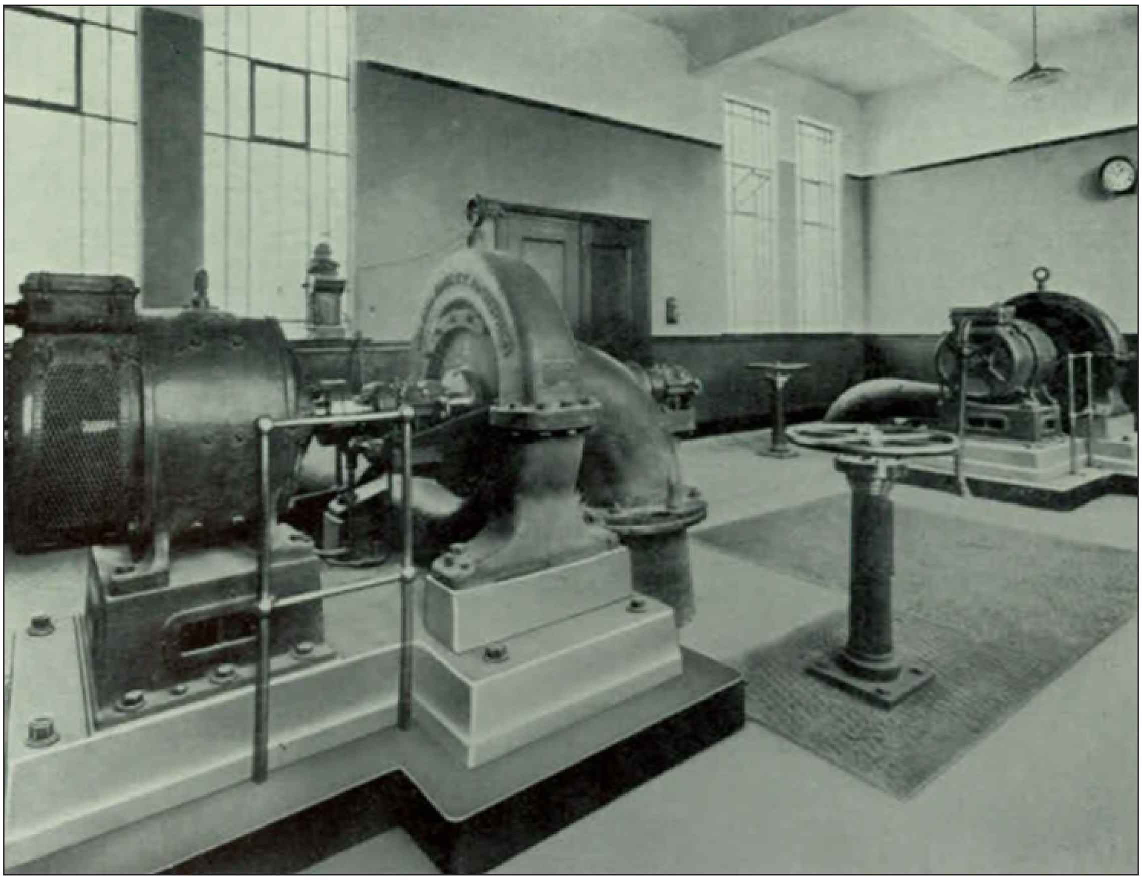


Figure 3.65 Bryan Donkin & Co Turbo Gas Boosters, Partington Gasworks. Image courtesy of National Grid Gas Archive.

3.3.3 Tar Washing and Removal

Gas washing systems were employed for two purposes. Firstly, to remove residual tar trapped in the gas, and secondly to remove soluble components such as ammonia or phenol from the gas.

Having passed through the condenser, the gas still contained small amounts of tar which needed to be removed. The first device designed for this purpose was the breeze box which was introduced about 1820. This was a metal chamber filled with layers of coke breeze, which was designed to catch droplets of tar trapped within the fog (Stewart 1958, Stewart 1960).

Only a few further developments occurred until about 1870, these included a method involving the use of a rotating fan with perforated blades patented (No.11661) in 1847 by George Holsworthy Palmer. William Bowditch (1853) and William Malam

(1854) both proposed the use of wire gauze to capture the tar droplets. Around 1870 several new tar washers were developed, these included Cathel's Washer, Anderson's Washer, Livesey's Washer and Walkers Washer (Newbigging 1889, Meade 1921, Stewart 1958).

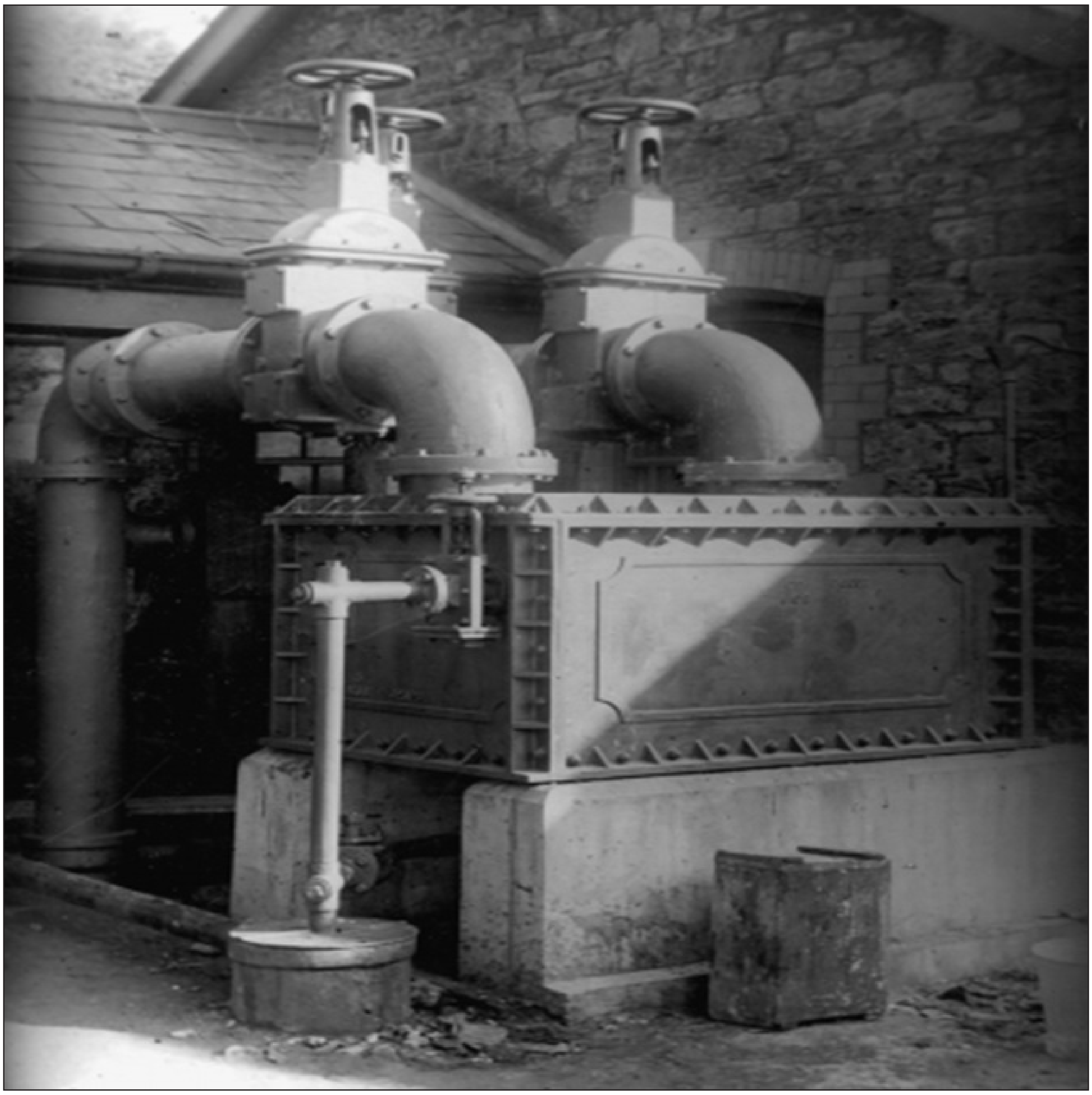


Figure 3.66 A Livesey washer. Image courtesy of National Grid Gas Archive.

Cathel's washer was divided into sections placed one above the other in an oblong or square vessel. The gas entered at the bottom of the vessel and passed in divided streams through numerous serrations extending the full length of the vessel, the gas passed upward through each section and out at the top of the highest section. When the concentration of liquor in the bottom section was the correct strength, it was removed and replaced by weaker liquor from the section above. Fresh water was placed in the top section. Anderson's washer had a cast iron outer vessel, operated on a similar principal but used weak liquor from the condensers instead (Newbigging 1889, Stewart 1958).

The most commonly used version of the tar washer was the Livesey Washer (Figure 3.66 and Figure 3.67), developed by the famous gas engineer George Livesey of the South Metropolitan Gas Company. The gas was bubbled through small perforated holes in gauze tubing under water. The tar collected on the surface of the perforated tube whilst the gas passed through and out of the tar washer. The tar was collected and drained to the tar well. The Walker Washer developed in 1872 worked on the same principles of bubbling the gas through perforated tubes.

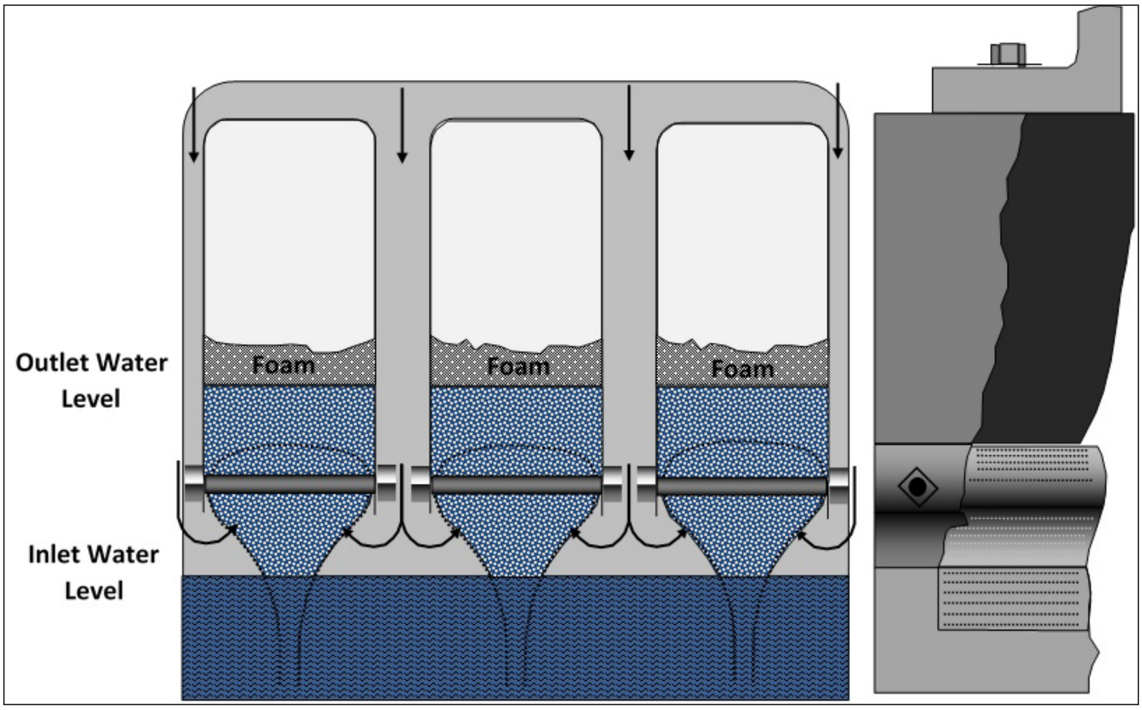


Figure 3.67 A schematic cross section of the inside of a Livesey Washer. Source R. Thomas

The French engineers Pelouze and Audouin developed a tar extractor which worked on different principles. The Pelouze and Audouin tar extractor consisted of an outer cylindrical casing with the gas inlet entering through the centre of the base. A bell similar to a small gasholder was suspended over the inlet pipe and had its base sealed in liquor. This created various perforated walls through which the gas would have to travel, providing the greatest possible disturbance to the gas and maximising the possibility for removing tar. It worked on the impingement principle of tar suspended in the gas being projected through small holes at high velocity onto a wall on to which the tar droplets would stick and then gradually drain to the tar well. This machine was automatic and could increase its surface area if gas flows increased (Meade 1921).

In 1900 the cyclone tar extractor was developed. A Colman's version of the cyclone is shown in Figure 3.68. This device was located in a different situation to other tar extractors located about half-way between the hydraulic main and the condensers. It consisted of an iron or steel cylinder, to the bottom of which was connected an inverted conical chamber, having a seal pipe attached to its lower end. The gas inlet was rectangular, entered the cylinder at a tangent and contained a flap valve which was used to regulate the velocity of the gas. As the gas entered the vessel it was set in a cyclonic motion forming a vortex. This forced the tarry matter within the gas on to the sides of the vessel by centrifugal force. The tarry matter would then run vertically down the vessel to the seal where it was collected and drained to a tar well. The cyclone would also remove some liquor as part of the tarry matter. The gas was removed from the vessel by way of the central vertical pipe.

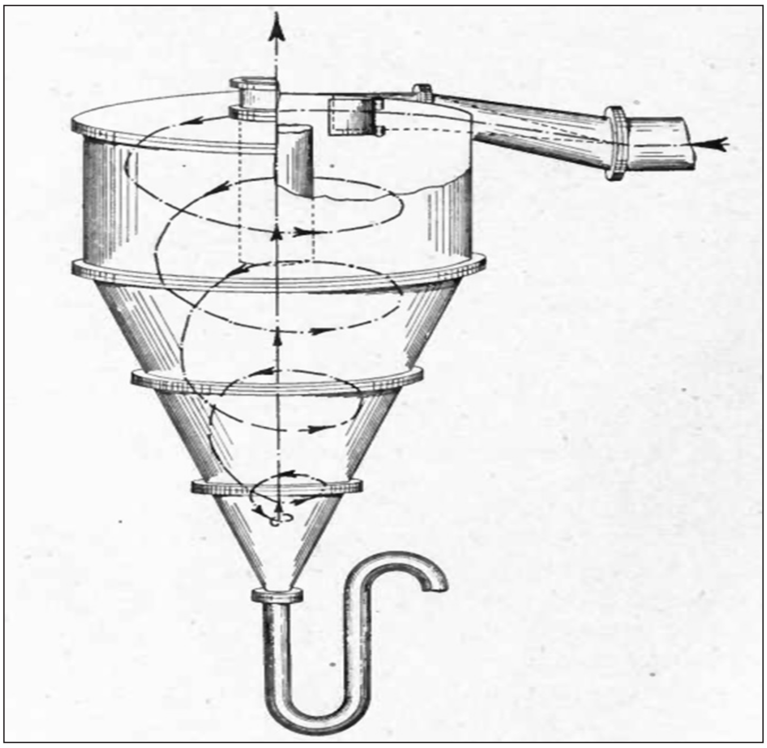


Figure 3.68 Colman's Cyclone Extractor. Source Meade 1921.

3.3.4 Electrostatic Detarrer

Hohlfeld, in 1824 and Guitard in 1850 undertook experiments which removed fog in the case of the former and tobacco smoke in the case of the latter from a vessel, although interesting the experiments did not stimulate any practical development. In 1884 Sir Oliver Lodge rediscovered the principle of electrostatic removal. The American Frederick Gardner Cottrell took an interest in electrostatic precipitation in the first decade of the 20th century. This work eventually led to him devising the Electrostatic tar precipitator in 1926. It worked on the principal that as the gas particles passed through the electrostatic detarrer, they were exposed to a very high negative voltage, giving the tar particles a negative electrical charge. As the gas continued through the detarrer, it was exposed to a high positive voltage. The negative charge of the tar particles would then attract them to the positive electrode where the tar would be removed. A spray of oil helped wash the tar from the positive electrode. The tar would collect at the base of the detarrer and then flow by gravity to the tar tank (Meade 1916, Stewart 1958, White 1957).

Gas passed through the cylindrical plant as it would a condenser, but an electrical current was used to remove the tar instead of cooling.

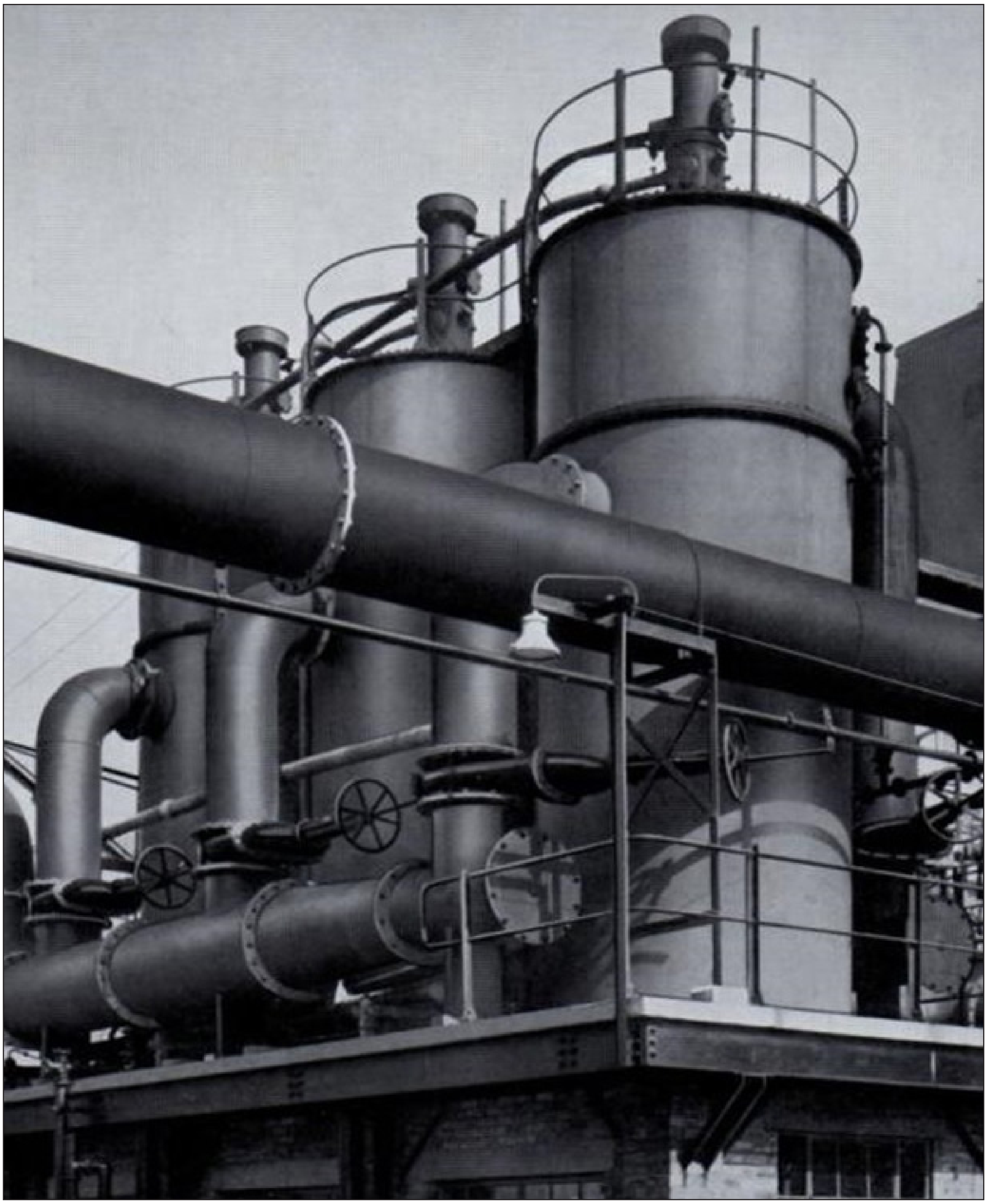


Figure 3.69 Three electrostatic detarrers. Image courtesy of National Grid Gas Archive.

The first electrostatic detarrer installed in England was installed at the Hinckley gasworks, Leicestershire, in 1926, to an American design.

The first British-designed electrostatic detarrer was built by Simon-Carvès Ltd and Ferranti Ltd and used static electrical rectifiers. It was installed on a coke oven battery at Billingham in Teesside in 1929. The first British electrostatic detarrer installed on a gasworks was at Southall, West London in 1931. A similar technology is still used today to remove particulate matter from the smoke in power station chimneys and in other processes that generate dust.

3.3.5 Ammonia Washing and Scrubbing

Having passed through the condensers and tar washer most of the tar would have been removed, along with around 50% of the soluble impurities of ammonium and phenolic compounds. To remove the remaining soluble impurities the gas required further washing and scrubbing. A relatively late example of ammonia washer is shown in Figure 3.70. In the background electrostatic detarrers are visible, which are described later.

Figure 3.70 Ammonia washers with electrostatic detarrers and primary and secondary condensers in the background, Rotherhithe gasworks, London 1948. Image courtesy of National Grid Gas Archive.

For most of the 19th century, non-mechanical means were used to perform this function, such as the tower scrubber shown in Figure 3.71. From the 1880s onwards, mechanical plant started to be introduced (Humphrys 1911, Meade 1916, Stewart 1958).

Figure 3.71 Two tower scrubbers. Image courtesy of National Grid Gas Archive.

The purpose of the washer and scrubber was to expose the gas to the largest possible wetted surface area, achieving the most intimate contact between the gas and washing medium. This enabled the greatest quantity of the soluble impurities to be removed. The medium used to wash the gas was usually a weak solution of ammoniacal liquor, although water could be used. It was generally the aim to generate as concentrated a liquor as possible, both to increase its value for sulphate of ammonia production and to minimise the volume of liquor generated. The washing medium dissolved the ammonium and phenol present in the gas, forming ammoniacal liquor (or increasing the strength of the initial ammoniacal liquor solution). Once it had attained a suitable strength, the ammoniacal liquor would be drained to the tar and liquor tank by gravity, where it would float on top of the tar in small tanks or drain via weirs into a separate liquor tank or compartments. The liquor used in a washer was much stronger than that used in a scrubber. (Humphrys 1911, Meade 1916, Stewart 1958). The washer/scrubber could come in a wide range of designs, but here were three main types of plant employed to further wash the gas:

the tower scrubber, the mechanical washer and the washer scrubber (Humphrys 1911, Meade 1916, Stewart 1958).

Scrubbers were normally used after the washers, although small gasworks would sometimes use just scrubbers. The most common form of the scrubber was the tall cast iron circular towers (see Figure 3.71) filled with coke, bricks, wooden boards or ceramic rings. As the gas flowed slowly up the tower scrubber, it met a spray of cooled water passing down the scrubber. This would cover the filter media (e.g. coke) and provide the largest possible surface area to absorb the ammonia and phenol. It would then fall into the base of the scrubber and drain to the tar well. These tower scrubbers were relatively simple and problem-free (Humphrys 1911, Meade 1916, Stewart 1958).

The mechanical washer-scrubber benefitted from a very large freshly wetted surface and the mechanical means to break up the gas into the fine bubbles. A horizontal cylindrical mechanical washer can be seen in Figure 3.72. The mechanical washer-scrubber could also carry out some of the tar removal function which the Livesey washer would undertake. If two washing units were used, then it was typical that the latter unit would be fed by clean water to maximise the amount of ammonia which could be removed from the gas. In small gasworks, it was common to have only one or two tower scrubbers with no mechanical washing equipment. The most popular combination was the mechanical washer scrubber, followed by either one or two tower scrubbers (Humphrys 1911, Meade 1916, Stewart 1958).

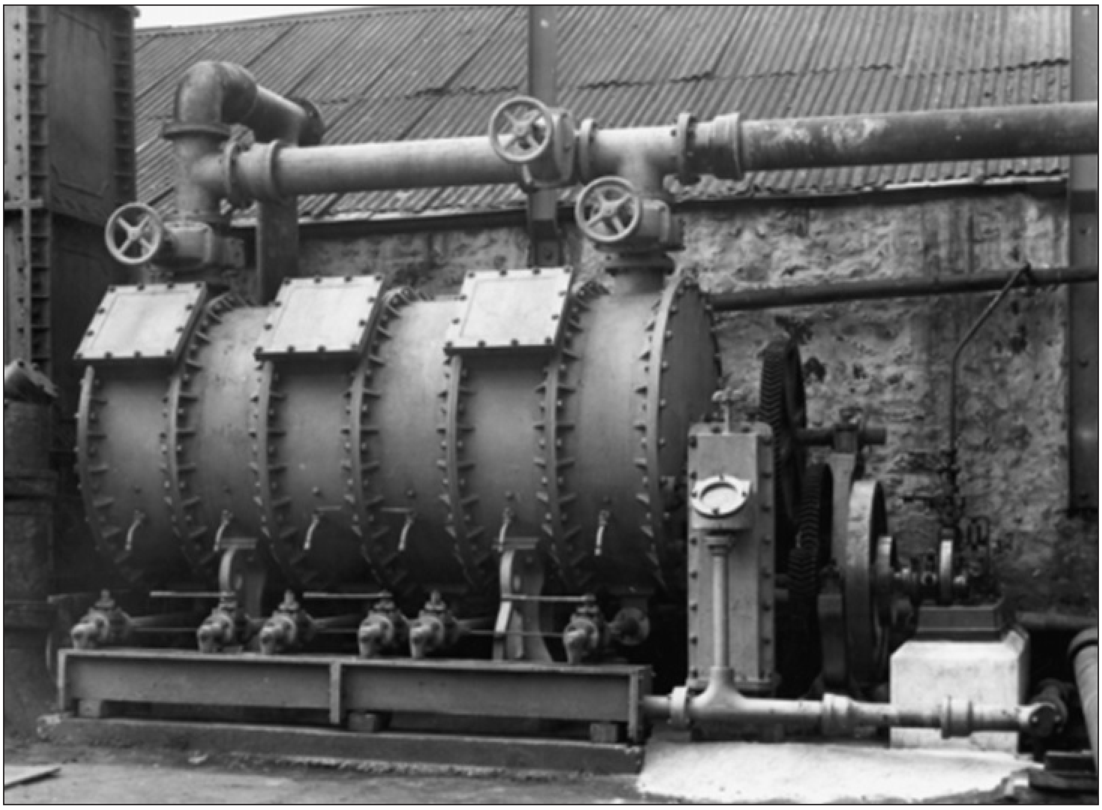


Figure 3.72 A rotary mechanical washer. Image courtesy of National Grid Gas Archive.

Later scrubbers employed rotating horizontal (Figures 3.72 and 3.73) or vertical cylinders. These cylindrical were fabricated from concentric cast iron rings in sections bolted together and divided into separate compartments by means of circular division plates. These had openings in the centre to permit the passage of the gas. The machine was constructed in two sections. An axel ran the length of the unit and was supported at the centre with intermediate bearings and separate bearings at each end. A connecting main provided for the passage of the gas between the sections. along the axel in both sections was attached filter media which a large surface area (Meade 1921).

The gas and water ran counter current directions, as in the tower scrubber. The Kirkham, Hulett and Chandler's Rotary Washer-Scrubber was the best-known example of the washer scrubber and can be seen in Figure 3.73.

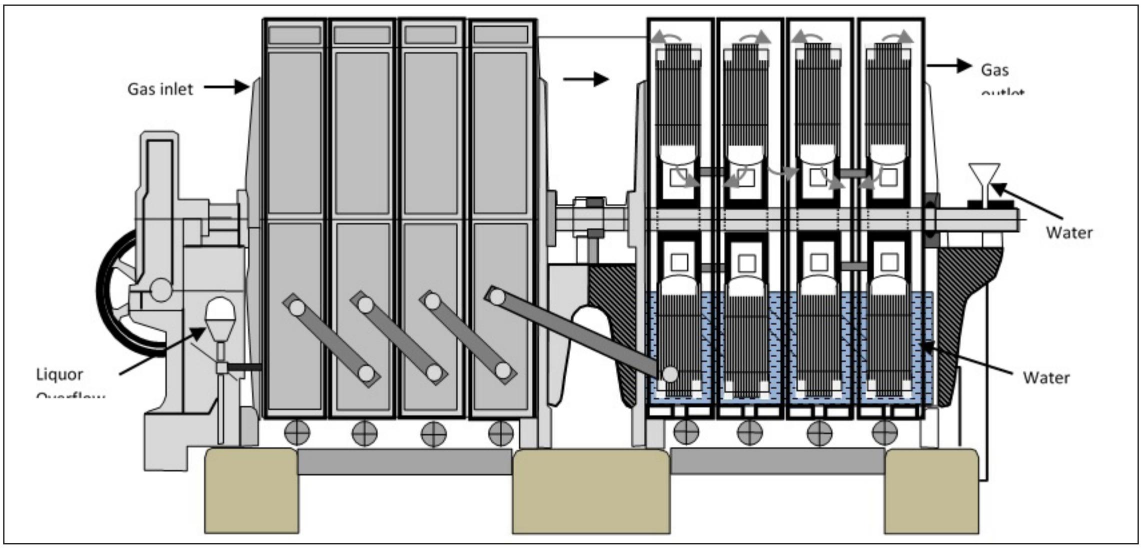


Figure 3.73 A schematic of a Kirkham, Hulett and Chandler's Standard Rotary Washer-Scrubber. Source R. Thomas.

A cross section of this horizontal washer scrubber is shown in Figure 3.73. The rotary washer scrubber was filled with the corrugated iron filter material shown in Figure 3.74. Other popular designs were the Whessoe and Holmes washer-scrubbers.

These same washers-scrubbers were also employed for benzol and naphthalene removal using oil as the washing agent. They were also used as gas drying plant, removing moisture from the gas by washing it with calcium chloride (Meade 1921).

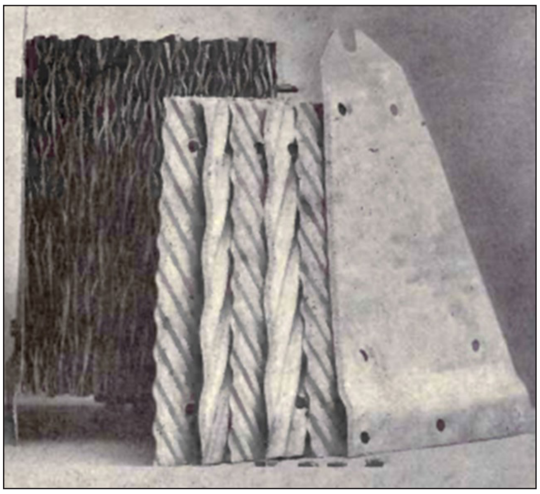


Figure 3.74 The corrugated filter material used inside the standard washer-scrubber. Source Meade 1916.

3.3.6 Purification

With the removal of tar, ammonium and phenols from the gas, two other poisonous substances were removed: hydrogen sulphide and hydrogen cyanide. Hydrogen sulphide was the predominant contaminant of concern and was present in the gas at a much higher concentration than cyanide. The sulphur had been a problem from the earliest years of the industry, the sulphur dioxide smell being known to as the Soho stink referring to the smell from the gas lighting experiments undertaken at Boulton and Watt's factory. If sulphur was not removed from the gas, when it was burnt it formed noxious fumes of sulphur dioxide, which would then form sulphuric acid. Sulphuric acid would then cause the corrosion of gas fittings and deterioration of fabric, paintings and other items within the consumer's house (Clegg 1841, Stewart 1958, Barash and Gooderham 1971).

The sulphur compounds found within coal gas originate from the coal. The source within the coal is the decomposed parent plant matter which had formed the coal and the sulphate in seawater which had flooded peat swamps. The sulphur concentration varies between coals, its abundance being largely controlled by the degree of seawater influence during peat accumulation and by post-depositional changes. Sulphur within the plant matter is subsequently reduced by bacteria into hydrogen sulphide, polysulphides, and elemental sulphur. The preference of the gas engineer was for coals to have low concentrations of sulphur to aid purification. Cannel coal tended to have lower concentrations of sulphur and it was preferred in some situations in the early years when purification was in its infancy, because it reduced the sulphur concentration in the gas. Other sulphur compounds were also formed in the gas, this included organic sulphur compounds such as carbon disulphide, for which process to remove it were developed (Lowry 1945, Chen-Lin 2012).

William Murdoch had worked on the principal that the water within the gasholder would purify the gas sufficiently for use, however, it was ineffective at removing the sulphur from the gas (Newbigging and Fewtrell, 1878). Murdoch and Creighton experimented with the use of quick-lime to purify the gas, it proved effective but gave only a poor-quality light, (Matthews, 1827).

During 1804 the chemist Dr William Henry had been undertaking a series of chemistry lectures in Manchester where he distilled coal gas and burnt it using an argand burner (Newbigging and Fewtrell, 1878). He undertook extensive experimentation on the coal gas to understand its composition and how it could be best used for gas lighting. He had commented in Nicholson's Journal in 1805 and communicated to the Royal Society in 1808 on the use of lime to purify sulphur from coal gas (Henry 1805, Henry 1808).

In 1806 Edward Heard, one-time assistant to Winsor, patented (British patent No.2941) a method to purify sulphur from gas by stratifying lime with the coal during their distillation. The patent also described passing the gas over lime in a separate vessel and noted that fixed alkali's or alkaline earths such as Barytes when deprived of their carbonic acids could be substituted for lime, as could metals or their oxide such as "iron, manganese, zinc copper or lead" (Anon, 1860). Many of these aspects were later incorporated in purification processes developed by others (Carpenter, 1914).

Gas purification to remove hydrogen sulphide, then known as sulphuretted hydrogen, was attempted using lime as early as 1806, by Samuel Clegg, when he was lighting the house of Henry Lodge, whose mill he had previously lit in Sowerby Bridge in Yorkshire. Clegg added the lime to the gasholder tank, but it just settled at the base of the tank and had limited effect on sulphur removal (Newbigging and Fewtrell, 1878). In 1808 when Samuel Clegg used lime within the gasholder tank at the gasworks he was building at the Harris Works in Coventry, he incorporated a paddle system to agitate the lime, however, it only provided a partial purification of the gas (Bennett 1986, Chandler and Lacey, 1949).

Albert Winsor had included the use of lime water or cream of lime within a separate vessel in his British patent (No. 3200) of 1809 (Anon, 1860). Richards also designed a lime purifying machine in 1810 (Stewart, 1960).

The issue of purifying the gas became a major issue for Clegg, when he was asked to install a gas plant for the Stonyhurst College near Preston in 1811. Clegg was aware that the gas would need to be purified before being burnt within the enclosed rooms of the college (Bennett, 1986).

He was able to experiment within the laboratory facilities at the college and through this experimentation he devised a separate lime purifying machine, which used lime water. Unlike the lime used within the gasholder, it was possible for the spent lime to be removed. The system was fitted with an agitator which enabled the wet lime to be mixed. The purifier was installed prior to the gas entering the gasholder. This system was incorporated in future gasworks built by Clegg (Figure 3.75).

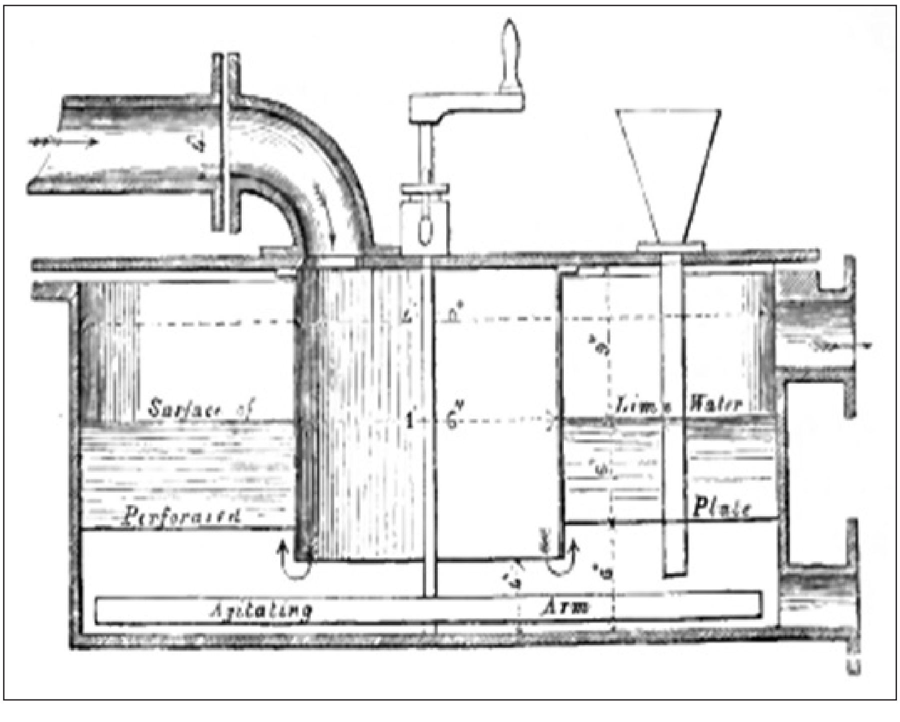


Figure 3.75 The wet lime purifier developed by Samuel Clegg. Image courtesy of IGEM archive.

Whilst a big improvement, Clegg's wet lime purifiers provided uneven purification as the performance dropped as the lime became fouled. These purifiers could also become clogged, which increased the risk of back pressure building up within the purifier and with that a potential explosion (Tomory 2012).

The wet lime process also used a large amount of water and where this was not available, such as the Great Peter Street Gasworks of the GLCC, it was a problem (Everard, 1949). To avoid using large amounts of water, Samuel Clegg in 1815, attempted to use dry lime instead at the Great Peter Street gasworks, despite promising early results, it did not prove particularly effective (Everard 1949).

The wet lime purifier was further developed by John Malam. He developed a treble purifier, shown in Figure 3.76 which was three wet lime purifiers built over one another, this provided the advantage a single axel could be used.

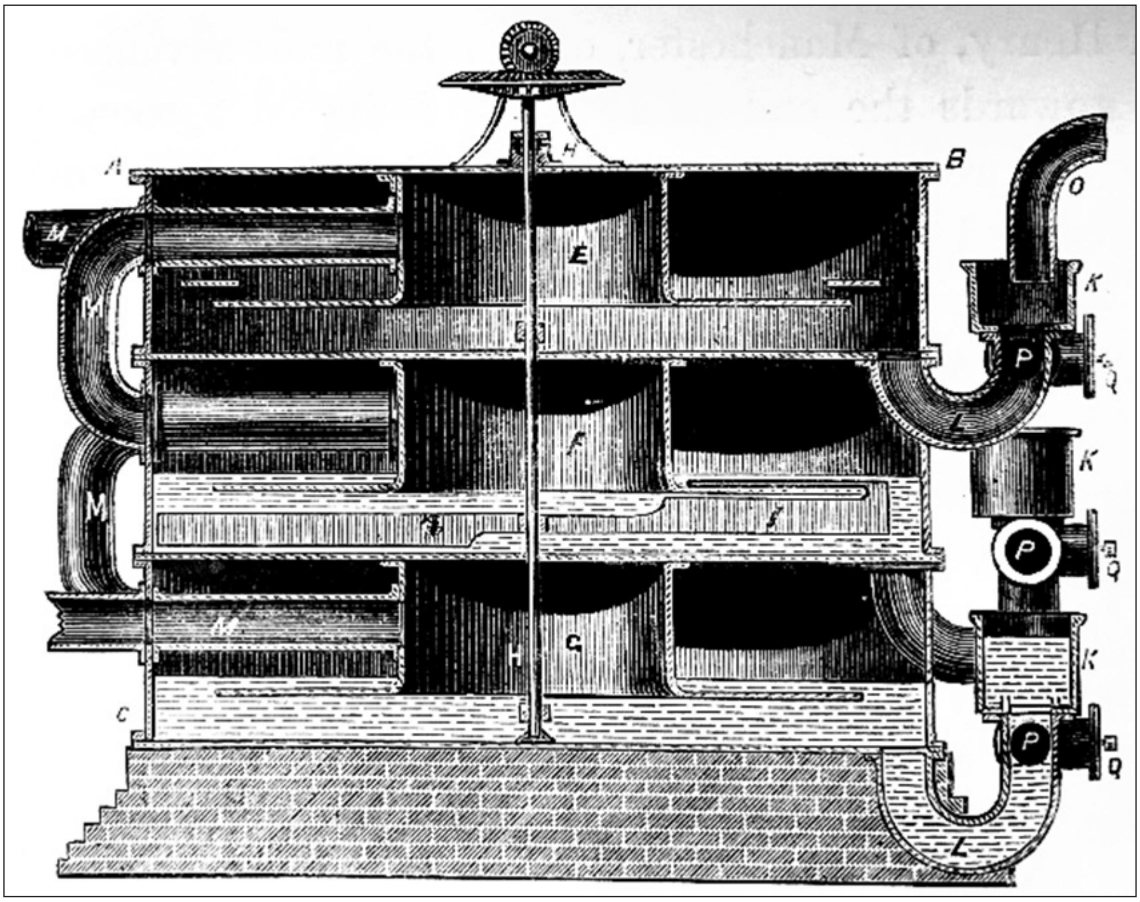


Figure 3.76 The Treble wet lime Purifier devised by John Malam. Source Richards 1877.

The wet lime process had a major drawback, it produced a bluish lime-rich waste known as 'Blue Billy' which had a very sulphurous stench. The problems associated with wet lime had become apparent as early as 1815, as the GLCC had become embroiled in various lawsuits with its neighbours from the nuisance caused by the waste (Tomory 2012). It almost led to the closure of the Great Peter Street works, which was averted when agreement was reached with the "Committee for the Navigation of the River Thames" for permission to lay pipes directly from the Gasworks to the River Thames, subject to an annual fine. The wet lime process, which was widely adopted early on caused continual waste disposal problems for the gas undertaking. One method of disposal developed was the use of waste heat to evaporate the moisture from the wet lime, which was employed in the mid C19th across many the gasworks in London (Everard 1949).

The dry lime purifier did not emerge till later, although attempts were made to use the process at the GLCC gasworks at Great Peter Street. The box purifiers did not appear till later.

The first work on a dry lime purifier was undertaken by Reuben Phillips of Exeter (1817). Mr Phillips' purifier was in many ways similar to the system employed later in most gasworks, as it worked on the basis of forcing the gas through layers of hydrate of lime. However, the system was flawed as it was water sealed and the purifier had no solid base (Newbigging and Fewtrell 1878, Stewart 1958, Nabb 1986). This was later rectified by adding a solid base and a removable lid as can be seen in Figure 3.77.

The lime used was hydrated rather than dry, as moisture was required to make the process work. The hydrated lime would react with the hydrogen sulphide forming calcium sulphide, and with hydrogen cyanide to form calcium thiocyanate and to some extent calcium ferrocyanide (Meade 1921).

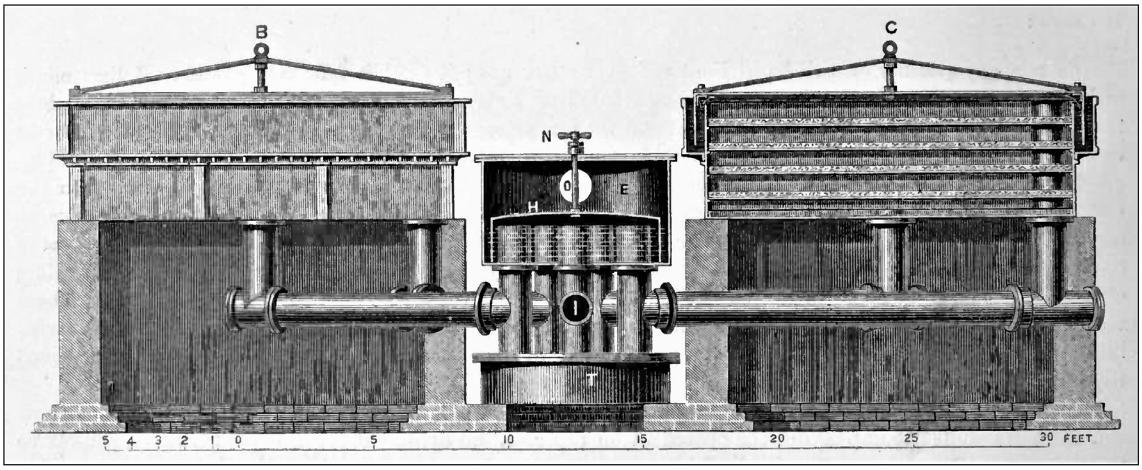


Figure 3.77. Malam's arrangement of purifiers showing a cross section of the box purifiers. Source Richards 1877.

In 1845 Malam produced a design with a central hydraulic valve controlling the arrangement of four or six purifiers shown in Figure 3.77, this design remained almost unaltered for over a century. In 1857 Cockey produced a dry centre valve in place of the hydraulic valve developed by Malam (Stewart 1958).

Lime was later superseded by the use of bog iron ore, although they were sometimes mixed and used together. Experiments were made with metallic oxides, notably manganese dioxide by Croll in 1840 and iron oxide (hydrated iron oxide) by Evans in 1842, Langmaid in 1848 and Laming and Hills in 1849. Although not the original discoverers, Richard Laming and Frank Hills patented the process of revivification of spent oxide, the waste formed when the iron oxide was used to treat the gas, which is described later. It was adopted for use on larger British gasworks by 1853 and used worldwide by the 1860s (Stewart 1958).

The Metropolis Gas Act 1860 enshrined that gas "shall with respect to its purity, be so far free from ammonia and sulphuretted hydrogen" and then in the "City of London Gas Act, 1868", but most notably in the Gasworks Clauses Act, 1871. Section 12 of the Gasworks Clauses Act of 1871 enacts that the "gas shall as to its purity not exhibit any trace of sulphuretted hydrogen when tested" (Scholefield 1911).

The Gasworks Clauses Act of 1871 also contained elaborate provisions for a place where the gas may be tested for illuminating power and purity, and for the appointment by the local authority of a competent and impartial person to be a gas examiner for conducting such tests during prescribed hours of each day. Following these acts provisions were inserted into many Special Acts imposing restrictions regarding the amount of sulphur impurities in the gas. The net effect of this act was to make it impossible to replace lime purification entirely with iron oxide purification, which was not quite as effective. Bog iron ore was more economical and less troublesome than lime (Scholefield 1911, Stewart 1958).

The sulphur limits in gas enshrined in the Gasworks Clauses Act of 1871 were partially revoked on evidence of the report of the Departmental Committee of 1904, and the London Gas Act, 1905, by which the London gas companies were relieved from the liabilities imposed on them as to sulphur impurities other than sulphuretted hydrogen, similar acts were then introduced for provincial gas undertakings. After 1905 it was then possible to undertake purification by iron oxide alone, completely replacing lime. A drawback with the use of iron ore alone was that it was less effective at removing carbon disulphide, so some works developed specific plants for the removal of carbon disulphide from gas (Scholefield 1911, Stewart 1958).

When the hydrogen cyanide present in coal gas was passed over bog iron ore, it would predominantly form ferric ferrocyanide, also known as 'Prussian blue'. The hydrogen sulphide would react with the bog iron ore and form ferric sulphide, ferrous sulphide and sulphur.

The purifiers were usually square or rectangular, made from iron (Figures 3.77 and 3.78), and could be built on a large scale. Later, much larger circular tower purifiers (Figure 3.79) were used on some large gasworks and coking works.

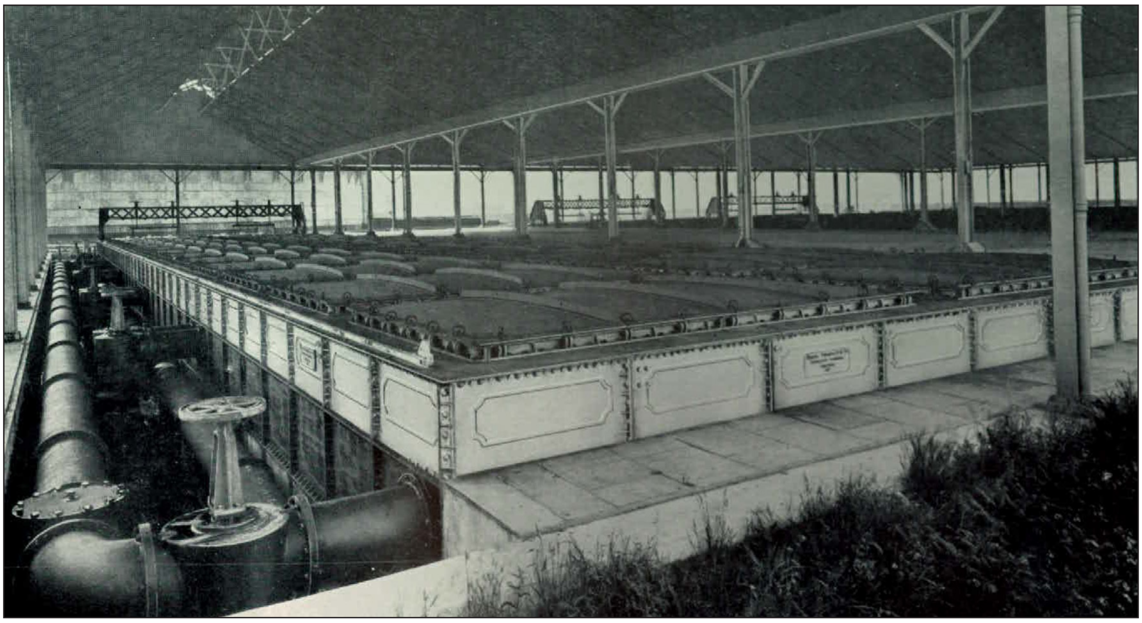


Figure 3.78 An example of box purifiers at the former Partington Gasworks. Image courtesy of National Grid Gas Archive.

Figure 3.79 Tower purifiers at the former East Greenwich gasworks. Image courtesy of National Grid Gas Archive.

The slaked lime or hydrated iron oxide would be laid on wooden (often oak) grids inside the boxes in layers 12 inches (30cm) to 18 inches (45cm) deep, sometimes with lime mixed in with the iron oxide. The moisture content in the boxes was important and regulated by the addition of steam. The gas was also heated prior to entry into the purifiers so the reaction could operate at the optimum conditions (Meade 1921).

Both the lime and iron oxide could be regenerated two or three times by exposure to air within the yard (a process called revivification), before becoming either 'foul' or 'spent', respectively, containing high concentrations of cyanide (>6%) and sulphur (50-60%). Opening the purifier boxes could be hazardous, as the purifying medium would rapidly oxidise on exposure to air and could spontaneously combust, producing toxic gas. Later processes were developed which would revivify the oxide within the purifiers, removing some arduous manual handling. The conditions involved in handling the oxide can be seen in Figure 3.80.

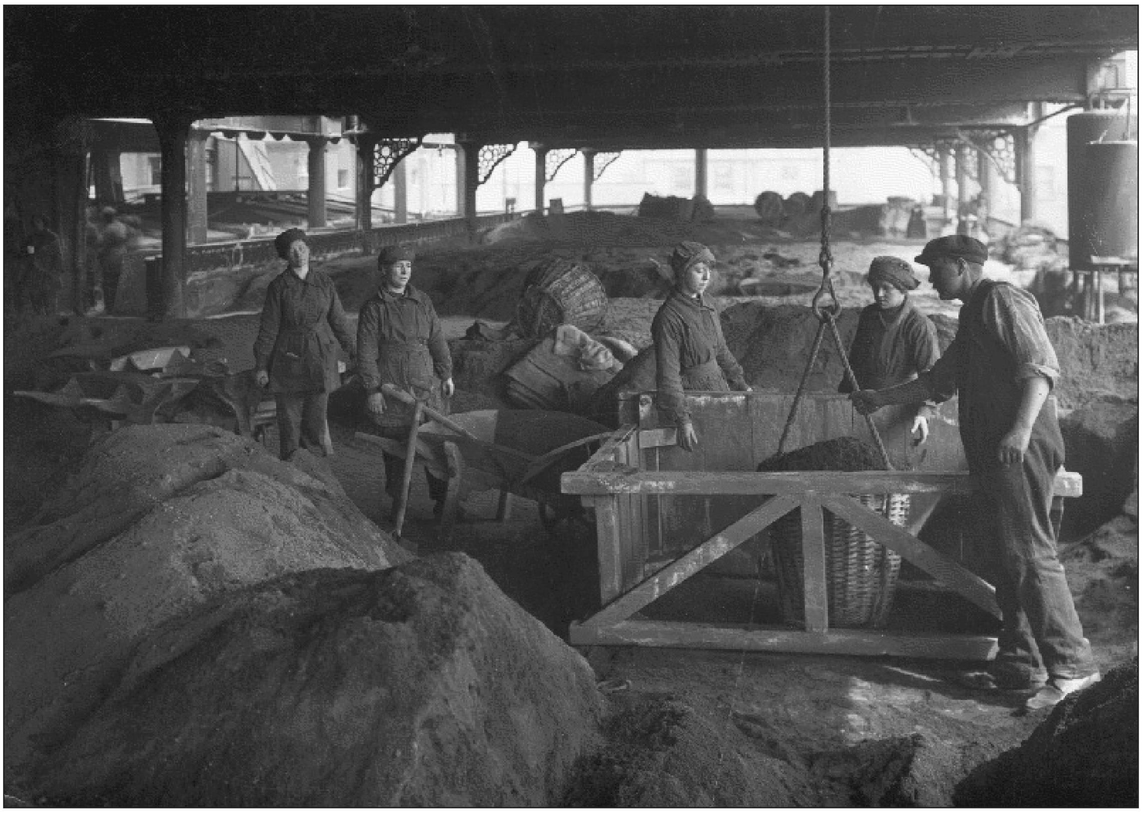


Figure 3.80 Male and female works handling iron oxide for use in the purifiers, Vauxhall gasworks during WWI. Image courtesy of National Grid Gas Archive.

Foul lime became a rock-solid material of a greenish white colour and high pH (11). It was sold to farmers or allotment holders as a fertiliser. Spent oxide (Figure 3.80) was a blue/green material of low pH (4) used as a by-product for the manufacture of sulphuric acid, but also occasionally used as a weed killer.

3.3.6.1 The Chemistry of Gas Purification

The main role of the purifier was to remove two key components from the gas, namely hydrogen sulphide (the largest impurity) and hydrogen cyanide. Hydrogen sulphide accounted for roughly 1% of the total volume of the unpurified gas, it was present at an order of magnitude greater concentration than hydrogen cyanide, which accounted for 0.1% of composition of the unpurified gas. These were not the only impurities in the gas; others would have been present such as trace amounts, such as thiocyanate salts, carbon disulphide, ammonium salts and coal tar. It should also be highlighted that some of the soluble forms of cyanide, such as ammonium salts of cyanide would have been removed prior to the purifier, through the action of the washers and scrubbers depositing the cyanide compounds in the ammoniacal liquor. Ferrocyanide salts would also be present in the spent liquor from an ammonium sulphate plant often found on larger former gasworks.

3.3.6.2 Lime purification

Gas was originally purified by passing it through wet lime; however, this was later superseded by dry lime processes. As wet lime processes were phased out relatively early on their chemistry will not be discussed further, although there are obvious similarities to the dry lime process, which used hydrated lime.

Lime purification used hydrated lime otherwise known as calcium hydroxide $Ca(OH)_2$. During lime purification of coal gas hydrogen cyanide would be removed as calcium thiocyanate ($Ca(SCN)_2$)) and to some extent as calcium ferrocyanide, $Ca_2Fe(CN)_6 \cdot 12H_2O$.

$$CaH_2O_2 + H_2S = CaS + 2H_2O$$

The calcium sulphide formed reacts with carbon dioxide in the gas through the following reaction.

$$CaS + CO_2 + H_2O = CaCO_3 + H_2S$$

The gas then passed into a second purifier box where the initial reaction would occur again.

$$CaH_2O_2 + H_2S = CaS + 2H_2O$$

As can be seen from above, the lime also removed carbon dioxide from the gas, predominantly in the first purifier box. Once the capacity of the lime to remove impurities from the gas started to diminish significantly, the gas would be diverted to a duplicated set of purifiers to be purified. The contents of the first set of purifiers would then be dug out and left to weather in the air, once weathered the lime could be reused a couple more times until saturated with sulphur and cyanide.

3.3.6.3 Bog Iron Ore Purification of Gas

Bog iron ore in its natural form contained between 50 to 60% water, between 30 to 35% ferric oxide (Fe_2O_3) and an additional 15 to 25% of organic vegetable matter and inert silica base mineral). When the hydrogen cyanide present in coal gas was passed over bog iron ore it would predominantly form Ferric Ferrocyanide $Fe_4[Fe(CN)_6]_3$ also known as “Prussian blue”, the complexity of cyanide chemistry is such that many other forms would have been present albeit at lower concentrations. This intense “Prussian Blue” colour is what gave spent oxide its distinctive colour which can be seen in Figure 3.81 (Meade 1921).

Figure 3.81 Blue staining on a wall at a former gasworks from Spent Oxide. Source R. Thomas.

For sulphur removal the ferric oxide in the bog iron ore would react with the hydrogen sulphide forming ferric sulphide and releasing water, in addition another reaction between ferric oxide and hydrogen sulphide would form ferrous sulphide and sulphur and water (Meade 1921). These chemical reactions are shown below:

$Fe_2O_3.H_2O + 3H_2S = Fe_2S_3 + 4H_2O$

$Fe_2O_3.H_2O + 3H_2S = 2FeS + S + 4H_2O$

As with lime purification once the capacity of the bog iron ore started to diminish significantly then it needed to be revivified by exposure to air, this would normally be achieved by digging the oxide out by hand on to a covered revivifying area. As the oxidation reaction which would occur by exposing the highly reduced oxide to air was exothermic and the sulphur combustible, the oxide would occasionally spontaneously combust, making this operation quite hazardous. During revivification the ferric and ferrous sulphides would react with water to reform ferric oxide and sulphur through the equations below:

$2Fe_2S_3 +3H_2O = 2Fe_2O_3 +3S_2$

$12FeS + 9H_2O = 6Fe_2O_3+ 6S_2$

This revivification process could be repeated 2 to 3 times before it became spent, forming the well-known by-product/waste called “Spent Oxide” (Meade 1921).

Foul lime was a greenish white cementitous substance often found to be similar to a weathered cement when encountered on a former gasworks. The material was very alkaline as you may expect from its predominantly lime composition. Once weathered the foul lime was a very effective fertilizer and disposal was not usually a problem and the material was often sold for such purposes (Richards 1877, Stewart 1958).

Spent oxide was used for the manufacture of sulphuric acid, it could be roasted in a Herrishoff furnace like sulphur rich ores such as iron pyrites, with the resulting sulphur dioxide gas collected and used for acid manufacture. The Prussian blue colour was also used as a dye in the textile industry and as eye shadow. Spent oxide was often used as a weed killer a practice often carried out on former gasworks. These markets disappeared in the early part of the 20th century and the material then had to be disposed of as a waste.

The cyanide present in spent oxide forms up to 6% of the total weight and is predominantly in the form of complex metal cyanides and thiocyanate. Spent oxide also consists of about 3-9% iron, 0.08-0.36% manganese, 2-3% sulphate and 36-60% free sulphur. The predominant iron cyanide complex is insoluble iron ferricyanide ($Fe_4[Fe(CN)_6]_3$) 'Prussian Blue', a stable and highly insoluble form of cyanide with a pH of about pH4. Prussian Blue was also manufactured between 1885 and 1922 by some larger gas undertakings. Several processes were used, but they all involved washing the gas prior to the ammonia washing plant with solutions of iron salts in the presence of ammonia. It could produce about 2 pounds of Prussian blue for each ton of coal carbonized and made the purification step easier, however, it became uneconomic and ceased circa 1922 (Stewart 1958).

3.3.6.4 Liquid Purification

Gas could also be purified by passing it through alkaline solutions of sodium carbonate. These methods were not adopted in Britain as they were deemed inferior to purification by iron oxide and caused more nuisance from odours (Stewart 1958).

Another method developed was the Thylox process. This washed the hydrogen sulphide from the gas using a solution of ammonium thioarsenate. The process was highly effective at removing hydrogen sulphide; it could be regenerated by exposure to oxygen, with the sulphur precipitating out as foam which could then be collected. The Thylox process would also remove cyanides in the gas as thiocyanates. The health, safety and environmental issues in using arsenic-based solution limited the use of this method (Stewart 1958, North Western Gas Board 1965).

The most successful of the liquid purification processes was the Stretford process, developed by the North-Western Gas Board and the Clayton Aniline Company in England. The process originally used an aqueous solution of carbonate/bicarbonate and anthraquinone disulphonic acid (ADA). The process initially struggled due to its very low affinity for dissolved sulphides, resulting in high liquid circulation rates. The sulphur formation reaction was also very slow, requiring large amounts of solution to be stored. A significant amount of thiosulphate was formed as a by-product as well. These problems were largely overcome by using alkaline vanadate's in the solution, replacing dissolved oxygen as the direct oxidant in the conversion of hydrosulphide ions to elemental sulphur. Although the vanadium additive used in the Stretford Process increased the reaction rate for converting the hydrosulphide ions to sulphur, it was still a slow reaction. The process is still used today, although not associated with coal gas but with other sulphur rich gases (Stewart 1958, North Western Gas Board 1965).

3.3.7 Tar Tanks and Wells

The tar and ammoniacal liquor recovered from the hydraulic and foul mains, condensers, tar extractors, electrostatic detarrers, washers and scrubbers were usually drained by gravity (pumps could also be used) to underground tar and liquor tanks, examples of which can be seen in Figures 3.82 and 3.83). These tanks, also referred to as wells, had a wide range of designs, from simple cylindrical structures cut into clay to large cast iron, steel, brick or concrete structures (Newbigging 1889).

Figure 3.82 Interior of a tar tank at the former gasworks, Sydenham. Image courtesy of National Grid Gas Archive.

Williams Richards suggested that “The tar well is in the most isolated place, in order that any nuisance arising therefrom may be confined to the locality.” He also recommended that the “purifiers and tar well, as a matter of precaution, are placed at a considerable distance from the retort house.” (Richards 1877).

Many early gasholder tanks on former gasworks were converted for use as tar tanks when they became too small to be used efficiently as gasholders. Such conversions often involved the installation of brick arched roofs, as in Figure 3.82. In small gasworks, tar tanks were often simply brick tanks lined with puddle clay and covered with wooden planks (Figure 3.83), relying on gravity to separate the tar and the liquor. Tanks could also incorporate a series of weirs to separate the tar from the ammoniacal liquor as shown in Figure 3.83.

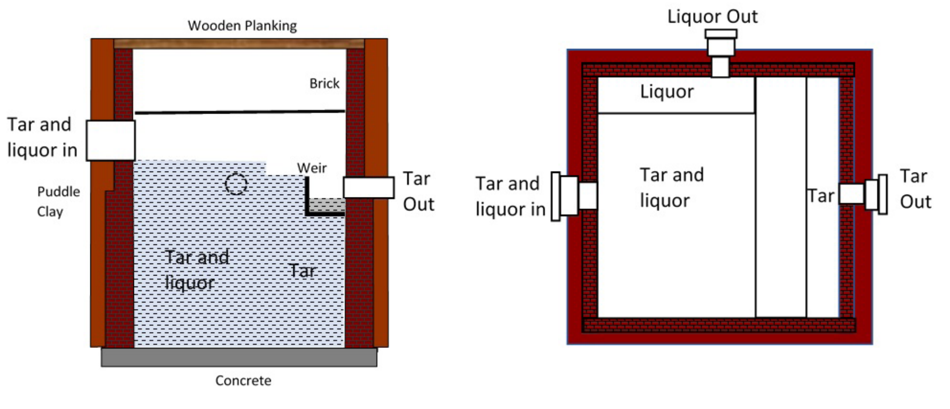


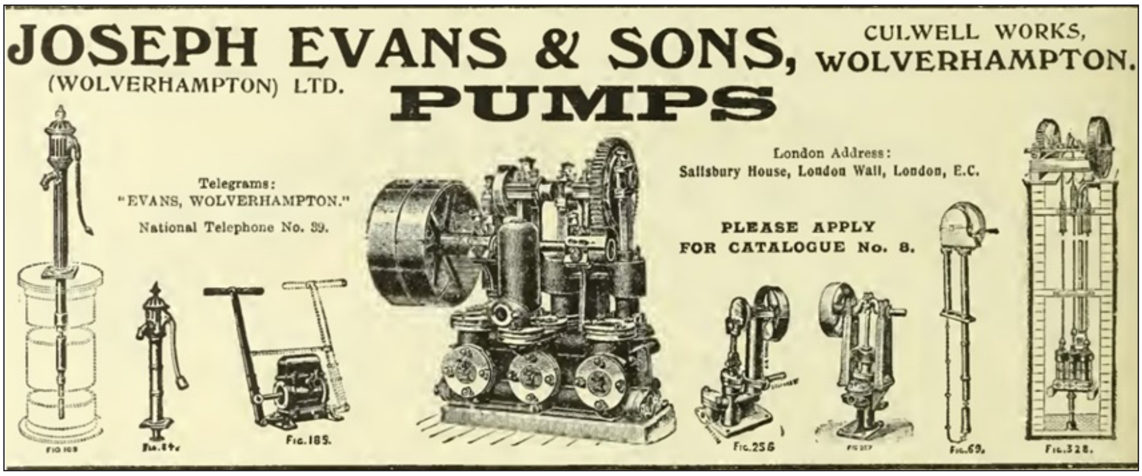
Figure 3.83 A schematic of a tar tank, vertical section (left) plan (right). Source R.Thomas.

Tar tanks formed from cast or wrought iron plates, would be bolted together with the joints either planed or caulked. Iron tanks were preferred in situations where building the appropriate foundations for a brick tank was questionable (Newbigging 1889).

Adjacent to the tar tank, another well of a smaller size relative to the main tank, was built. This served as a lute or seal, into which tar from the different plant would drain through pipes which dipped into the tar well. From this well, at a depth of about 15 or 18 inches below the surface of the ground, an overflow-pipe or channel conveyed the tar and liquor into the main tank (Newbigging 1889).

Tar and liquor were removed separately from the tar tank, as shown on Figure 3.83. Tar was often pumped by steam pumps, the heat from which would reduce the viscosity of the tar and make it easier to pump to above-ground tar tanks. Such types of pumps are shown in the advert in Figure 3.84.

Usually the tar would be transferred to an overhead tar tank prior to loading into road or rail tanks, to be transported to a tar distillers or chemical works. Some large gasworks such as Beckton, Southall and East Greenwich would have their own tar distillation plant, a topic mentioned later in the section on tar distillation.



JOSEPH EVANS & SONS,
(WOLVERHAMPTON) LTD.

CULWELL WORKS,
WOLVERHAMPTON.

PUMPS

Telegrams:
"EVANS, WOLVERHAMPTON."
National Telephone No. 39.

London Address:
Salisbury House, London Wall, London, E.C.

PLEASE APPLY
FOR CATALOGUE No. 8.

Figure 3.84 An Advert by Joseph Evans and Sons Ltd, showing pumps typically used on a gasworks, some of which were used with the tar well. Image courtesy of IGEM Archive.

3.3.8 Naphthalene Washer

After purification, two more by-product recovery processes were used on medium to large gasworks (and by-product coke ovens); these were benzole and naphthalene recovery.

Naphthalene and associated compounds were very troublesome for the gas engineer. Naphthalene can desublimate, which meant that it was able to transform directly from a gas to a solid in the gas mains, it would form a gum, which would gradually block the mains at the gasworks, and within the gas distribution network as the gas continued to cool. Naphthalene would sublimate, meaning it went straight from vapour to solid phase within the pipes or even appliances; it was therefore not captured in the moisture which collected in the syphon pots. As it separated out of the gas, it took on a very bulky crystalline form, exacerbating the problem. Similar problems could result from the presence of styrene and indene, both of which can polymerise to form a sticky gum.

Naphthalene and the other associated compounds were removed by passing the gas through a static or rotary washer through which gas oil was circulated (Figure 3.85). It worked in much the same way as the ammonia washer but using gas oil as a solvent instead of water.

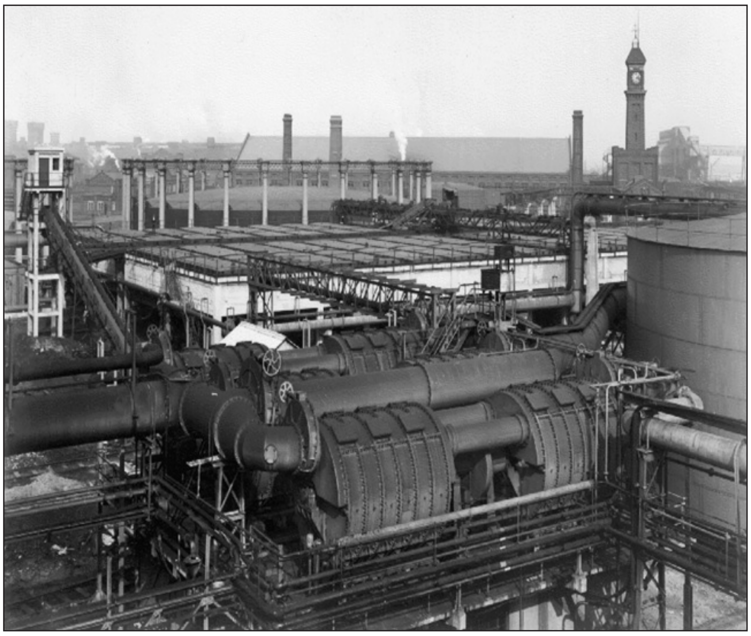


Figure 3.85 Naphthalene washers at the former gasworks in Beckton. Image courtesy of National Grid Gas Archive.

The gas was passed through the washer in a counter current direction to the gas. Once a high concentration of naphthalene had accumulated in the oil, it was removed and replaced with fresh oil. The naphthalene-saturated oil was then subjected to fractional distillation to remove the naphthalene and then the oil could be reused in the washer.

3.3.9 Benzol Plant

Benzol (which was also spelt benzole) was a light oil consisting of benzene, toluene, ethyl-benzene, xylene and their homologues. It was used primarily as a motor fuel, this was particularly important during war time as Britain's only oil resources were the Scottish oil shale and a number of small on-shore oil fields, Britain was heavily reliant on oil imports.

The toluol fraction was important in the manufacture of explosives during wartime, it was also an intermediate for dyestuffs. Benzol could be extracted from the gas by two processes. These were the washing of the gas with a solvent (either a mineral oil or creosote oil), in which the benzol would dissolve or by passing the gas through activated carbon, in which the benzol would be absorbed (Stewart 1958 p28).

One ton of coal would produce about 3 gallons of benzol from which 3 lbs of toluene could be further extracted. If removed by solvent washing, then the process would be almost identical to that described for naphthalene. Benzol was recovered from the oil using fractional distillation, sometimes under vacuum to reduce the steam requirements. The benzol, toluol, xylol and solvent naphtha fractions were treated with sulphuric acid and caustic soda for further purification to reach 90 % purity (Gas Council 1953).

With the activated-carbon method, the gas was passed through the activated carbon (As seen in Figures 3.86 and 3.87). The benzole was absorbed onto the activated carbon until it became saturated, at which point the gas was diverted to another vessel filled with fresh activated

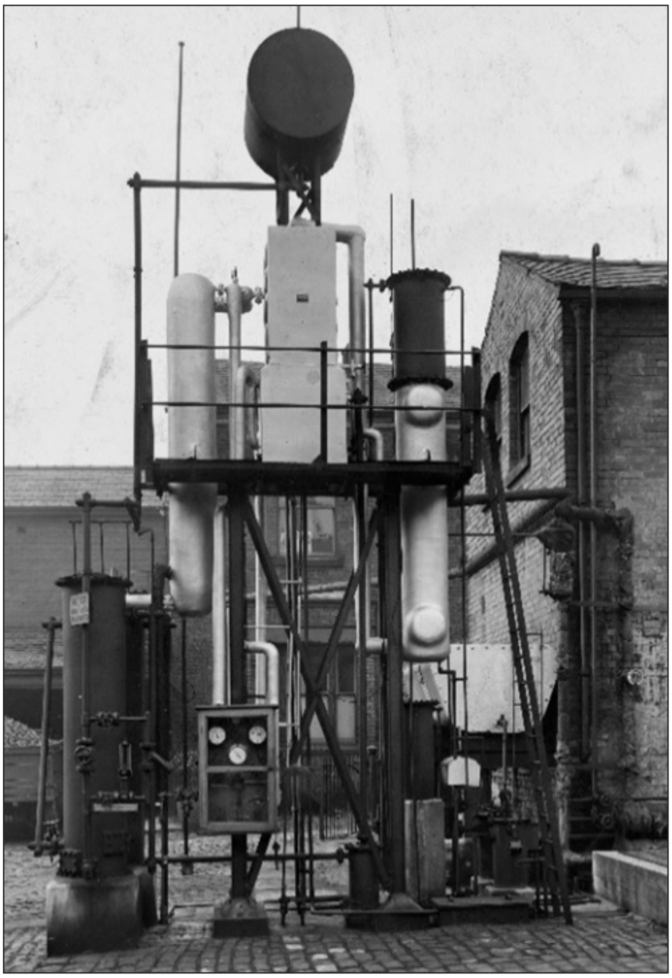


Figure 3.86 A small benzole plant at the former gasworks in Middleton, Lancashire. Image courtesy of National Grid Gas Archive.

carbon. The benzole was then removed from the activated carbon by steaming, often under vacuum. The activated-carbon method became the most popular form of benzole recovery, although it lost out to the petroleum industry which could produce similar products more cost effectively. Benzole plants were at their most important around the time of the Second World War, when the benzole and toluol produced were important sources of motor fuel and base product for manufacturing explosives (Gas Council 1953, Stewart 1958 p28).

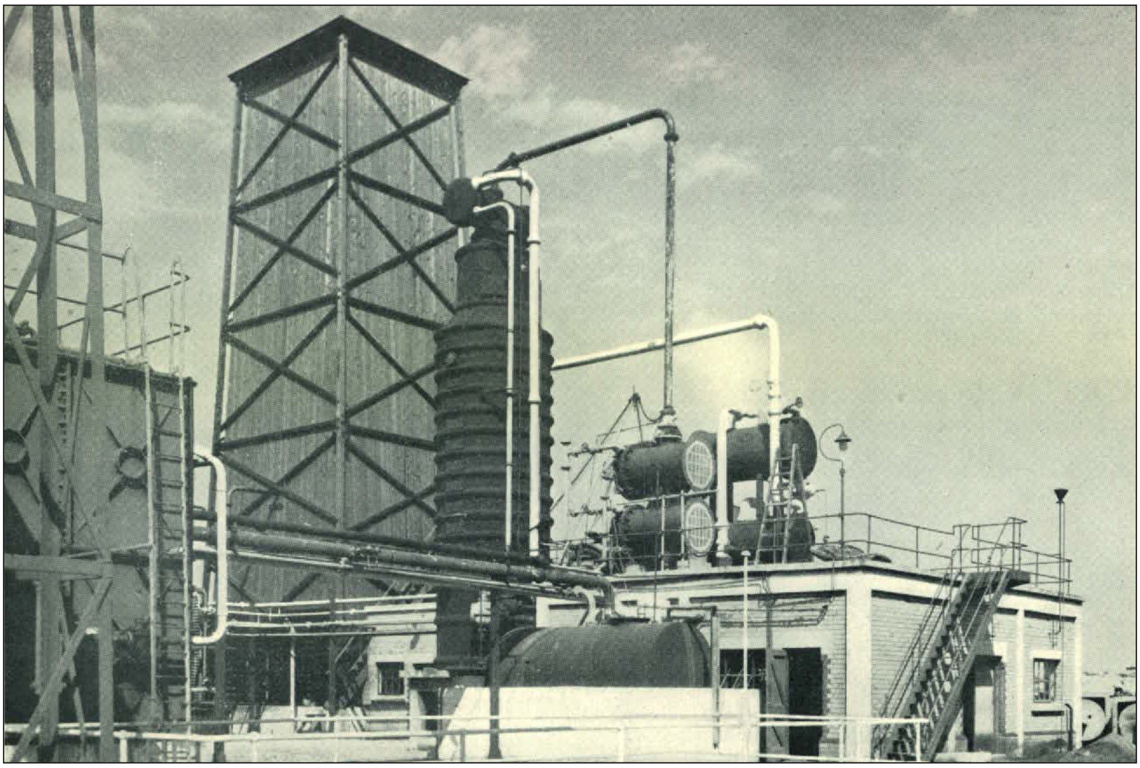


Figure 3.87 Large benzole plant at the former Foleshill gasworks in Coventry. Image courtesy of National Grid Gas Archive.

3.3.10 Coke Plant

After the carbonisation of the coal had finished in the retorts a layer of coke remained. The coke accounted for about 70-75% of the original weight of the coal (Brackenbury 1901).

The coke was removed from the retort, a process described in an earlier section using manual or mechanical means. Within a smaller gasworks the coke would be raked out of the retort into the coke barrow and quenched with water and taken to the coke pile, where if needed it was quenched again. Thorough quenching of the coke was important as fires in the coke pile could soon spread and were very dangerous.

In the horizontal retort houses of the larger early gasworks, the coke was removed from the retorts and pushed through an opening in the floor to a lower level, where it would be quenched and removed (Meade 1921).

As mechanisation was introduced in the larger retort houses, the removal of the coke was also mechanised. The coke pushed from the retort on to a metal conveyor to be removed (Figure 3.88) for quenching and then coke storage hoppers or it would be taken directly to the coke screening plant (Brackenbury 1901, Meade 1921).

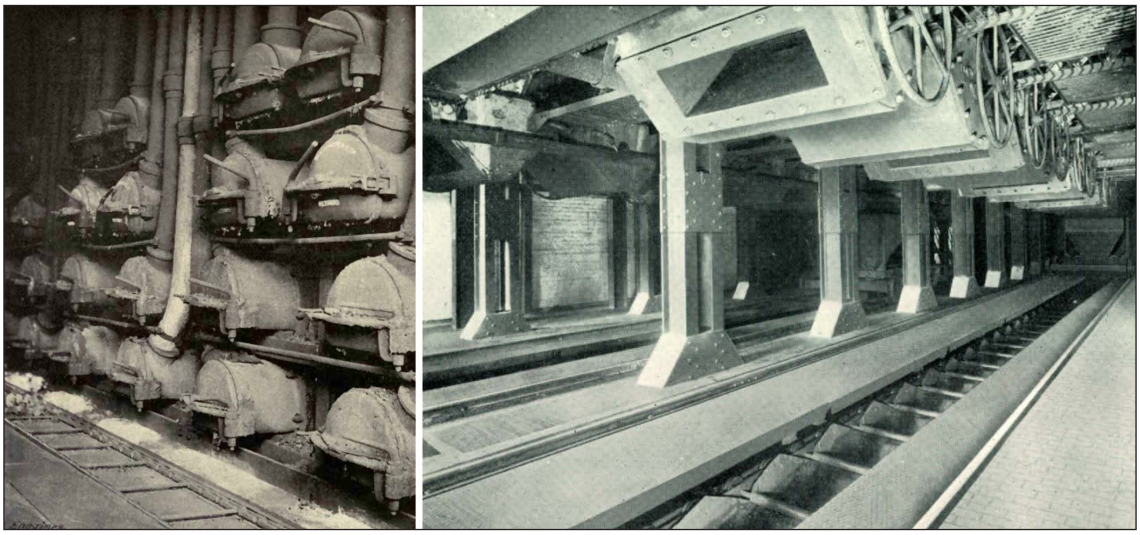


Figure 3.88 A “De Brouwer” Coke Conveyor built by W. J. Jenkins placed in from of horizontal retorts (left) and the under setting of a Woodall-Duckham Continuous Vertical Retort, showing the travelling chutes and lip bucket conveyor used to remove coke (right). Image courtesy of National Grid Gas Archive.

Vertical retorts would remove coke via the coke extractors, these developed a similar system where the coke would drop on to a conveyor via a travelling chute as seen in Figure 3.88. The coke could be cooled through steam injection in the retort to produce water gas, prior to exiting the coke extractor (Meade 1921).

The coke needed to be screened, so oversized coke could be cut down and fine coke breeze separated from the lumps of coke (Brackenbury 1901).

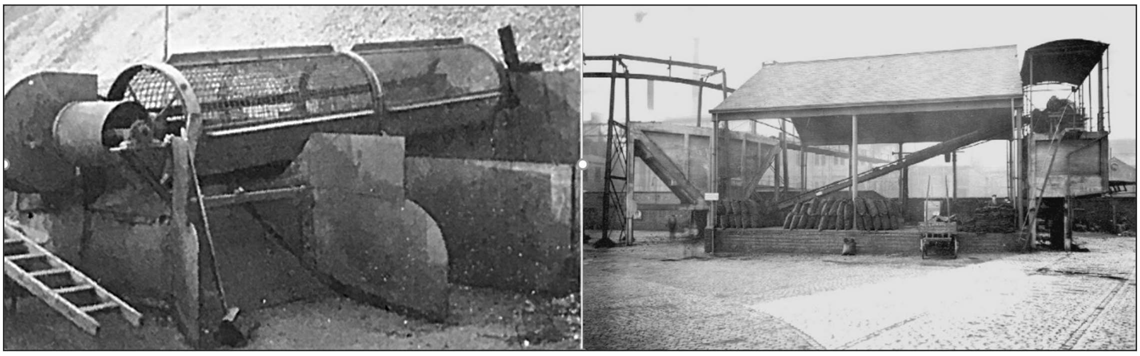


Figure 3.89 Early coke screen plant recovering coke and separating coke breeze at Southend Gasworks (left) and Adderley Street, Birmingham (Right) circa 1900s. Image courtesy of National Grid Gas Archive.

Early grading processes were relatively simple, manually operated and used basic screens for grading. They were similar to that shown in Figure 3.89. The process was later mechanised.

Coke screening plant would receive coke from the retort houses into hoppers. The coke would then be fed into a grading and cleaning plant, where it was separated into breeze, (boiler) nuts, broken coke and large coke by passing over a series of vibrating mesh screens. Oversized coke would be removed by a scalping screen (Figure 3.90) and cut down to size using a coke cutter. The coke nuts were separated from unwanted shale by passing it over a perforated table through which air was blown. The air displaced the coke, leaving the shale behind (Brackenbury 1901, Meade 1921).

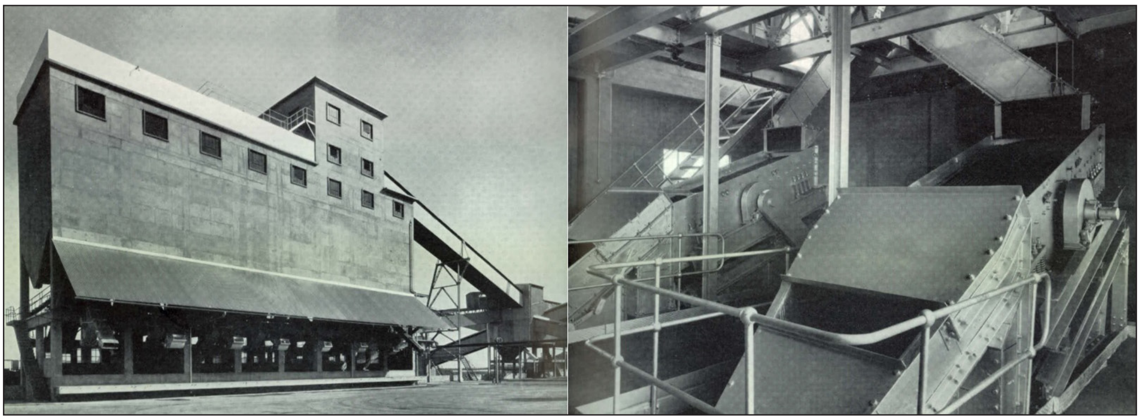


Figure 3.90 Coke bunkers and Screening plant (left) and Coke scalping and debreezing screens, Hendon Gasworks, Sunderland. Image courtesy of IGEM Archive.

It was also possible to operate a mobile coke grading unit, such as the Harmer loader shown in Figure 3.91 which could grade and bag the coke.

At larger more modern gasworks, the coke was graded in large concrete structures as shown in Figure 3.90. Using screens and conveyors, the coke would again be sorted into different sizes and stored in bunkers prior to weighing and dispatch into wagons. The plants could be fitted with dust collection systems to remove the exposure of the workers to harmful dusts.

Coke could also be recovered from the unburnt furnace ash. If economical this could be separated and graded for sale (Stewart 1958).

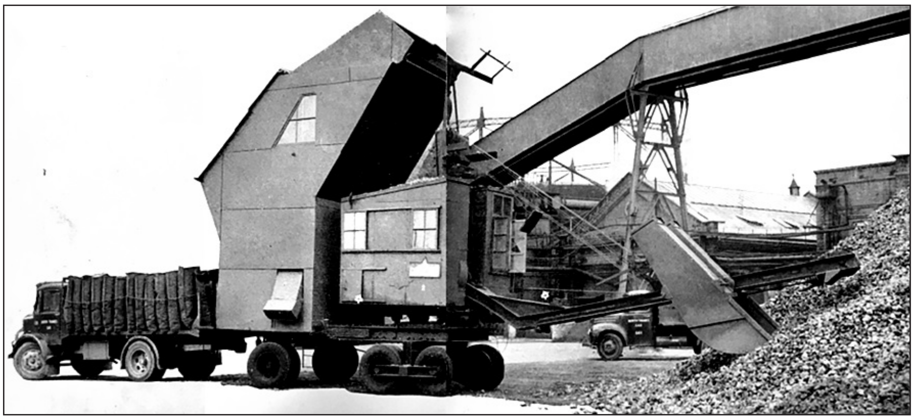


Figure 3.91 A mobile Harmer coke screening and bagging plant at Southend Gasworks circa 1950s. Image courtesy of National Grid Gas Archive.

3.3.11 Governor House

The governor house contained the station governor or governors, although they were often found within the same building as the meter house, along with the station meter.

The governor was invented by Clegg in 1815, who built it as a machine for regulating and equalizing the flow of gas from the gasometers to the mains. It was typically the last piece of apparatus through which the gas passed before leaving the gasworks.

The governor in simple terms, consisted of a valve in the main suspended from a small gasholder bell. The interior of the bell was connected to the outlet side of the valve. If the outlet pressure reduces then the bell also fell which acted to open the valve which would restore the pressure and ***vice-versa***. The level of pressure required was set by adding or removing weights to the floating bell (Hole 1912, Stewart 1958).

Before the development of the governor, the pressure in the gas mains was provided by the weight thrown by the gasholder. This was in turn, dependent on the power of the exhauster (after its introduction) which pushed the gas into the gasholders. The pressure was typically expressed in inches water gauge pressure. The pressure thrown was consistent with a single lift gasholder, which could typically be about 4 inches Water Gauge pressure (0.0099 bar). Even in this situation, it was possible that demand may be so low that the pressure thrown may have displaced the water in the consumers wet meters.

A telescopic gasholder with multiple lifts, was more complex, as each lift threw its own weight. For example, a four-lift spiral guided gasholder, which had a water gauge pressure of 7.5 for the first lift, 3 inches for the second lift, 3 inches for the third lift and 3 inches for the fourth, had a combined water gauge pressure of 16.5 inches. The pressure increased or decreased with the number of lifts in use, which directly related to the amount of gas it held. Such a variation in pressure would have been problematic and potentially dangerous on the gas distribution mains, so a compensated governor was required.

With this design, the inlet pressure of gas acted upon the valve, was made to act upon a portion of the bell equal area to the valve but in an opposite direction (Stevenson, 1901).

Clegg's original governor was improved upon by Hunt, Cowan, Parkinson and Braddock (Figure 3.92) to secure more precise operation. This was done by the balancing of the valve, water loading of the bell and making the valve parabolic in form to secure a linear relationship between valve opening and flow. (Clegg 1841, Hole 1912, Stewart 1958).

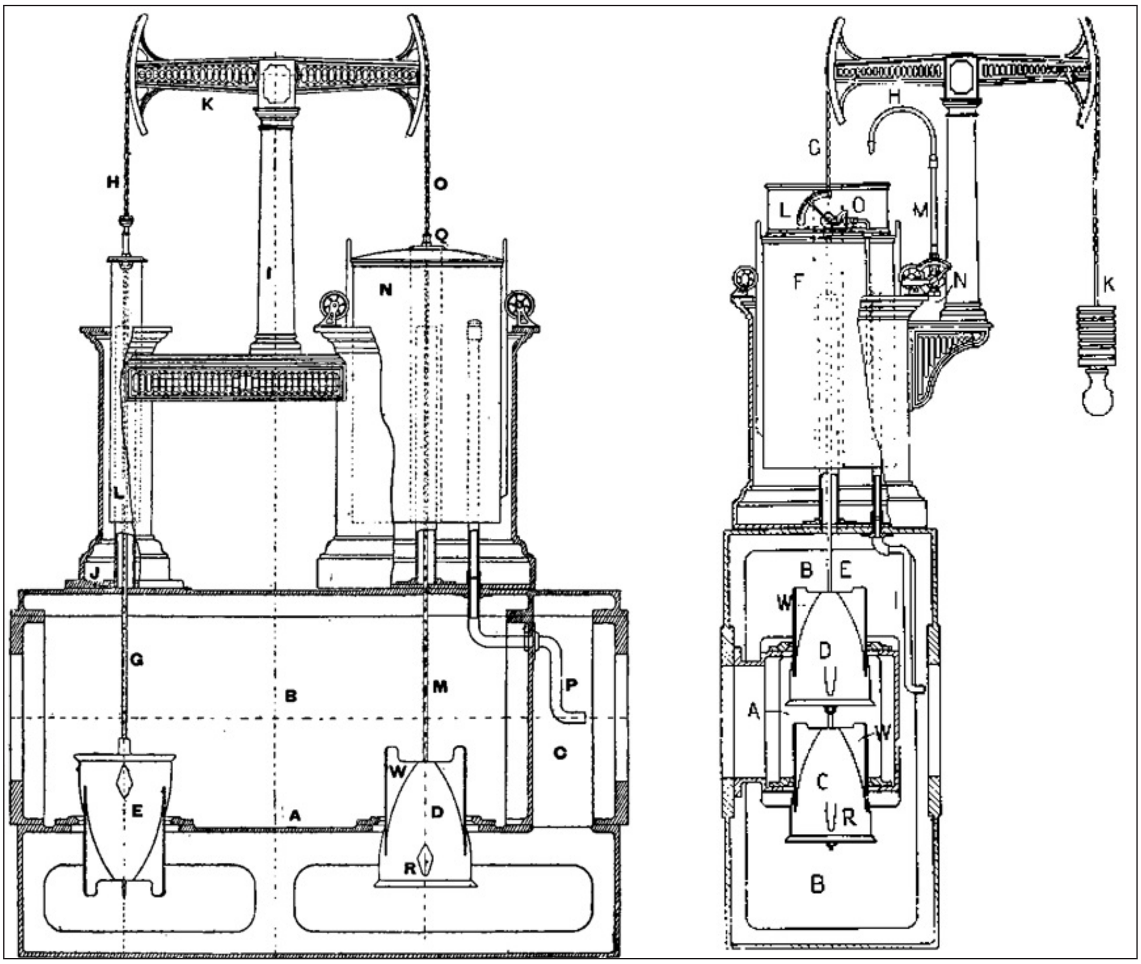


Figure 3.92 Section through Braddock's Balance Governor (left) and Counterbalance Governor (right). Image courtesy of IGEM Archive.

For a station governor to be both efficient and effective, it was required:

(a) To be able to reduce the excess of pressure thrown by the gasholder, to that required for the supply of the district.

(b) To adjust itself to any variation of initial pressure due to cupping, uncupping of the gasholder lifts, or change of gasholder.

(c) To be sensitive to any fluctuation, small as well as great, in the consumption of gas in its district.

(d) To work quite steadily and without the least oscillation.

The governors were improved further by developing self-loading arrangements on the governors. These attempted a form of automatic regulation to react to changes within the hour which may occur. They included devices which would increase or decrease the weight pushing on the valve by the use of water in the case of the Braddock device. These self-loading devices included those manufactured by Braddock, Connelly, Parkinson and Cowan, and Peebles (Hole 1912).

An added difficulty was introduced when the distribution network was not at the same height, as was often the case. As the gas was lighter than air, the gas pressure would increase or decrease by 1/10 inch water gauge pressure for each 10 ft gained or lost. The gas, if uncontrolled, preferentially migrates to the highest parts of the gas network. This would result in higher gas pressures building up in the higher parts of the network and *visa versa* (Hole 1912). The district governors were introduced to prevent such differences occurring and therefore a gasworks may have had multiple governors, for example in 1954, the Bradford Road Gasworks in Manchester had 4 Governors. Each one supplied a different district in the surrounding area. The inside of the former Governor House in Sydenham is shown in Figure 3.93.

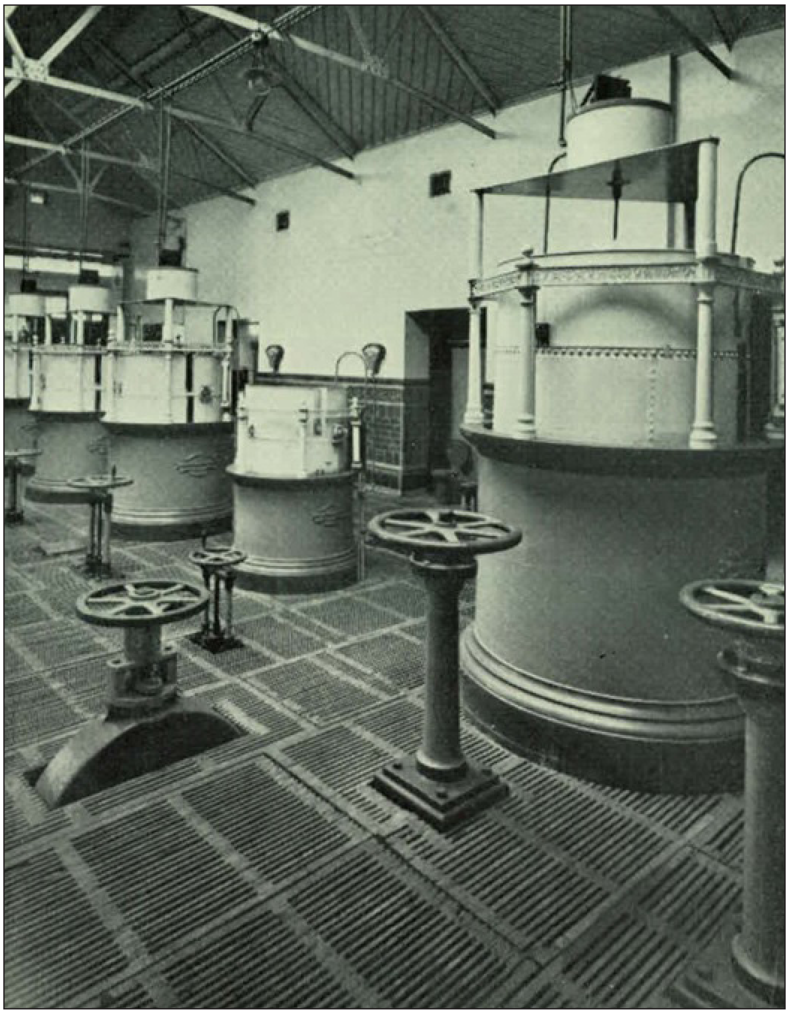


Figure 3.93 District Governors at the Governor House, former Sydenham gasworks.

District governor houses were also found within the gas distribution networks where their role was to take gas from one pressure regime (e.g. medium pressure) and convert it to another (e.g. low pressure). These features still form an important part of the gas distribution network. They are now the most visible above ground feature of the gas distribution networks and have the appearance of small to medium sized rectangular buildings of brick, steel or reinforced glass fibre construction, with louvered ventilation panels built into the walls. Two examples of District Governor houses can be found in Figures 3.94 and 3.95.

Figure 3.94 Governor house Sidmouth 1980's. Image courtesy of IGEM archive.

Figure 3.95 Inside a large governor house, Cornwall, 1980's. Image courtesy of IGEM archive.

The French engineers Pauwels and Dubouchet introduced a retort house governor in 1850 (Stewart 1960). The retort house would often also have its own governor, especially in larger gasworks. This governor had a different purpose, being used for reducing and controlling the intensity of vacuum created by the exhauster (Meade 1921).

3.3.12 Meter House

The meter house would house the station meter. The purpose of the station meter was to record the gas produced by the gasworks after it has been purified.

On larger gasworks there may be multiple station meters, each metering a separate retort house or water gas plant. The meter house may also contain, the station governor(s), exhaust and pressure register, a range of pressure gauges, and a jet photometer, which allowed the engineer to understand the performance of the gasworks from a single location. The meter house would typically be brick or stone built, rectangular with a pitched gabled roof, a simple example for a small gasworks from 1911 is shown in Figure 3.96. Some later designs had a flat roof.

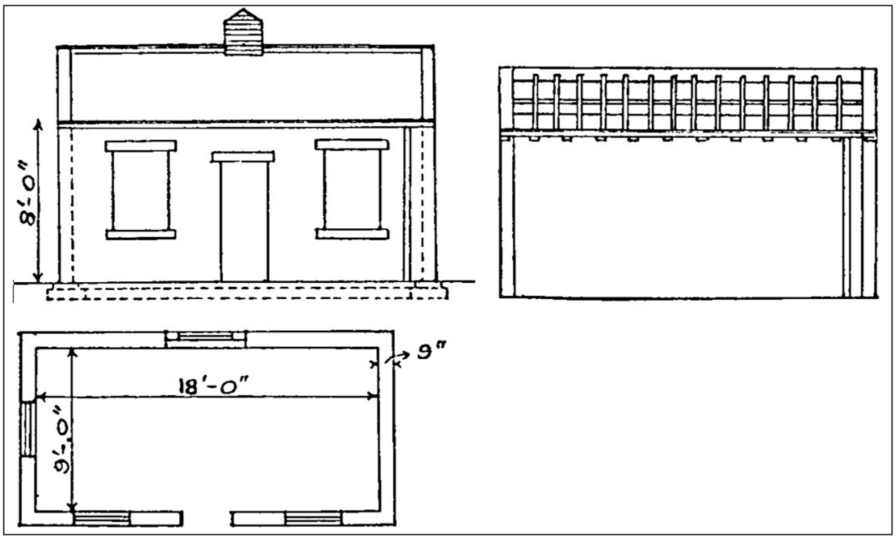


Figure 3.96 A Governor House or Meter House of a simple design of for a small gasworks. Source Humphrys 1911. Image courtesy of IGEM Archive.

The most important aspects of the meter house were that it was well ventilated and was kept very clean, to assist the latter the meter house was sometimes tiled on its interior (Humphreys 1911).

The meter house was susceptible to ornamentation house and was often the most ornamental part of the gasworks. The station meter was typically highly ornamented with the appearance of a roman temple as can be seen in Figures 3.97 and 3.98. The larger sizes of station meter were fitted with a clock and tell-tale, the latter making a complete and continuous record upon specially prepared charts of the gas manufactured throughout twenty-four hours (Hole 1912).

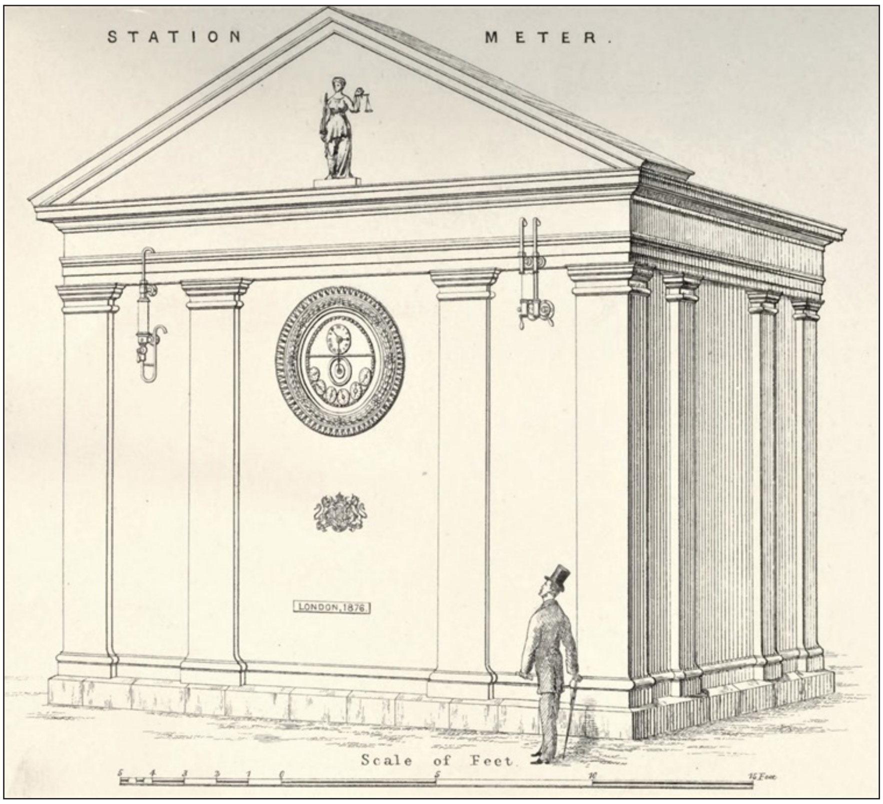


Figure 3.97 Drawing of a station meter. Source Richards 1877. Image courtesy of IGEM Archive.

Figure 3.98 Three station meters in the meter house. Image courtesy of National Grid Gas Archive.

Clegg designed a wet gas meter in 1816, which was improved both by Malam and Crosley, but the design remained largely unchanged for a hundred years. Within the housing of a wet meter, there was a rotating drum. Gas would enter through a fixed tube in the center of the drum, which typically had four partitions. The bottom half of the meter contained water and the water level had to be carefully positioned in line with the drum. The gas as it entered the drum would fill the partition and rotate the drum, once the partition was filled the gas would then pass on through the meter, whilst the next partition is being filled, causing the meter drum to continually rotate. The axis of the drum would then drive a series of dials on the front of the gas meter which would display the gas volume manufactured (Barash and Gooderham 1971). This design was used for both station meter and domestic meters. The domestic gas meter in the consumers house was largely replaced by the dry meter, whose design was perfected by William Richards in 1844 in collaboration with Alexander Angus Croll (Moyano Jimenez and Thomas 2016), but this design was not used for station meters.

Later gas meters were more functional and less ostentatious. The Holmes Connersville meter shown in Figure 3.99, was built on the same principle the Holmes Connersville exhauster, consisting of two rotor within a cast iron (later steel) casing. The pressure of the gas forced the rotors to revolve within a chamber of known size which allowed the volume of gas to be measured. Three such meters were used on the new Swan Village gasworks built for the West Midlands Gas Board in 1953.

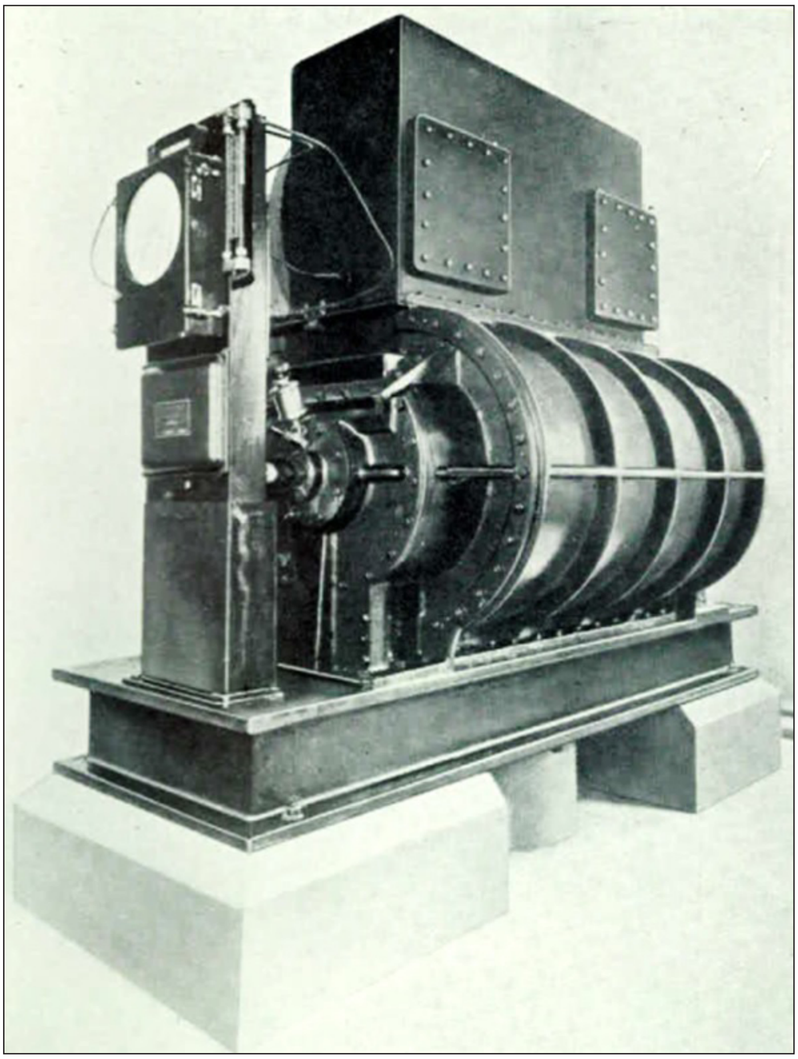


Figure 3.99 Holmes Connersville Gas Meter Partington gasworks. Image courtesy of National Grid Gas Archive.

Other types of meter were also developed, which included meters which operated by the use of devices for producing a differential pressure. The amount of differential pressure produced being a function of the gas flow, and was recorded on a chart and calibrated in terms of flow (Levy 1922). An orifice meter was such a device, it passed gas through an orifice and the resulting change in gas pressure was measures and inferred to a flow rate (Barash and Gooderham 1971)

Electrical station meters were also developed, these worked on the principal of measuring the electrical energy required to maintain a certain temperature difference in the gas stream flowing between two selected points. The energy required was a function of the flow, and was recorded in terms of the latter (Levy 1922). A similar method used a hot wire, with the passing gas removing the heat, the faster the gas flow the greater the heat reduction and this was calibrated against a property such as electrical resistance (Barash and Gooderham 1971).

However the flow was measured, in later years, the gas would also have its temperature and pressure measured as well, as this affected the volume (Barash and Gooderham 1971).

3.3.13 Boiler House

The boilers, with the exception of waste heat boilers, were normally housed within a boiler house and would be located centrally for supplying steam for exhausters, mechanical washers, sulphate plant, pumps, etc. The water gas plant may also have its own boilers specifically for the supply of steam to the water gas plant.

A steam boiler is a form of heat exchanger whose function was to transfer heat energy from burning coal or coke fuel to the water within the boiler creating steam.

Boilers were typically divided into two principal types:

(1) those in which the products of combustion passed through the tubes or flues, called fire-tube boilers, and;

(2) those in which the water and steam pass through the tubes, called water-tube boilers.

The Cornish and Lancashire type boilers (Figure 3.100) belonged to the fire tube boilers and Babcock and Wilcox boilers were typical of water tube boilers.

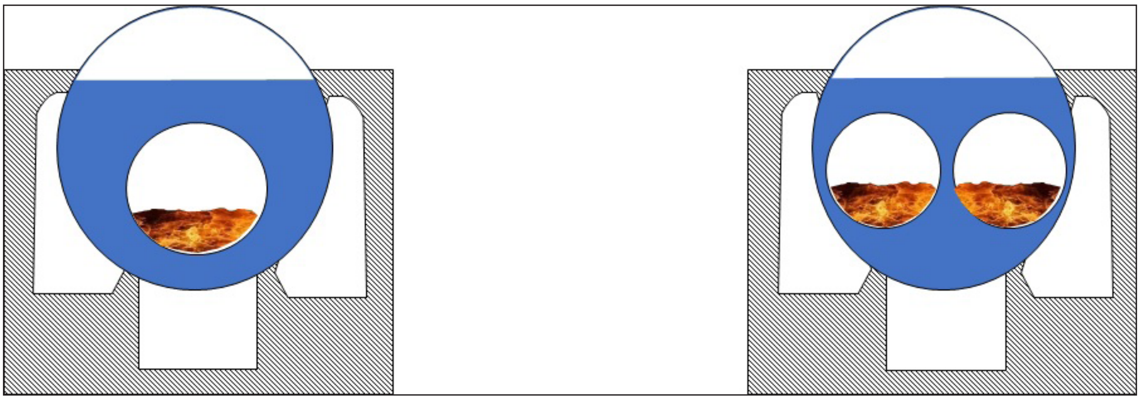


Figure 3.100 A simple schematic of the design of a Cornish (left) and Lancashire (right) boiler. Source R. Thomas.

The boilers typically used in gasworks were either Cornish or Lancashire boilers, which were similar in design. The Cornish boiler had one internal cylindrical flue extending the whole length of the boiler, the furnace being in this flue, at its front end (Fig. 9.100). The Lancashire boiler has two internal cylindrical flues extending the whole length of the boiler (Figure 3.101), the furnaces were also located in the front end of the flues (Mentor and Taylor 1900).

Of the water-tube boilers, the most commonly used version on gasworks was the Babcock and Wilcox water-tube boiler. This consisted of a series of inclined steel tubes, connected at their ends to what are known as “headers,” which lead to a large horizontal steam drum situated over the tubes, as shown in Figure. 3.102. The vertical rows of tubes were placed in a zigzag orientation, so that the hot combustion gases would come well into contact with the tubes heating surfaces. Each vertical row of tubes was also connected to a box at each end, these boxes being connected to the main steam drum by rising tubes, all tubes being expanded into their respective holes. The outer holes in the headers, opposite the tube ends, were fitted with plugs, or doors. The back headers were connected to a mud drum at their lower ends, in which any sediment could collect. This could be emptied by periodically blowing it clear. The whole boiler was suspended from two beams resting on four pillars, and the brick setting was built up around the boiler (Figure 3.102). The mountings were similar to those of an ordinary cylindrical boiler, the whole of the front being of cast iron (Mentor and Taylor 1900).

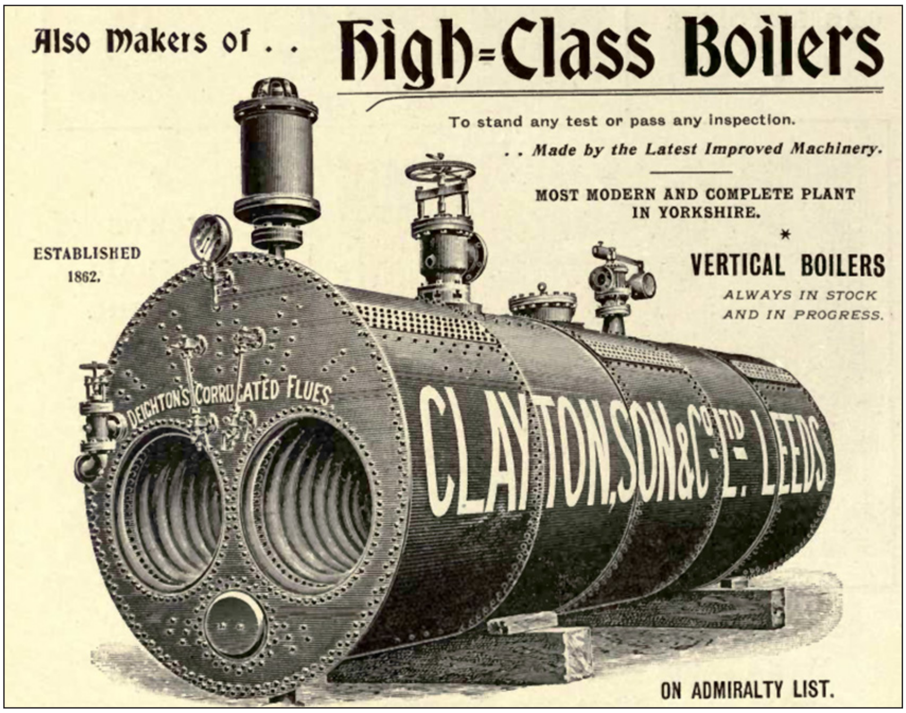


Figure 3.101 A drawing of a boiler featured in an Advert by Clayton, Son and Company of Leeds. Source Brackenbury 1901. Image courtesy of IGEM Archive.

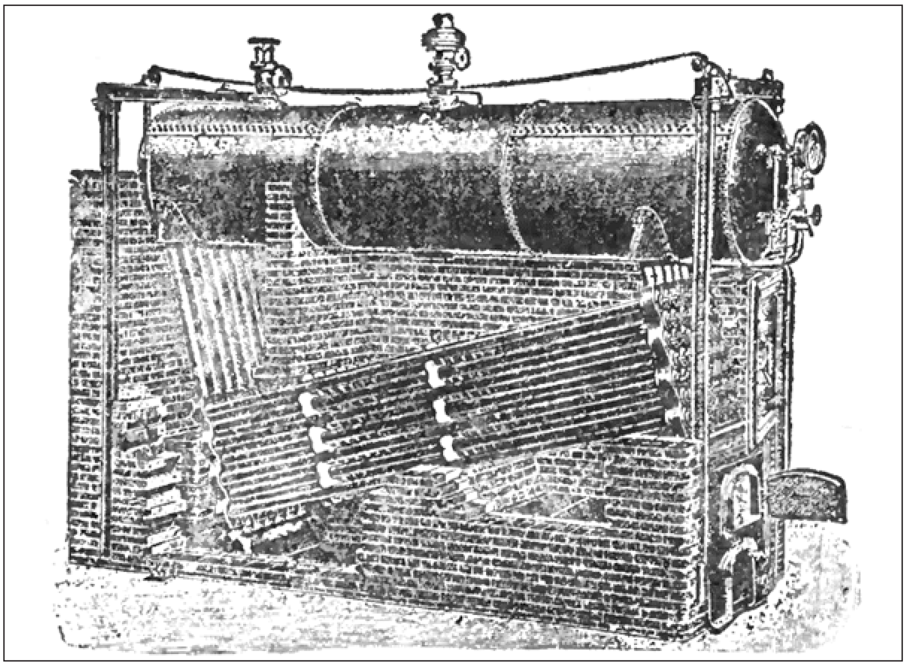


Figure 3.102 A Babcock and Wilcox water-tube boiler. Source Mentor and Taylor 1900. Image courtesy of IGEM Archive

The water would rise along the tubes and headers into the steam drum, as it became heated, the water in the drum at the same time descended to the back headers and then back into the tubes to be heated (Mentor and Taylor 1900). Figure 3.103 shows a Boiler house built at the Bromley by Bow gaswork to house Babcock and Wilcox boilers.

Figure 3.103 Babcock and Wilcox Boiler House Bromley by Bow Gasworks. Image courtesy of National Grid Gas Archive.

The advantages of this type of boiler were its greater power of withstanding pressure (on account of the small diameter of the steam drum and tubes) and the greater ease with which the boiler could be transported, and erected in cramped positions not possible with the Cornish or Lancashire type boilers. The amount of space occupied for a given steam production was also small (Mentor and Taylor 1900).

On the later gasworks it was possible to remove the requirement for conventional boilers and supply the required steam from waste heat boilers alone (Meade 1921, Stewart 1958).

3.3.14 Waste Heat Boilers

The first attempt to extract the waste heat from gas was developed in 1848 by Emmott, when he fired steam boilers using the waste heat from coke ovens. Laming also attempted the use waste heat in 1849 to dry quenched coke (Stewart 1960).

The main development of waste heat boilers occurred around 1920 as a means to recover the heat lost up the retort house chimney in the waste gases. Even with the combined use of gas producers and regenerators, the quantity of heat lost via the waste gases existing chimney represented between 18 to 25 per cent, of the total heat supplied (Meade 1921).

Unless mechanical means were used to create a draught, some heat energy loss via the chimney was required to create a natural draught which would draw air into the producers. (Meade 1921).

The waste-gases from the retort benches were collected using flues and transferred via insulated pipes to the waste heat boiler, where the heat was used to generate steam which would be used to provide steam power for various purposes, such a powering steam driven pumps. The boilers were fitted with boiler feed pumps which supplied the necessary water for the steam raising. The wastes heat boiler would have supplemented the conventional boilers used for steam raising on the gas works. From the boilers the waste gases were vented via the chimney (Meade 1921).

Examples of waste heat boilers designed for small and large gasworks are shown in Figure 3.104 and Figure 3.105 respectively.

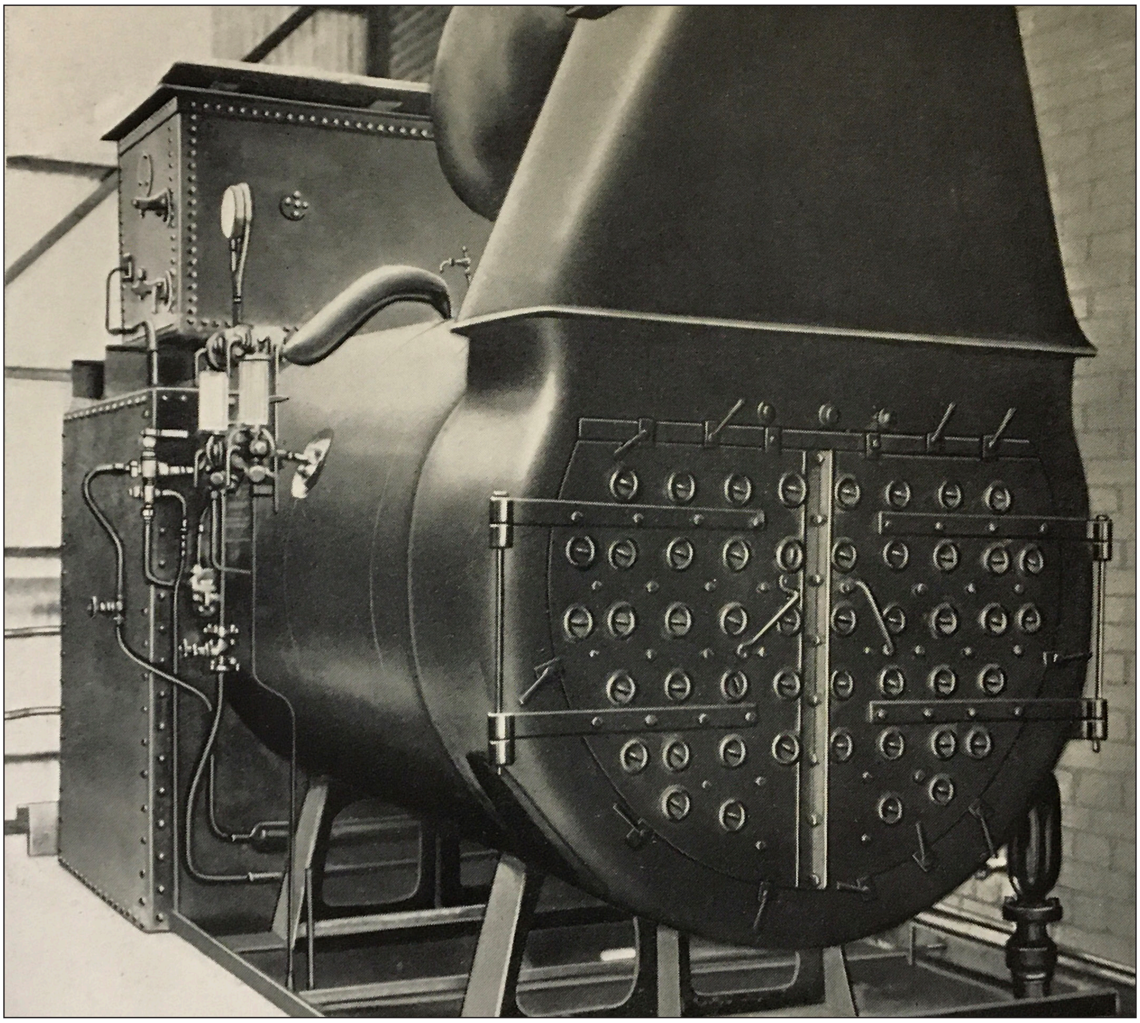


Figure 3.104 A Woodall-Duckham horizontal fire tube natural draught waste heat boiler. Image courtesy of IGEM archive.

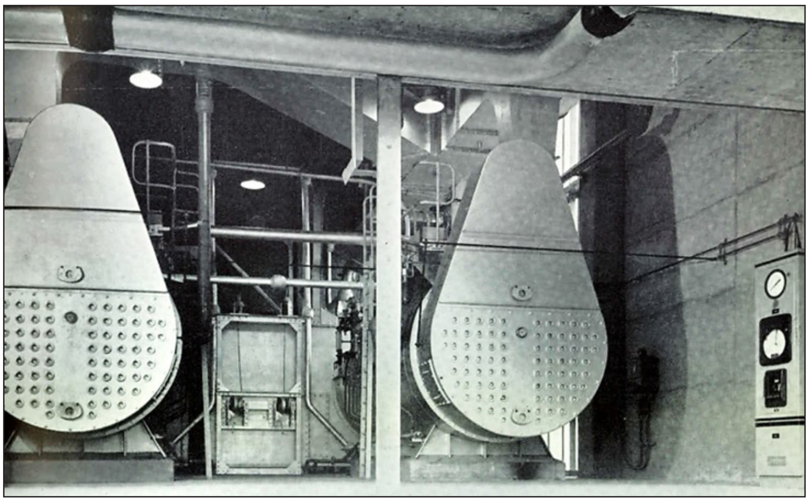


Figure 3.105 Waste Heat Boilers at the former Hendon Gasworks, Sunderland. Image courtesy of IGEM archive.

Another method for extracting waste heat was developed by the Sulzer Company, who devised a system for extracting waste heat from coke. In this process coke from the retorts was transferred via a hoist into a chamber which was then sealed and non-combustible gases recirculated using a fan, these gases were then then passed through a waste heat boiler to raise steam before returning to the chamber to be heated again. As the coke cooled it was removed and discharged to a pit to be screened. A photograph of the Sulzer plant installed at the Oswald St. Gasworks in Burnley is shown in Figure 3.106.

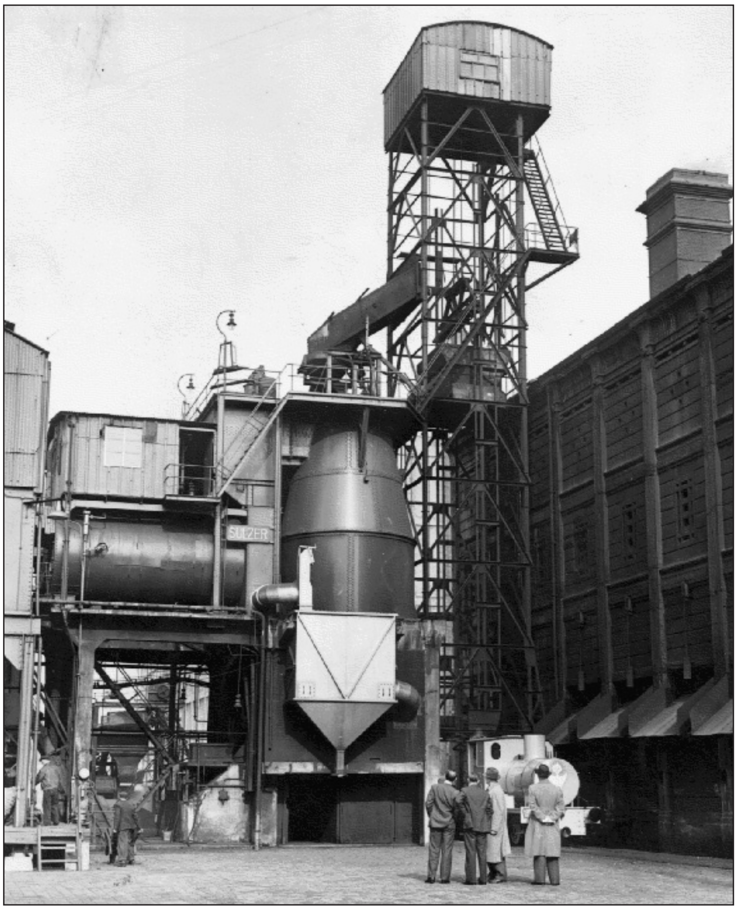


Figure 3.106 Sulzer Plant and fireless locomotive, Oswald Street gasworks, Burnley 1954. Image courtesy of National Grid Gas Archive.

3.3.15 Power House

The purpose of the Power House was to house the machinery to supply electricity to the gasworks. Some gasworks would take a supply of electricity from the local electricity undertaking. In some cases, as in Ascot, the gas and electricity undertaking were combined. It often came down to cost, whether it was cheaper to buy in the electricity or generate it at the gasworks. On gasworks the electricity could be generated as Direct Current (DC), however, electricity from the local undertaking would be provided using Alternating Current (AC). Both would be suitable for running the machinery. The electricity would be generated by a dynamo, which would be powered by standard horizontal single cylinder gas engines on small to medium sized gasworks. For very large works vertical high-speed gas engines with two or more cylinders were preferred. The engine and dynamo would be connected either by a belt or direct drive (Meade 1921).

Although Meade (1921) recommended gas engines for electricity generation, steam could also be used to drive the dynamos. This could use steam raised by the waste heat boilers for other purposes on the gasworks, although purpose-built boilers may also have been used. The steam being used to turn the dynamos to generate electricity. The booster fans were often a major consumer of electricity.

At some gasworks, such as the Swan Village in Birmingham (Figure 3.107), the waste heat was used to produce steam to power electricity generation. In some circumstances the waste heat boilers were sufficient on their own and in other cases such as East Greenwich, additional coke fired Babcock and Wilcox boilers were installed. At East Greenwich gasworks the steam was used to drive steam turbines which would directly drive the dynamos.

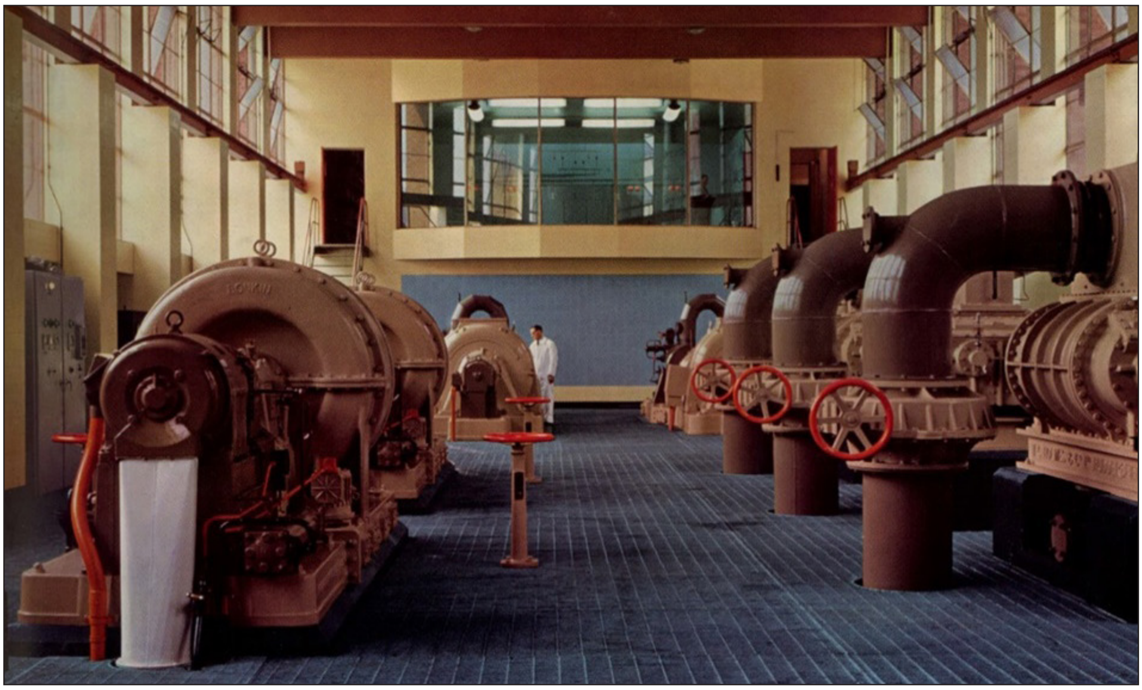


Figure 3.107 The inside of the former Power House, showing the electricity generating plant to the left, Swan Village Gasworks, West Bromwich. Image courtesy of National Grid Gas Archive.

Power was used on site for the powering of electrically driven motors, which became particularly important for powering the boosters in the gas distribution system.

The Power House also contained transformers and electrical switchgear. For a large gasworks such as East Greenwich (Figure 3.108), the electricity supply system consisted of separate outer and inner ring main cables connected to six substations.

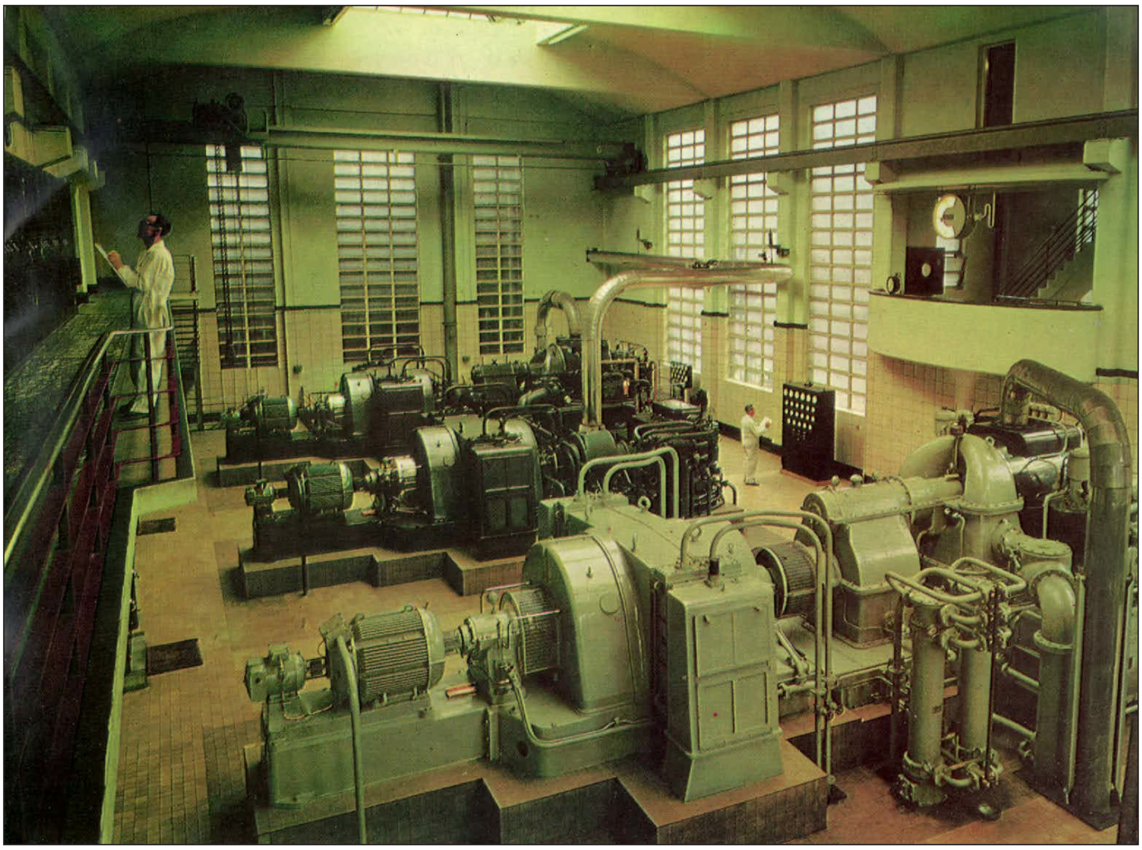


Figure 3.108 The inside of the Power House at East Greenwich Gasworks 1965. Image courtesy of National Grid Gas Archive.

These were situated at various points on the gasworks and were where the voltage was transformed to the working voltage of 415 volts A.C. and rectified by mercury arc rectifiers where D.C. variable speed motors were installed (South Eastern Gas Board 1960).

3.3.16 Coal and Coke Stocking Grounds

Coal storage typically was provided under cover in buildings adjoining the retort houses, these buildings being of brick or concrete construction. It was typical to maintain sufficient coal for a twenty-one day maximum production.

Due to occurrence of strikes in the mining, gas and transport industries, the larger gas companies endeavoured to store additional coal supplies. The amount of additional storage would depend on the availability of coal and the distance of the gasworks from the supplying coal mine. The additional storage typically accounted for gas production of between two and three months. It was not possible to house such vast quantities of coal, so large heaps were stacked out in the open. Such a coal storage ground is shown in Figure 3.109 (Meade 1921).

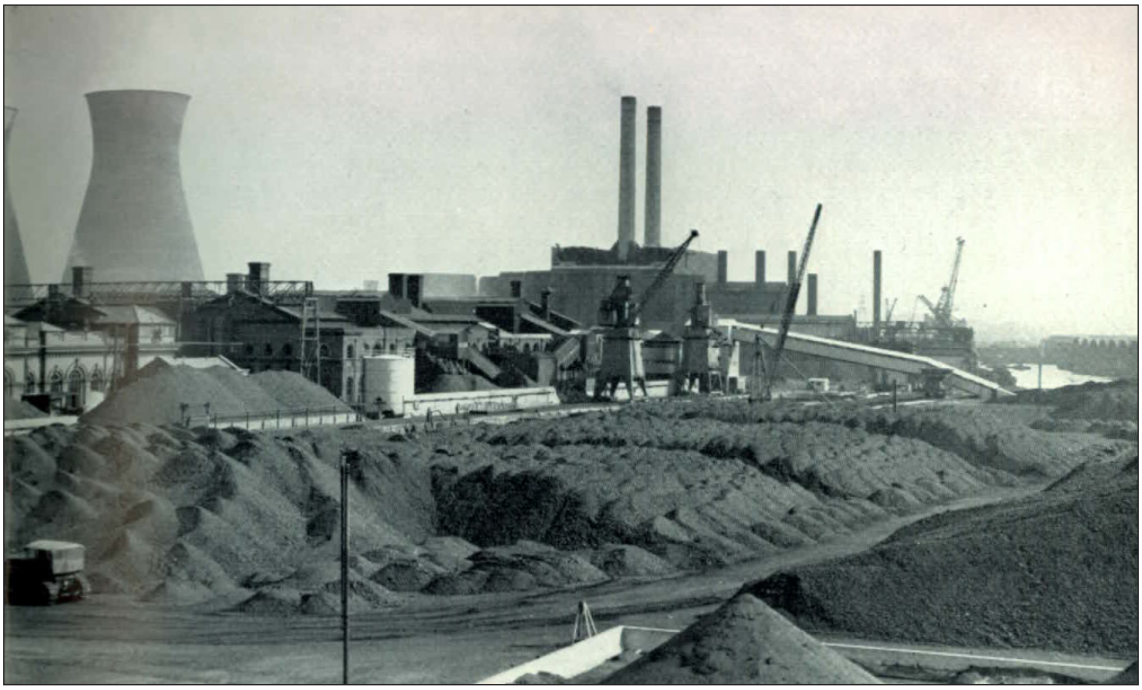


Figure 3.109 Coal Stocking grounds Bromley by Bow Gasworks. Image courtesy of National Grid Gas Archive.

A large area of land was typically taken up by coal and coke storage. The later was preferably sold to customer or used for water gas or producer gas manufacture in line with production demand.

Coal would not be stacked to a depth greater than 20 feet, owing to the danger of spontaneous combustion. The ground on which the coal was placed would be designed so that it was free draining and that the coal would not be sat in water. Damp coal had an undesirable effect when carbonized in ordinary horizontal retorts, although its use in the later carbonisation processes using chamber ovens or vertical retorts, had little effect (Meade 1921).

3.3.17 Coal Handling and Wharfs

Importing coal to a gasworks was one of the biggest costs in gas manufacture. Preferably coal would be delivered directly by barge or collier if the gasworks was adjacent a canal or navigable river or directly via a rail siding, if the gasworks were adjacent a railway line. If neither of these were options then considerable expense could be spent on transporting the coal from the nearest wharf or station by hand cart, horse and cart or steam tractor. Figure 3.110 shows the collection of coals from a Collier at Great Yarmouth using horse and cart.

Figure 3.110 Unloading coal at Great Yarmouth Docks into horse drawn wagons, Circa 1910. Image courtesy of IGEM archive.

The example shown in Figure 3.111, shows coal being unloaded by a travelling electro-hydraulic crane at the Bromley by Bow Gasworks on the River Lea in London.

The large wharves built at Beckton gasworks (See Figure 3.4), were also used to load coal on to smaller vessels which would transfer coal to other GLCC gasworks along the River Thames.

Figure 3.111 Electro-hydraulic crane unloading coal from a barge on the River Lea, Bromley by Bow Gasworks, 1950's. Image courtesy of National Grid Gas Archive.

3.4 Manufacture of Gas by Gasification

These processes were all forms of gasification where the main aim was the conversion of the fuel directly into gas, without the formation of a carbon rich intermediate such as coke, which occurred through the carbonisation processes mentioned previously.

3.4.1 Producer Gas

The conventional production of gas from coal is well documented; however, there was also another simpler method of gas production which is less well known, called "producer gas". Although producer gas was manufactured at gasworks, it was not generally used to provide a public supply. Its main application was supplying a cheap low calorific value gas for industrial heating purposes.

Producer gas plants in their own right, started to become popular in the early 1880s and were in extensive use by 1910. As producer gas plants developed from the first plant built by Bischof (Figure 3.112) until their demise in Britain from competing technologies in the mid-20th century, many varied types evolved.

The German metallurgist Carl Andreas Bischof undertook the early pioneering work on the development of the gas producer. Bischof who came from Mägdesprung in the Harz Mountains of the Saxony-Anhalt region of Germany, constructed the first gas producer in 1839. This was built simply from bricks as shown in Figure 3.112. It worked under suction conditions with air drawn through the producer from the top of the fuel bed. Bischof was closely followed by Ebelman in France in 1840. Ebelman's design was based on a blast furnace and operated quite differently to Bischof's. Ebelman's producer was of a slagging type, using a mixture of coke and charcoal as fuel which was admixed with lime or furnace slag to produce a fusible ash. The producer was operated at a high temperature to ensure the slag was removed in a molten form (Dowson and Larter 1907).

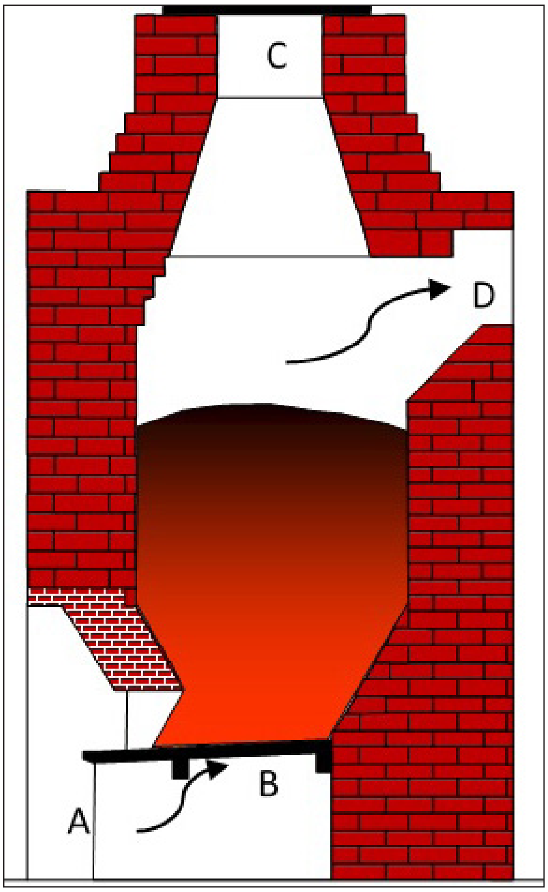


Figure 3.112 Bischof Gas Producer. Air was drawn into the producer (A) through the fire bars (B) and fuel, exiting via the vent (D). Fuel was loaded via door C. Source R. Thomas

The next major development was that of Fredrick Siemens who developed a combined gas producer and regenerative furnace in 1857. This system was gradually improved and introduced to the UK through William Siemens. Producer gas plants provided a considerable benefit to those industries requiring high and uniform temperatures. This greatly aided those industrial processes which were unable or found it very difficult to use directly fired solid fuel furnaces. It also saved fuel as the gas could be burnt at the exact point required (Dowson and Larter 1907, O'Connor 1910).

A simple drawing of a gas producer using just air or air and steam is shown in Figure 3.113. A represents the fire bars or grate, B is the air inlet, C is the column of fuel, D is a hopper with a close-fitting valve through which the fuel is introduced, and E is the gas outlet.

The next major advance in the application of gas producers came in 1878, when Dowson developed the Dowson complete gas plant. This plant could be used both industrially and domestically. Dowson went on to demonstrate the effectiveness of gas engines (developed by Otto circa 1876) when in 1881 he combined one of his producer gas plants with a 3 horsepower (HP) Otto gas engine (Dowson and Larter 1907).

These early gas engines had a maximum of 20 HP, equivalent to 14.9 kilowatts. But by 1910, gas engines had reached 2,000 HP, equivalent to 1,491 kilowatts .

Circa 1900, suction gas plants (Figure 3.114) and engines were introduced; these plants could make more effective use of the lower quality producer gas, which made them popular.

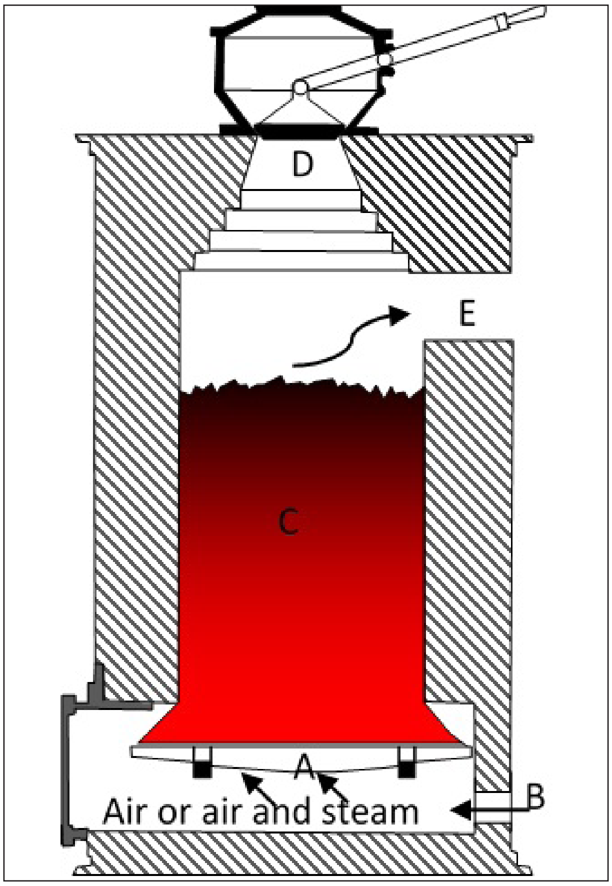
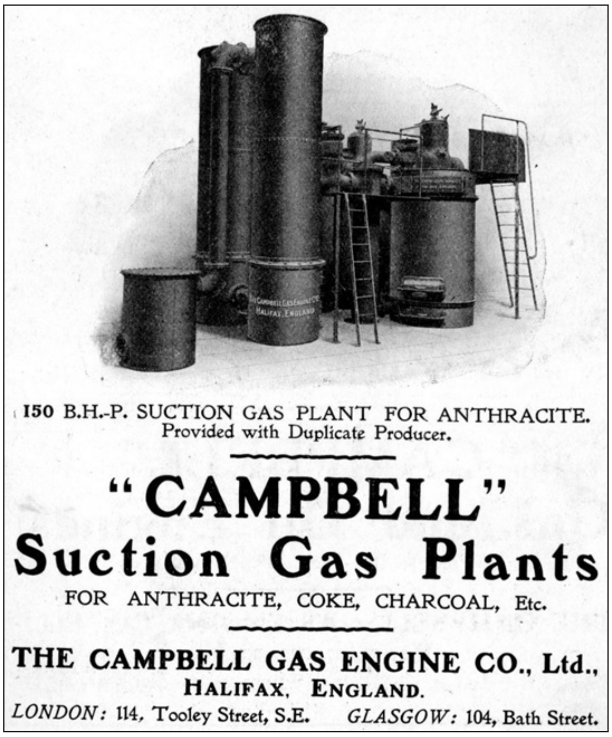


Figure 3.113 Gas Producer working with air or air and steam. Source R. Thomas.



150 B.H.-P. SUCTION GAS PLANT FOR ANTHRACITE.
Provided with Duplicate Producer.

"CAMPBELL"
Suction Gas Plants
FOR ANTHRACITE, COKE, CHARCOAL, Etc.

THE CAMPBELL GAS ENGINE CO., Ltd.,
HALIFAX, ENGLAND.
LONDON: 114, Tooley Street, S.E. *GLASGOW:* 104, Bath Street.

Figure 3.114 An advert for a Suction Gas Producer Plant circa 1900. Source R. Thomas.

3.4.1.1 Principles of Producer Gas

Producer gas manufacture differed from traditional gas production in the way and conditions in which the gas was made. A traditional gasworks would manufacture gas by indirectly heating coal contained within a retort from a separate furnace located beneath the retort. The retort was an oxygen-free environment, meaning that as the coal was heated, it would not combust, but instead would thermally decompose, releasing gas and other by-products such as tar. This gas had a complex composition (Dowson and Larter 1907, Meade 1921).

By comparison, and in simplistic terms, a producer gas plant would manufacture gas by partially combusting coke in an oxygen-limited atmosphere. The gas produced primarily consisted of carbon monoxide, carbon dioxide and nitrogen. In slightly more detail, the producer gas plant made gas by forcing or drawing air, with or without the addition of steam, through an incandescent deep bed of fuel in a closed producer vessel. The fuel was gradually consumed during the process and the gas was simply piped to where it was required (Dowson and Larter 1907, Meade 1921).

An important characteristic of the producer gas process was that no external heat was applied to the producer: it was heated by the partial combustion of the fuel within the producer itself. The skill in effectively operating a gas producer was to ensure that the fuel bed was of sufficient depth and the air supply was not too great, limiting the amount of combustion (Dowson and Larter 1907, Meade 1921).

Once the fuel inside the producer had started to burn, the air supply was carefully controlled to allow continuous combustion in the lower regions of the fuel bed. This provided the high temperature required to produce the necessary reactions higher up the fuel bed and, if steam was added, to decompose the steam. The producer gas process focussed on the incomplete combustion of carbon to maximise the carbon monoxide produced and minimise the amount of carbon dioxide (which had no calorific value). This was achieved through the reactions shown below (Dowson and Larter 1907, Meade 1921).

Within a conventional fire, the carbon in coal would react with oxygen forming carbon dioxide, an exothermic reaction where each kilogram (kg) of carbon would produce 33 megajoules (MJ) of energy.

$$\text{(i)} \qquad 1\text{ kg } C + O_2 = CO_2 + 33\text{ MJ/kg}$$

This reaction also occurred within the fuel pile at the base of the producer. Due to the limited oxygen supply, carbon monoxide was also formed in the fuel bed, in the reaction below. This was also exothermic, producing 10 megajoules for each kg of carbon.

$$\text{(ii)} \qquad 1\text{ kg } 2C + O_2 = 2CO + 10\text{ MJ/kg}$$

As the carbon dioxide formed passed up through the bed of coke, it was reduced by further hot carbon higher up the fuel bed. This formed carbon monoxide through an endothermic reaction where 13 megajoules of energy would be consumed for each kg of carbon:

$$1\text{ kg } CO_2 + C = 2CO - 13\text{ MJ/kg}$$

This reaction was reversible, and the amount of carbon dioxide converted to carbon monoxide was highly dependent on temperature. At 850°C, the reaction forming carbon dioxide was found to proceed 166 times more rapidly than the reverse reaction.

Where moisture was present in the fuel, or where steam was injected into the producer, additional reactions between the carbon and carbon compounds and water would occur. When steam interacts with carbon at a high temperature, it decomposes, and the oxygen is transferred to the carbon, producing hydrogen. The oxygen released from the reaction of the steam could, depending on the conditions, combine with carbon to form carbon monoxide or carbon dioxide. These reactions are the basis of water gas production, which is described elsewhere in this document (Dowson and Larter 1907, Meade 1921).

When coal gas was produced in a retort, complex organic compounds within coal would thermally decompose, forming gaseous and vapour phase organic compounds within the gas. If soft or bituminous coal was used in the producer, similar by-products would form in the gas. In Great Britain, coke and anthracite were primarily used as the fuel in a gas producer. These fuels were primarily composed of carbon and produced few organic by-products within the gas (Dowson and Larter 1907, Meade 1921).

Theoretically, producer gas would consist of 34.2% carbon monoxide and 65.2% nitrogen, but these conditions would never actually occur. A composition of 25% carbon monoxide would have been the target.

Considering the composition in more detail, producer gas was a mixture of carbon monoxide, hydrogen, carbon dioxide and nitrogen, in varying proportions, and a very small quantity of gaseous hydrocarbons (predominantly methane) and hydrogen if steam was admitted into the furnace (Meade 1921).

The carbon monoxide, hydrogen, gaseous hydrocarbons were combustible (30-45% of the gas composition), and the calorific value of the gas was dependent on the relative proportions in which they were present. The carbon dioxide and nitrogen were diluents which lowered the calorific value and subsequent flame temperature of the combustible gases when burnt. The nitrogen concentration in producer gas was much higher than in coal gas. This was because the producer was aerated by a restricted supply of air (nitrogen forms 78% of air) and coal gas was an enclosed process and not aerated (Dowson and Larter 1907, Meade 1921).

Gas from producers can be split into two different types: “hot unpurified gas” and “cooled and purified gas”. For most industrial heating purposes, the gas was used in a hot and unpurified state, allowing the entrained heat in the gas to be used in addition to the heat generated from burning the gas and any tar which may be present in the gas. This avoided the cost of cooling the gas and minimised the use of regenerators to heat incoming air. There were problems using producer gas in this way, any precipitated tar and dust could block pipes, allowing only short pipe runs to be used. Using coke would minimise tar deposition and bituminous coal would greatly exacerbate the problem (Dowson and Larter 1907, Meade 1921).

If the item being heated was sensitive, such as kilns fired for glass or ceramic ware, then the dust and tar could damage the finished product. In these situations, and when used for heating retort/coke ovens or powering gas engines (Figure 3.115), the gas would be purified, removing any dust, ammonia and tarry residues. The gas was cleaned with a scrubber, which is described on page 125.

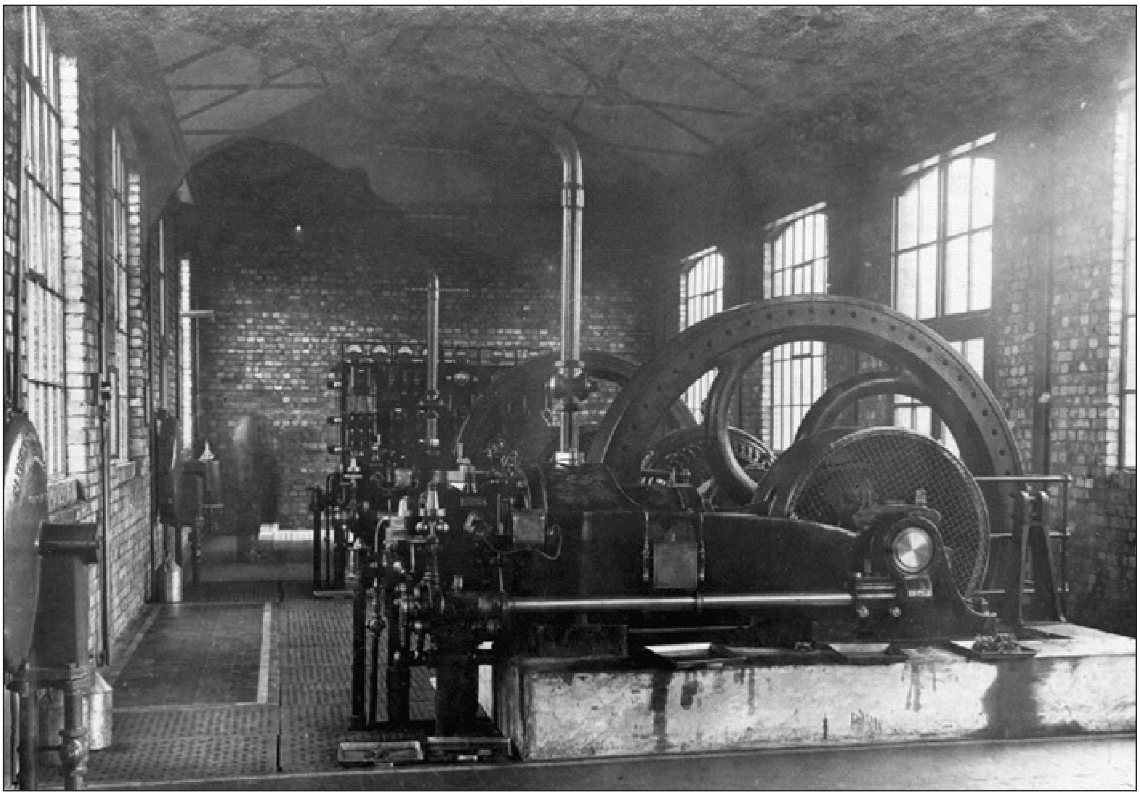


Figure 3.115 Two gas engines Installed at the former Wandsworth power house. Image courtesy of the National Grid Gas Archive.

Producer gas could be obtained from almost any carbonaceous fuel. The type of fuel used depended not only on the purpose for which the gas was to be used, but on its cost and the ease with which each fuel could be purchased locally.

Producer gas was predominantly made from anthracite or coke, especially where the gas use was sensitive. Where the end use of the gas was not sensitive, bituminous or semi-bituminous coal could be used and, in some circumstances, it was also possible to use brown coal, lignite, peat or charcoal. The composition of the gas and by-product was largely influenced by the nature of the fuel used as a feedstock.

3.4.1.2 Suction Gas

Early gas producers operated using the suction of gas through the fuel; this was later disregarded in preference to pressurised gas injection. Developments in the 1860s gradually led to the construction of efficient suction gas plants based on Dowson's design shown in Figure 3.116.

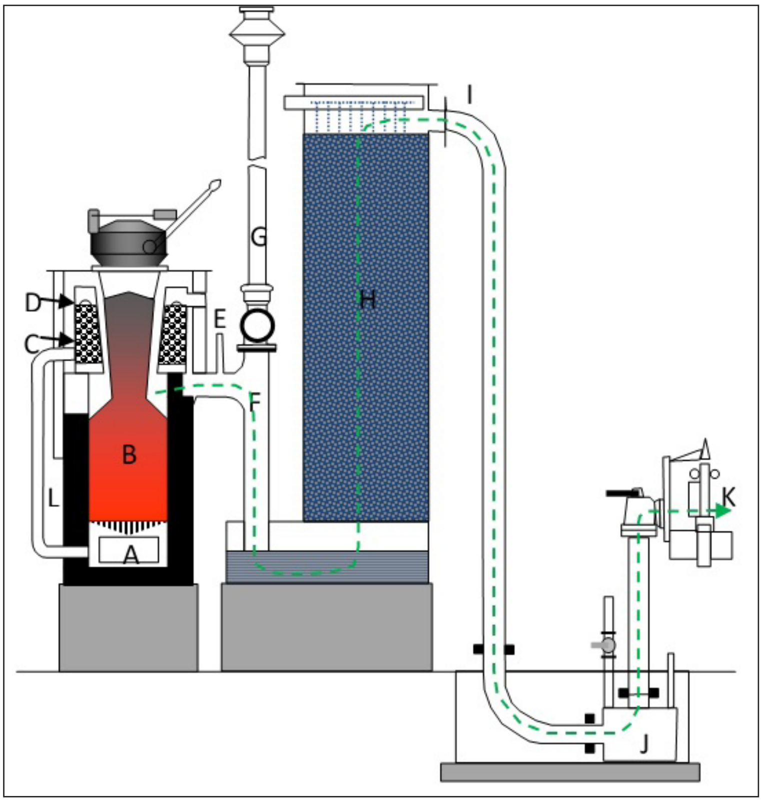


Figure 3.116 A Suction Gas Plant of the Dowson Design. Source R. Thomas

Suction gas plants were very effectively employed in combination with gas engines optimised for suction gas producers. The operation of the system can be explained by referring to Figure 3.116, where A was the grate on which the fuel was placed; B was the container holding the store of fuel, which entered through the hopper and valve at the top; C was a circular chamber filled with broken firebrick; D was a circular pipe which sprayed water into the system; E was the air inlet and F the gas outlet; G was the chimney; H was the scrubber with a water seal at the bottom; and I was the gas outlet leading to the expansion box (J) and gas engine (K).

The fuel in the producer was lit with the aid of some oily waste and wood, placed on the grate and the producer was filled with small pieces of anthracite or coke. The feeding hopper was closed and the fire then lit. The fan (not shown in Fig. 5) was set in motion, and the exiting gases from the producer were initially allowed to escape through the chimney. Once combustion was effective, the water supply would be turned on; as soon the gas produced was burning effectively it was connected to the gas engine. The engine would be started, and the fan stopped. From this time, the engine itself would suck the air required into the producer. Before entering the engine, the gases passed upwards through the coke-filled scrubber, ascending through a column of coke continually sprayed by water. The role of the scrubber was to purify the gas, removing fine dust, ammonia and tarry residues. The gases then passed along the pipe main and into an expansion box, which was in direct communication with the engine cylinder (Dowson and Larter 1907).

3.4.1.3 Mond Gas

Mond gas was a variant of producer gas and was a form of complete gasification whereby coal would be fully converted to ash, rather than to coke as would happen in a retort. The Mond gas process was designed to enable the simultaneous conversion of bituminous small coal (slack) into flammable gas, largely composed of hydrogen, and at the same time recover ammonium sulphate.

Sir George Bielby and William Young (of oil shale fame) did much of the early work on both the complete gasification process and the steaming of the char subsequently produced. Despite this, recognition for the Mond gas process goes to its namesake, Dr Ludwig Mond, who commercially developed the process in 1889. Mond realised that by greatly restricting the air supply and saturating that air with steam, the fuel bed could be kept dark red in colour, providing a low working temperature. There were two key reasons for the low temperature. Firstly, it was below the temperature of dissociation for ammonia, which prevented its destruction and maximised the amount of ammonia which could be obtained from the nitrogen entrained in the bituminous coal. Secondly, the low temperature prevented the formation of clinker which would hamper the operation of the process, the ash being easily removed from the water seal around the base of the cone of the producer (Meade 1916).

The first Mond gas plant was put into operation at the Brunner, Mond & Co's Works at Northwich, Cheshire. These plants required a massive capital outlay for them to be profitable, as only very large plants were economically viable. They had to use over 182 tonnes of coal per week for the ammonia recovery to be profitable. The efficiency of the Mond plant was as high as 80 per cent. To achieve this, however, a large excess of steam was required so that the small proportion of steam which was decomposed (about one third) was sufficient to absorb the heat evolved in the formation of carbon dioxide and carbon monoxide from air and carbon. For each tonne of coal, two tonnes of steam would be required for the process. This amount was reduced to one tonne of steam if ammonia was not being recovered by the plant (Wood 1903, Robson 1908, Meade 1916).

Coal would be fed by coal elevators up to hoppers which would feed the small pieces of bituminous coal down into the Mond producers. The Mond producer operated at about 600°C and was fed with hot moist air (250°C) from the superheater.

Following the mechanical washer, the gas was subjected to treatment in the acid tower (labelled as 4 on Figure 3.117), which removed ammonia. The gas passed upwards through the tower against a counter-current flow of weak sulphuric acid sprayed down the brick- and tile-filled tower, forming ammonium sulphate. The weak sulphuric acid solution would be recirculated until a concentration of between

36 and 38% ammonium sulphate was reached. At this point, the solution would be removed and replaced by fresh weak sulphuric acid. The ammonium sulphate solution removed, was evaporated, yielding the ammonium sulphate. The acid tower was lead lined as lead was resistant to corrosion and had been commonly used in processes involving acids (Wood 1903, Robson 1908, Meade 1916).

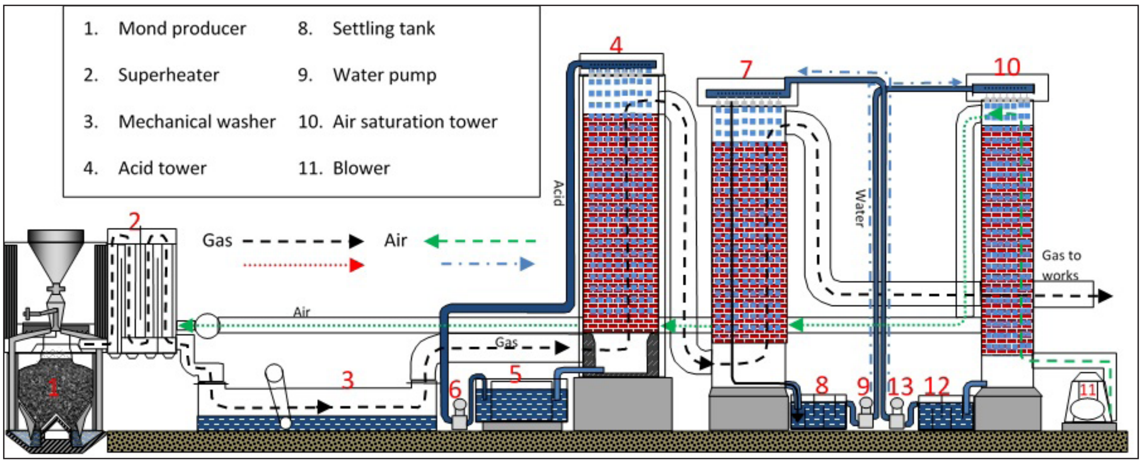


Figure 3.117 The Mond System of Gas Production and Ammonia Recovery. Based on Historical Process Drawings. Source R. Thomas.

With the ammonium removed, the gas was then passed through the gas cooling tower (labelled as 7 on Figure 3.117), where the up flow of gas was met with a downward spray of cold water, cooling the gas. Following this treatment, the gas could be used for its intended purpose. The water from the gas cooling tower emerged hot, and any tar suspended tar within the water was removed in the settling tank (labelled as 8 on Figure 3.117). This hot water was then pumped up to the top of the air saturation tower where it was used to heat (to 85°C) the hot moist incoming blast air being blown into the Mond producer.

The Mond gas process would produce between 19 kg and 40 kg of ammonium sulphate and between 3,960m^3 and 4,530m^3 of gas per tonne of coal. The amount of ammonia produced was dependent on the nitrogen content of the coal, the latter having a preferred nitrogen content higher than 1.5%. The predominant reaction in the Mond gas process is between carbon and water forming carbon dioxide and hydrogen. The water gas process which predominates at higher temperatures forms carbon monoxide and hydrogen. Both reactions are shown below.

Predominant reaction in Mond gas process:

$$C + 2H_2O = CO_2 + 2H_2$$

Predominant reaction in water gas process:

$$C + H_2O = CO + H_2$$

The gas manufactured was hydrogen rich and carbon monoxide poor (water gas has a much higher carbon monoxide content). It was of limited use for heating or lighting, but it could be used for some industrial purposes and power generation. The tar produced would have been brown in colour and typical of a low temperature coal tar, being high in paraffinoid components and tar acids. It would have been removed and processed elsewhere (Wood 1903, Robson 1908, Meade 1916).

The Mond gas process was further developed by the Power Gas Corporation as the Lymn system. This process was found on some larger gasworks and was more popular than the earlier Mond gas system. It was like the Mond gas system but used much weaker sulphuric acid and a different configuration of washers. Lymn washers can often be found recorded on plans of large former gasworks.

The gas left the Mond producer via a piece of plant referred to as either a superheater or a regenerator (labelled as 2 on Figure 3.117). The purpose of this plant was twofold. The heat of the gas and steam leaving the producer was transferred to the incoming blast of air and steam from the air saturation tower (heated to 250°C). The reverse of this is that the gas and steam leaving the producer was cooled by this process equally. From the superheater, the gas enters a mechanical washer (labelled as 3 on Figure 3.117), a rectangular iron chamber where the gas was thoroughly washed with a fine spray of water generated by rotating dashers. This further cooled the gas (to 100°C), whilst removing dust or heavy tarry residues.

3.4.1.4 Gas Producers, Gasworks and Coking Works

Gas and coking works were major users of gas producers, not for producing gas to distribute (although it was sometimes used to dilute town gas) but to produce a cheap low-grade carbon monoxide gas for the heating of the retorts.

Early gasworks used horizontal retorts which were heated directly by a shallow fuel bed of coke lit beneath the bench of retorts. The direct radiant heat from the fuel bed in the furnace and the hot waste gases heated the retort. This approach was not very efficient and was only able to heat the retort to temperatures of approximately 600°C. As a result, the amount of gas produced was relatively low in comparison with later methods and the decomposition of the organic compounds in the gas and resulting tar was limited (Richards 1877, Meade 1916).

The heating of the retorts developed from these early directly fired settings, through semi-gaseous fired settings (allowing some secondary combustion of gases), to gaseous producer fired settings, see Figure 3.21.

The gaseous-fired setting used a gas producer to provide gas to heat the retorts. This system was used on all the different retort designs from horizontal to vertical. The gas producer did not need to be adjacent to the retorts (see Figure 3.21), although if it was, the heat loss was minimised. The producer could be located remotely on the gasworks supplying multiple benches of retorts. The fuel bed in a producer would be approximately 1.5m to 1.8m deep and the primary air supply was very carefully controlled to enable the correct composition of the producer gas. The producer gas was channelled to a combustion chamber directly adjacent to the retorts, where it was mixed with a secondary supply of air and burned. The subsequent hot exhaust gas was routed through flues around the retort, heating the coal in the retort.

The gas producer was the most efficient method of heating retorts. Fuel consumption was improved further in gaseous-fired settings if advantage was taken of the waste heat in the gas after heating the retorts. If the hot waste gas was used to heat incoming air via a heat exchanger, then this was called a recuperative or regenerative gaseous-fired setting. If the hot waste gas just passed out of the chimney directly or via a waste heat boiler then it was termed a non-recuperative gaseous-fired setting. These developments helped make the gas-making process more cost effective and much more efficient.

For large gasworks such as those at Partington (Manchester) the producers were housed in separate buildings (Figure 3.118) and the gas was purified through washers and scrubbers before being piped to the retorts. Like most other producers, this plant was generally located above ground; therefore, little evidence is found on former gasworks sites where the plant had previously existed.

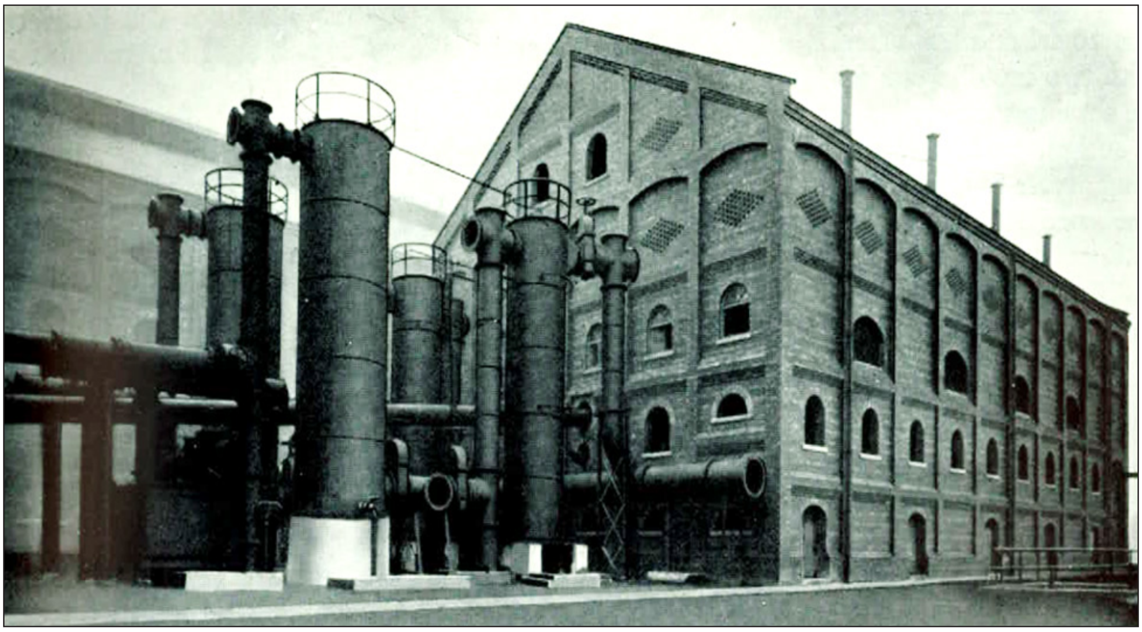


Figure 3.118 The Trefois Producer House, built by Drakes at the Partington Gasworks, Manchester, which supplied producer gas to the retorts. The ancillary washers and scrubbers can be seen outside the building. Image courtesy of the National Grid Gas Archive.

Later gasworks, for example the one at East Greenwich in South London, used larger more advanced gas producers such as the Marishka type gas producer shown in Figure 3.119. This type of gas producer was separate from the gas-making plant which at the East Greenwich works included both retorts and coking works. The producer gas was used for heating coke ovens as well as retorts. It was common practice at coke works to use producer gas to heat the ovens. As the value of coke oven gas has dropped (it cannot easily be sold for domestic or industrial use) and the value of the coke increased, most coking works use coke oven gas to heat the coke ovens, rather than producer gas.

The more advanced gas producers, such as the Marishka producer (Figure 3.119), used steam injection into the air blast. The purpose of the steam was to control the endothermic water gas reaction, the temperature of the zone of combustion, the degree of fusion of the ash, and the temperature of both the grate and exiting producer gas. The formation of water gas raised the calorific value of the gas above that of producer gas (Ward 1959).

Producer gas production was a highly efficient process. It had low capital costs and became one of the most widely used industrial gas production methods in Britain, as it did not require cooling or gas treatment. As natural gas, liquid petroleum gas and oil-based town gases became available and coke became costly and scarce, the popularity of gas producers diminished; they are now largely obsolete.

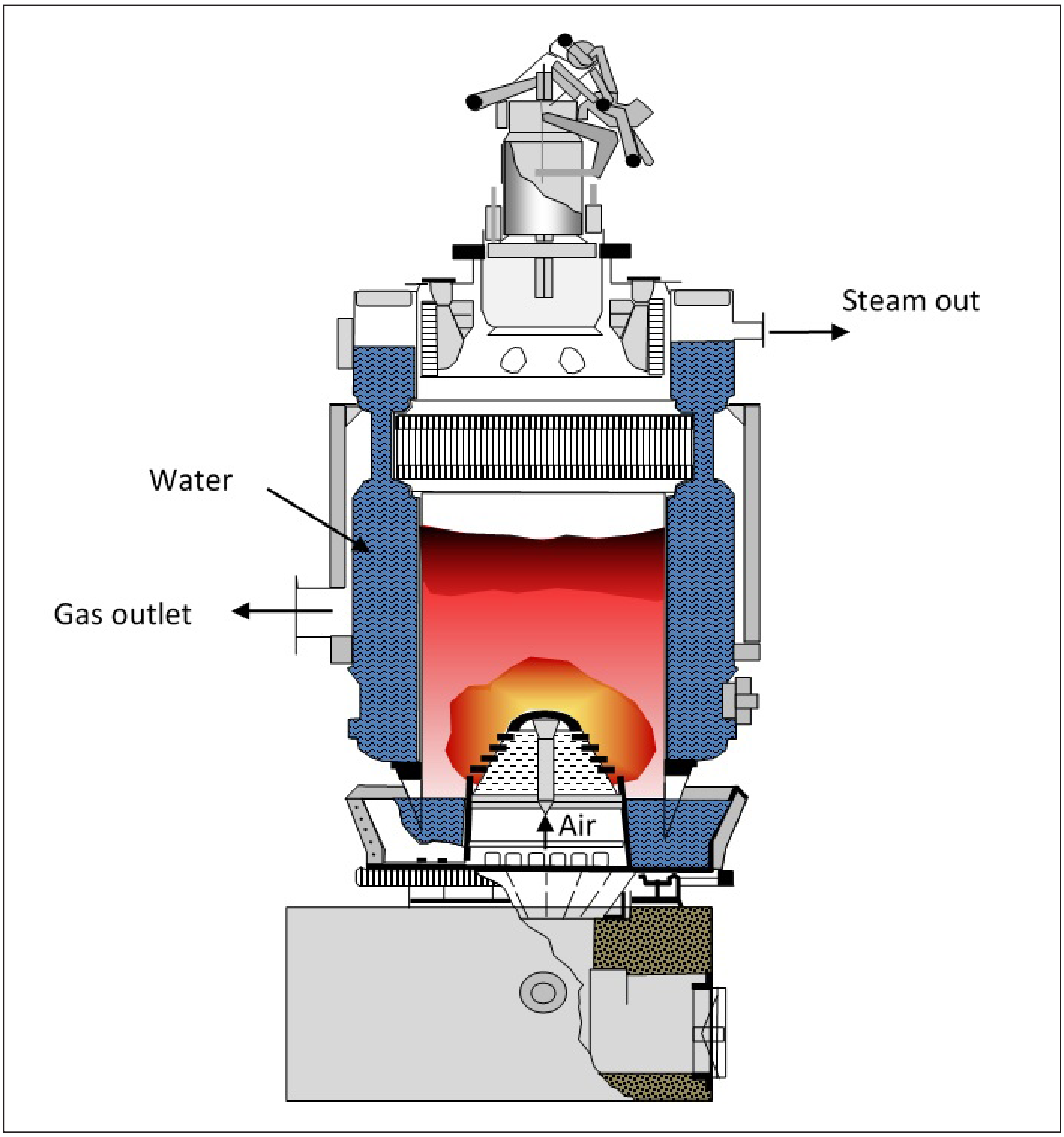


Figure 3.119 Cross Section of a Marishka type Gas Producer. Based on a Historical Drawings. Source R. Thomas.

3.4.2 Water Gas

The main drawback of conventional gas production from the carbonisation of coal, was the long period of time taken to get the gas plant operational and producing gas. This made gas production relatively inflexible and gas companies highly dependent on having sufficient storage available in gasholders (Stewart 1958 p20-21).

If insufficient gas storage was available, then the retorts would have to remain heated, in case any sudden increase in demand for gas occurred. This was both inefficient and uneconomic for the gas manufacturer. A more efficient method to meet peak demand for gas had been much sought after, it was eventually found in the form of water gas plants (Stewart 1958 p20-21).

Water gas plant (Figure 3.120 & 3.121) could produce gas much more rapidly (within 1-3 hours) than traditional coal carbonisation plant, allowing gas companies to satisfy peak demand more efficiently. Whilst this process was commonly employed on many larger town and city gasworks to produce gas rapidly, plant was also developed for smaller gasworks. In Britain, water gas was mixed with coal gas (30% water gas to 70% coal gas) prior to distribution (Meade 1916 p466, Stewart 1958 p20-21).

Figure 3.120 The interior of the water gas plant building at the former East Greenwich gasworks. Image courtesy of National Grid Gas Archive.

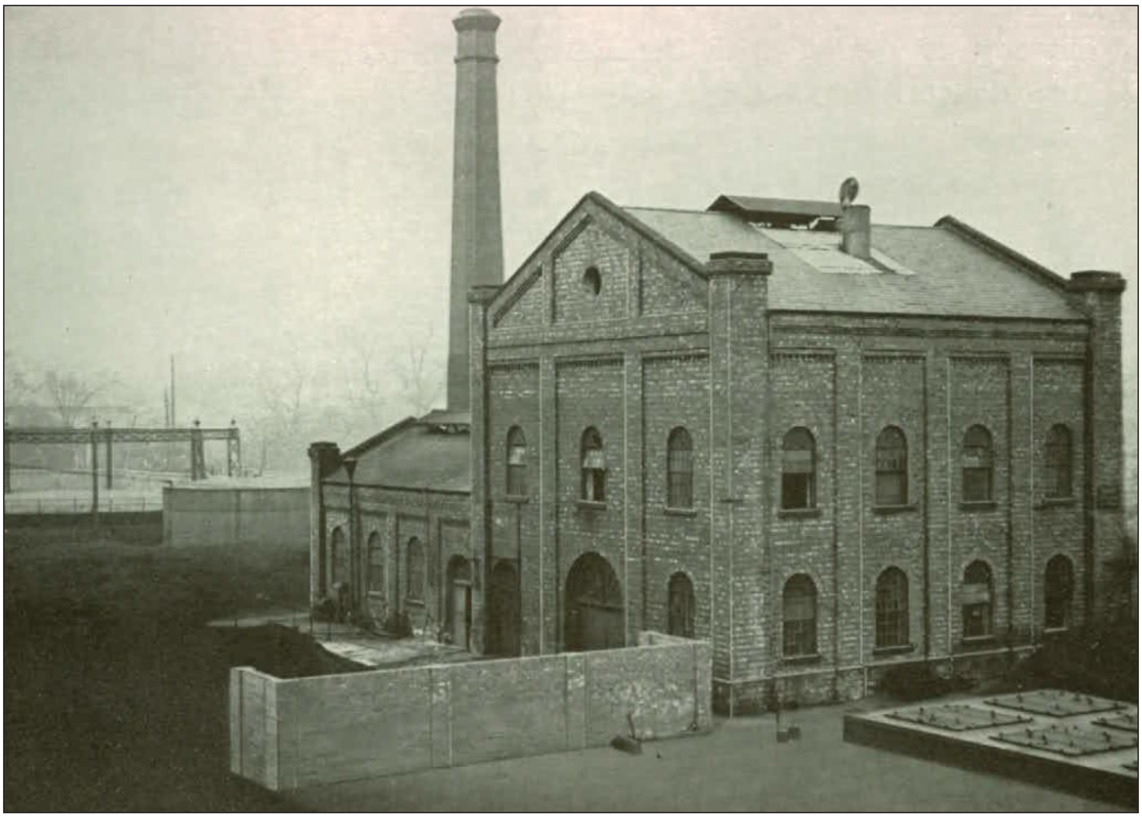


Figure 3.121 The Exterior of the Water Gas Building at the Former Monkbridge Gasworks, York. Showing the Purifiers (front right), Oil Storage and Relief Holder (rear left). Image courtesy of National Grid Gas Archive.

3.4.2.1 The Early Development of Water Gas

The discovery of producing water gas from coal is attributed to the Italian physicist Abbé Felice Fontana in 1780. Fontana was the director of the cabinet of natural history belonging to the Grand Duke of Tuscany. He found that when steam was passed through incandescent carbon, the oxygen present in the water molecules in the steam, had a greater affinity for the carbon than the hydrogen to which it was bonded (Brackenbury 1901 p45, Stephenson 1916 p9-21).

This led to the formation of carbon monoxide and hydrogen from the water and carbon in the reaction:

$$C + H_2O = H_2 + CO.$$

Fontana is also credited with the discovery of the water-gas shift reaction (WGSR) which describes the reaction of carbon monoxide and water vapour to form carbon dioxide and hydrogen, this reaction can occur as a subsequent reaction of the carbon monoxide and hydrogen within water gas:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

The WGSR became important much later in history with the development of industrial processes that required hydrogen, such as the Haber–Bosch ammonia synthesis. The gasification of coal being then linked to the WGSR to produce a pure hydrogen product.

The interest had originated from the ballooning craze of late 18th Century. The hydrogen used in air ballooning at that time was produced from the reaction of iron and sulphuric acid (named the Charles method), which was very expensive. Alternative methods had been sought and the Coal method devised by Fontana was one of these, the drawback was that the gas produced was impure containing about 40% carbon monoxide (Almqvist 2003).

Shortly afterward in 1784, Antoine Lavoisier and Charles Meusnier had devised the iron method, where water vapour was passed over iron at a temperature of about 600°C, which produced pure hydrogen. This was much cheaper than both the Charles method and the Coal method (Almquist 2003).

Fontana's discovery predated William Murdoch's discovery of commercial coal gas manufacture. The water gas produced however, had little or no illuminating power when burnt, so no practical use was made of the discovery at this time. Henry Cavendish had produced and analysed hydrogen gas in 1766 and had shown in 1784 that water was formed when hydrogen was burned in the presence of oxygen. (Cavendish 1784, Almquist 2003).

The first recorded patent (No. 4808) for water gas production was by William Vere and Henry Samuel Crane of London in 1823. The patent described the use of admitting water or steam into a retort containing coal, oil or other suitable material undergoing decomposition, but was not developed further (Torrey 1864).

John Holt Ibbetson attempted to utilise water gas on a commercial scale in 1824. He designed a retort which drew air down through the fuel bed, introducing steam into a decomposing chamber containing ignited coal or coal. Ibbetson published a patent (No. 4954) in 1826 but did not develop the technology further (Anon 1860, Torrey 1864).

Michael Donovan received a patent on the 6th October 1830, for lighting by water gas. To improve the illuminating ability of the gas he mixed the gas with vapours of turpentine, tar, naphthalene and other illuminants. This was tested on the street lights of Dublin. The scale of this demonstration is uncertain; however, it did not meet with much success and soon failed (Torrey 1864).

In 1831 George Lowe registered his British patent (No.6179), which included discharging the hot coke into a cylinder akin to a water gas generator, letting in air until white hot, sealing the vessel and letting in steam to produce water gas (Anon 1860). This was the first attempt to develop an internally fired water gas generator. His second related British patent (No.6276) included within it what became referred to as "Lowe's Naphthalizing Apparatus", it consisted of a vessel through which the gas passed over extended surfaces of liquid naphtha, to become saturated with its vapour. This enriched the gas with naphtha obtained from coal tar to improve its illuminating power (Torrey 1860).

The renowned Belgian scientist Jean Baptiste Ambroise Marcellin Jobard had deduced that the tars and oils produced from the distillation of coal, resin and fatty matter, were themselves a rich source of illuminant, if heated and introduced into water gas. Jobard worked at and was later director of the Museum of Industry in Brussels. He successfully experimented throughout 1833 with a method of enriching hydrogen gas produced using Döbereiner's lamp, a system which produced hydrogen gas through the reaction of zinc and dilute sulphuric acid. The experiments and gas produced by Jobard were reviewed by the Royal Academy in Brussels in 1834 and they confirmed the gas produced had a brighter flame than coal gas, but the economics of the process were uncertain, and they recommended a trial at a larger scale (Jobard 1846).

Jobard then constructed a larger apparatus including a gasometer and installed lighting in each room in his house. He passed the hydrogen gas through a cylinder containing gas tar oil, which took up vapours into the gas before entering the gasholder. He was concerned the gas would lose its illuminating power by the hydrocarbons dissociating from the gas after storage in the gasholder. He redesigned the process as follows. The coke was held in a vertical retort and heated until incandescent, into which steam was introduced, this gas was then mixed with gas produced by distilling tars, oils or fats. This would ensure that the hydrocarbons produced from distillation would be fixed in the final gas. Jobard took out a Brevet (license) in Belgium to cover this method of manufacture (Jobard 1846).

Jobard then travelled to Paris where he met and sold his invention to Alexander Selligue of Paris and Florimont Tripier of Lille for 10,000 francs and a third of the profits it generated. This was under agreement that Selligue was then recognised as the inventor (Jobard 1846).

Selligue's promoted a process where three cylinders were set in an upright position in a furnace, where they were heated to redness. Two of these were filled with wood charcoal, which could be replaced as required; the third cylinder was filled with chain and pieces of iron. A thin stream of water flowed into the first cylinder, and was converted there, in contact with the red-hot charcoal, into carbon monoxide and hydrogen, which process was completed in the second retort, in which a stream of shale oil was being decomposed by the red-hot iron (Spice 1875).

Under Selligue's name, the water gas process was introduced to Dijon, Strasbourg and Antwerp, as well as parts of Paris and Lyon (Jobard 1864, Anon 1861).

Selligue received a gold medal from the Society of Encouragement and the Academy of Industry. In 1839 he was to be awarded a gold medal from the Paris exhibition and the Cross of the Legion of Honour, however, Jobard was brought before the judging panel of eminent scientists including Guy-Lussac, and asked to explain his involvement, to which he showed his Brevet and Selligue was unmasked as a fraud, although Selligue did advance the method, with his own contribution (Jobard 1846). The fraud associated with the method made it lose popularity.

In 1839 Count John Alexander Phillip De Val Marino, was granted a British patent (No. 8126) for the production of gas from coke or charcoal, steam and oil in three vertical retorts each separately held within a single furnace. Each of the retorts being coke (or charcoal) filled and water or oil were dripped on to the hot coke to make water gas and enrich it with oil (Anon 1860). This design was identical or very similar to that of Jobard and there was also an Austrian variant of the patent held by Herr Offenheim (Anon 1861).

Val Marino constructed and lit three lamps on Berkeley Square, London, from his gas making plant which he demonstrated against lamps provided by the local gas company, the whole event being witnessed by HRH the Duke of Cambridge and Lord Grosvenor (Stewart 1960. Marino 1841, Torrey 1860).

The next significant development in water gas occurred in 1847 when Stephen White of Manchester took out a British patent (No. 11,654) for “A new means of producing gas, both as to apparatus and materials, from which the gas is produced”. His process had similarities to that of Jobard and Val Marino. White took out a second British patent in 1849 (No.12,536).

White’s idea was to produce a very rich gas, from fat, oil or tar, and dilute it to a reasonable candle power using a cheap, low-grade carrier gas. White’s success was boosted by favourable reports from Samuel Clegg and the renowned chemist Dr Edward Frankland. White’s method was tested on a large scale at a mill gasworks in Manchester and at the gasworks of the South Metropolitan Gas Company in London. Whilst these trials did not lead to permanent installations, White’s patented method was adopted as the original form of gas lighting in the town of Southport in Lancashire until 1853. The gasworks at Warminster, England adopted White’s process for gas manufacture (Fell 1904). The town of Petersfield in Hampshire, England, adopted White’s method but using coke instead of scrap iron in the central retort. White claimed that 60% more gas could be produced from his method than from conventional coal carbonisation (Newbigging and Fewtrell 1878, Richards 1877).

White’s usual method was to set the stop-ended retorts in a single setting (above one furnace). The central (water gas) retort contained hot iron scrap (or coke) onto which a trickle of water would fall, producing water gas. The other two ‘coal’ retorts made rich coal gas, being operated in the conventional way and receiving a supply of water gas by a connecting pipe from the mouthpiece of the central retort (Newbigging and Fewtrell 1878, Richards 1877, Fell 1904).

The gasworks at Warminster, England adopted White’s process for gas manufacture (Fell 1904). The town of Petersfield in Hampshire, England, adopted White’s method but using coke instead of scrap iron in the central retort.

The main failure of White’s process was the greater complexity of controlling this water gas process compared with coal gas. The relative amounts of rich gas and water gas produced had to be carefully controlled to ensure correct gas quality. Given the limited control available, its use led to continual variation in gas quality, which upset the consumers (spice 1875)

The process was exported, and in 1850 it was trialled over several months at the Philadelphia Gasworks (USA), but the results did not support full-scale adoption (Anon 1861).

Charles Blachford Mansfield applied for a British Patent (No.11,960) in 1847. His patent describes among other things, the "manufacture of bituminous substances which are so volatile that a current of atmospheric air, passed through them at ordinary temperatures, will when ignited, continue to burn with a luminous flame till all, or nearly all, such substances are consumed." The process simply vaporised flammable substances into air, which could then be burnt to produce light. An advert for this process is shown in Figure 2.30 in Volume 1. It was relatively successful and received some limited use in Britain and abroad (Richards 1877, Anon 1860).

Joseph Gillard made major advances in his works at Narbonne, France in 1856. He constructed a cupola like those found in iron foundries of the time, which was filled with coke or charcoal, and when the fuel was ignited and brought to a state of incandescence by a fan or blower. It was then sealed to the atmosphere and steam injected, an exhauster then extracted the hydrogen and carbon monoxide by an exhauster. This process, then was repeated and formed an intermittent process. This manufacture was however too expensive and became uneconomic. Another innovation used by Gillard was the use of the water gas with argand burners to heat platinum wire cage mantles. The blue coloured water-gas flame heated a platinum wire cage which was extended a little above it. The platinum cage incandesced when heated producing a bright light. It was used to light Narbonne and a few small French towns. The high price of platinum made the cost effectiveness of this process very poor, and it failed. (Von Klinckowstroem 1959, Fell 1904, Stewart 1958, Hughes and Richards 1880).

The term 'blue-water gas' came from the fact that the water gas burnt with a blue flame which produced little light, so was no use for lighting purposes on its own. The blue colour was due to the complete combustion of hydrogen and carbon monoxide in the water gas, the latter burning a pale blue colour. When coal gas was used for lighting, soot formed from the incomplete combustion of the organic compounds in the gas. When soot particles entered the flame front of the gas burner they glowed, emitting bright white light.

Further developments in water gas were undertaken in America by Dr J. M. Sanders. In 1858, he constructed a gas plant in Philadelphia consisting of an L-shaped cast-iron retort (Figure 3.122, No. 1) which was heated from beneath by a furnace (Figure 3.122, No. 2). The retorts were filled with charcoal heated and superheated steam together with melted rosin (a form of resin obtained from pine and some other plants) which was injected into the top of the retorts via a pipe (Figure 3.122, No. 3). The gas produced from the process was 10% more expensive than coal gas, it was not stable, and the retorts deteriorated rapidly, these factors prevented the adoption of this process commercially (Meade 1921). Similar work had also been undertaken by Mr Brown of Baltimore and Mr Aubin of Albany in the 1850s (Anon 1860).

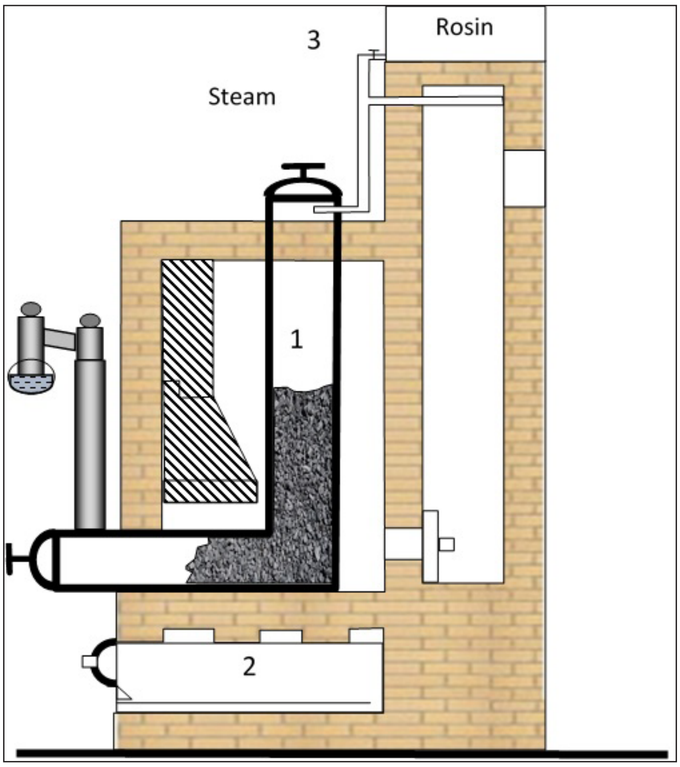


Figure 3.122 The Design of the Sanders Water Gas Apparatus. Source R. Thomas.

In the 1870s, Mr Robert Paulson Spice made water gas in horizontal retorts at a gasworks he leased in Chichester (England) for experimental purposes. He went on to build a large water gas plant at Wormwood Scrubs, London in 1874. It provided gas to the Great Western Railway Company, its hotel and some adjacent buildings. This gas plant used 6 vertical retorts developed for Scottish shale-oil practice. Spice referred to the furnaces as slow combustion furnaces, which he filled with coke breeze, he filled the retorts with a mixture of coke breeze and clinker from the furnaces, to save cost (Spice 1875).

Although the process was successful, the gasworks' lease reverted to the Great Western Railway in 1880 and the water gas plant was no longer used.

No practical gas making plant was developed until the separate work of two engineers in the USA, Strong and Lowe were undertaken *circa* 1873. These developed Intermittent water gas plants, the method which found the greatest use in the industry (Meade 1921, Stephenson 1916). This document provides a description of some of the major types of water gas plant used in England.

3.4.2.2 Different Systems Used for the Manufacture of Water Gas

A wide range of different systems were developed to manufacture water gas, many were unsuccessful, impractical or unpopular. Systems for making water gas could be classified under three headings: (1) The Intermittent System; (2) The Continuous System; (3) The Neat-Oxygen Method. In reality, only the intermittent system was a commercial success, however, short descriptions of the others are provided for historical reference (Meade 1921).

The intermittent system operated with ‘run’ and ‘blow’ phases, each succeeding the other at regular intervals. This was the most widely used and thought to be the only practicable method (Meade 1921). This is described in detail later in this section.

The continuous system for manufacturing water gas received considerable interest in the early history of its development. It was believed that a continuous process would be more efficient. The coke was to be heated externally such as described in the Jobard/Selligue process and enable the continuous production of gas. It suffered from practical difficulties due to problems with heat transfer and general process inefficiency (Meade 1921).

The last method which was investigated, was the neat oxygen method which produced a gas practically free from nitrogen, but it contained 65-70 per cent carbon monoxide, a toxic gas and considerably higher quantity than found in coal gas. Steam would be injected into the base of the generator along with a stream of pure oxygen. Whilst steam combined with a portion of the carbon to form water gas, the heat lost by the endothermic reaction was replaced by the exothermic combination of the oxygen with the carbon. If steam and oxygen were regulated correctly, the process would work effectively; its drawback was the difficulty obtaining pure oxygen economically (Meade 1921).

Whereas the manufacture of gas from coal was referred to as carbonisation (converting the coal to almost pure carbon in the form of coke), all water gas processes were referred to as gasification processes where the fuel (coke/oil) was converted to gas, leaving only waste mineral matter as ash and clinker.

3.4.2.3 The Development of Intermittent Water Gas Plants

Intermittent water gas systems were introduced *circa* 1873 when two similar methods were developed in the United States: the ‘Strong process’ and the ‘Lowe process’. These systems were both based on alternate periods of ‘run’ and ‘blow’, which are described in more detail later within this section.

The Strong process employed a high generator made from firebricks and two secondary chambers also packed with firebrick. These latter chambers, heated up during the blow, were employed as superheaters for the steam. Strong aimed purely at making a gas suitable for heating.

The intention of Thaddeus Sobieski Coulincourt Lowe was to make a gas for illumination purposes. Lowe was aware that water gas would not produce a suitable light for illumination. Lowe was a brilliant scientist who had been drawn into producing gas for balloons during the American Civil War (Norman 1922).

In 1874 Lowe’s original idea had been to spray oil on the hot coke in the generator to gasify it. The oil would enrich the gas to give it illuminating properties. Lowe’s original design consisted of a generator, a brick-lined cylindrical vessel (labelled 1 on Fig 3.123), the outer shell of which was constructed from wrought iron (Stewart, 1957). Fuel was placed on a metal grate in the base of the generator above a closed ash-pit. Air and steam were introduced alternately into the generator in cycles. The injection of air heated the generator through combustion of the coal. The steam was injected into the generator to produce water gas and oil would have also been injected into the fuel bed. The oil enriched water gas was then passed on to a large superheater (Labelled 2 on Fig 3.123), which was packed with firebricks and was designed to fix the oil in the gas. (Stewart 1958, Anon 1950, Meade 1921).

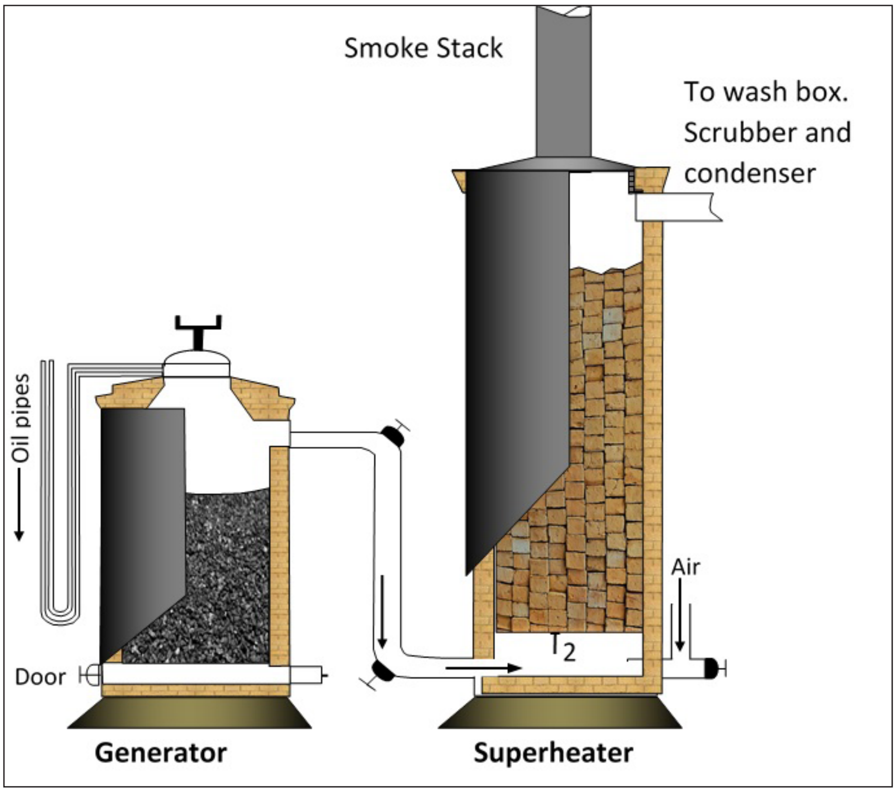


Figure 3.123 The Lowe Water Gas System. Source R. Thomas

Not achieving the results, he wanted, Lowe, perhaps influenced by Strong's design, revised his plant in 1882 to incorporate two chequer-brick filled chambers after the generator (Stewart 1958). Both chambers were heated from the combustion of the hot gas from the generator. The first chamber was called the carburettor, located between the generator and superheater. This was a similar brick-lined vessel to the superheater, but as the gas passed through this vessel, oil was sprayed onto the hot firebricks and gasified. As the gas then passed into the superheater the oil sprayed into the gas was fixed. The later design of Lowe's plant design was very similar to that employed in later water gas plants. This new process was highly effective and coincided with the availability of cheap naphtha and oils in the USA which could be used to enrich the gas (Stewart 1958, Meade 1921).

These oils had become available as lamp oils and lubricating oils from the growing petroleum industry which developed in the USA. This oil enriched process became known as the Carburetted Water Gas (CWG). In the US market with cheaply available oil supplies, CWG soon took a considerable portion of the manufactured gas market. Lowe's main contribution was probably his approach to constructing the plant from refractory material held within a steel shell; this gave the plant both the required amount of rigidity and flexibility to cope with the temperature changes caused by the cyclical nature of the intermittent process (Stewart 1958, Meade 1921). At the same time as Lowe but independent from him Tessie Du Motay had also devised a generator retort system which produced hydrogen gas which was enriched by passing it through a naphtha vaporiser and subjected again to heat in a second retort to fix the gas (Stephenson 1916 p12-13, Norman 1922).

The first water gas plant built in Britain was a small plant erected for Samson Fox at the Leeds Forge in 1887-88. Fox, hearing of a successful water gas plant constructed in Germany for Messrs. Schultz, Knaudt, and Company at Essen, who used the gas successfully for welding tubular boilers and lighting by incandescent devices which were relatively new at the time. Having had the process investigated, Fox acquired the British rights to the patents covering this and the other processes then in use and had a similar water gas plant installed in the Leeds Forge works (Figure 3.124) works in 1887 (Lewes 1900, Lewes 1907).

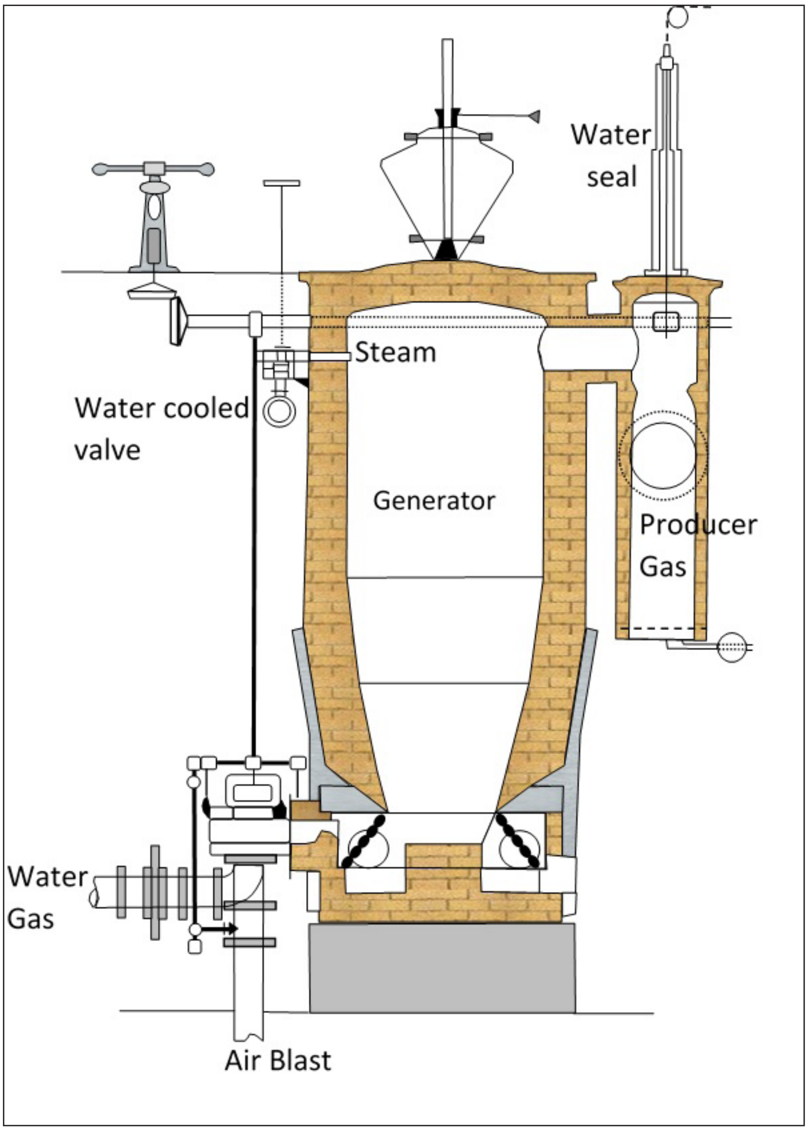


Figure 3.124 The Water Gas Plant constructed at the Leeds Forge Company works for Samson Fox. Source R. Thomas.

The plant was a simplified version of the Lowe generator and consisted of a cylindrical vessel constructed from boiler plate and lined with firebricks, the cylinder narrowed towards the base. The fuel (coke) would fall to the bottom in a cone, leaving an annulus around it which the air would alternately pass into the fuel and escape from it. Connected with the annulus through a port in the brickwork was the valve chamber, which was cooled by circulating water, and is provided with three passages, through one of which the air passed, and through another the gas escaped, the centre passage being in connection with the generator. The system worked effectively as a gas producer which was operated as an intermittent water gas plant, with cycles of steam injection and air injection to reheat the fuel bed (Sexton 1905). As in Essen this plant was used for welding, it also found use in lighting and heating. It's use at the Leeds Forge ended in Tragedy whereby two workmen were overcome by carbon monoxide poisoning from gas escaping from unlit gas lamps. The high percentage of carbon monoxide in water gas made it more toxic than coal gas (Blyth 1895, Lewes 1900, Lewes 1907).

Despite these deaths, this method of gas production was promoted by British Water Gas Syndicate in 1888 with Samson Fox being elected its chairman. Fox a wealthy businessman who had made his fortune from the Leeds Forge and its capability for specialist forging of corrugated boiler flues and building pressed steel underframes for railway wagons (Anon, 1895a).

The British Water Gas Syndicate was composed of sub-syndicates which included the North British Water Gas Company Limited, Nottingham and Derbyshire Water Gas Company Limited and the Yorkshire and Lancashire Water Gas Company Limited. Although the syndicate owned several patents, unfortunately the fortunes of the syndicate were not good, and it eventually led to an amalgamation of all the syndicates into the Amalgamated Water Gas Company Limited in 1893 but unfortunately this fared little better and was liquidated in 1898 (Anon 1895a).

The British Water Gas Syndicate had originally targeted the domestic gas market, which could have worked if the Welsbach gas mantle had been developed further by this time, whereas the gas at the time was only suitable for industrial use (Parker, 1925). A lot of people lost money from venture and it harmed Samson Fox reputation, although it was reported he had tried to compensate those who had lost out financially.

Separately in 1889 an American named Van Steenburgh came to England and erected a plant for the manufacture "carburetted hydrogen," at Humphries Hall in Knightsbridge, London. This small plant consisted of a water gas generator which had a port into which volatile oils could be injected on to the incandescent fuel, which gave a gas with a suitably high luminosity. This demonstration caught the eye of many gas managers, because it coincided with the rapid increase in the cost of cannel coal which had been added to common gas coal to enrich its luminosity (Lewes 1907).

Hearing that various forms of water gas apparatus were being used in the USA, George Trewby, the Chief Engineer of the Gas Light and Coke Company (GLCC) was dispatched to America to investigate the different systems in use there. Importantly Trewby visited the United Gas Improvement Company of Philadelphia.

The United Gas Improvement Co (UGI) was incorporated in 1882 in Philadelphia, Pennsylvania to exploit the new patented process of water gas manufacture developed by Lowe (Anon 1917, Edwards 1992).

UGI manufactured, sold and installed equipment needed for the Lowe process. The company also leased the production and distribution facilities of existing gasworks, operated the plants and sold the gas. UGI moved into the supply of gas and electricity, eventually moving away from the manufacture of gas, and into natural gas. The company still exists in the form of the UGI Corporation.

Whilst UGI was very big in the American market, it had limited interest in the European market. As a result, two 14,000 m^3 (0.5m ft^3) per day plants were ordered by the GL&C Co. Arthur Glasgow (Figure 3.125) was dispatched by UGI to assist the GLCC to commission the water gas plants which were to be built at Beckton, near London. On Glasgow's return to the USA, he tried to persuade UGI to expand into Europe, without success (Edwards 1992).

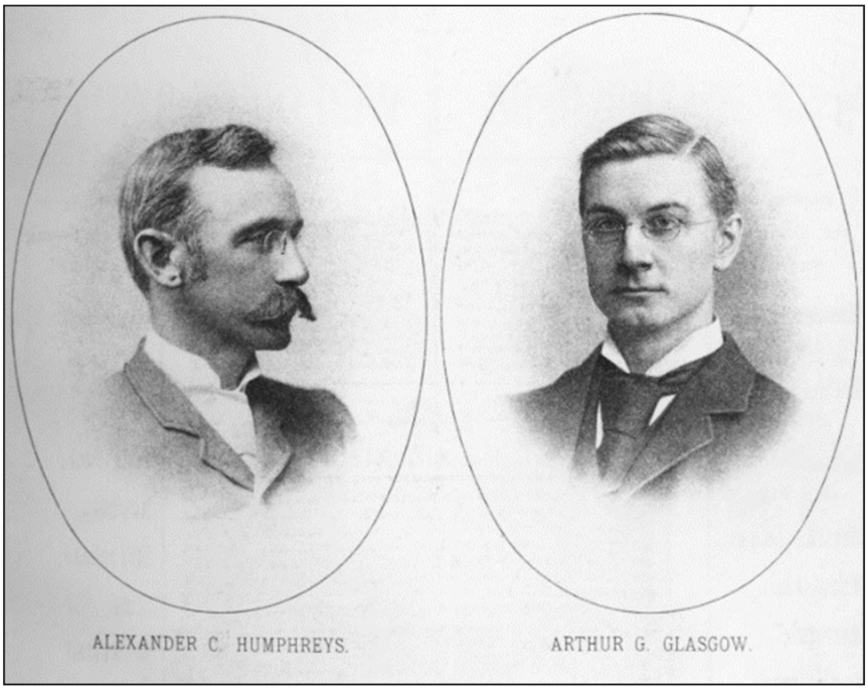


Figure 3.125
Dr Alexander Humphreys and Arthur Glasgow, founders of Humphreys and Glasgow. Image courtesy of IGEM Archive.

Glasgow then persuaded Dr Alexander Humphreys (Figure 3.125), then a senior UGI executive, to set up Humphreys and Glasgow in London in 1892. Both were American and experienced gas engineers; Dr Humphreys having undertaken much of the pioneering work on water gas at UGI. Humphreys and Glasgow (H&G) had an agreement with UGI to use its patents and any improvements developed (Edwards 1992).

H&G became the major player in the British and European market. H&G's first contract was to build two water gas plants in Copenhagen. Its first contract in the United Kingdom was at the Belfast Corporation gasworks in Northern Ireland. H&G established operations in London, Brussels and New York. It was very successful, and its gas plants were to be installed all over the world. By 1898, it had undertaken 91 water gas plant installation projects and by 1914 had installed 1,303 water gas plants across the world. H&G prospered until the 1960s, with many contracts from the area Gas Boards in post-war Britain. The company diversified into petrochemicals, but its fortunes declined as Britain switched to natural gas (Edwards 1992).

The Power Gas Corporation was a public company formed in 1901 to acquire the patents of Dr Ludwig Mond and the United Alkali Company. These patents related to the production of Mond Gas, as described in Section 3.4.1.3. They later became a competitor of H&G and produced many British water gas plants as well as producer gas plants and later expanded into petrochemical technologies.

Many other companies produced water gas plants (e.g. R & J Dempster built Dellwik plants in the UK) and some of these are also featured in this document. Plant were built at all sizes even suitable for smaller gasworks (Figure 3.126).

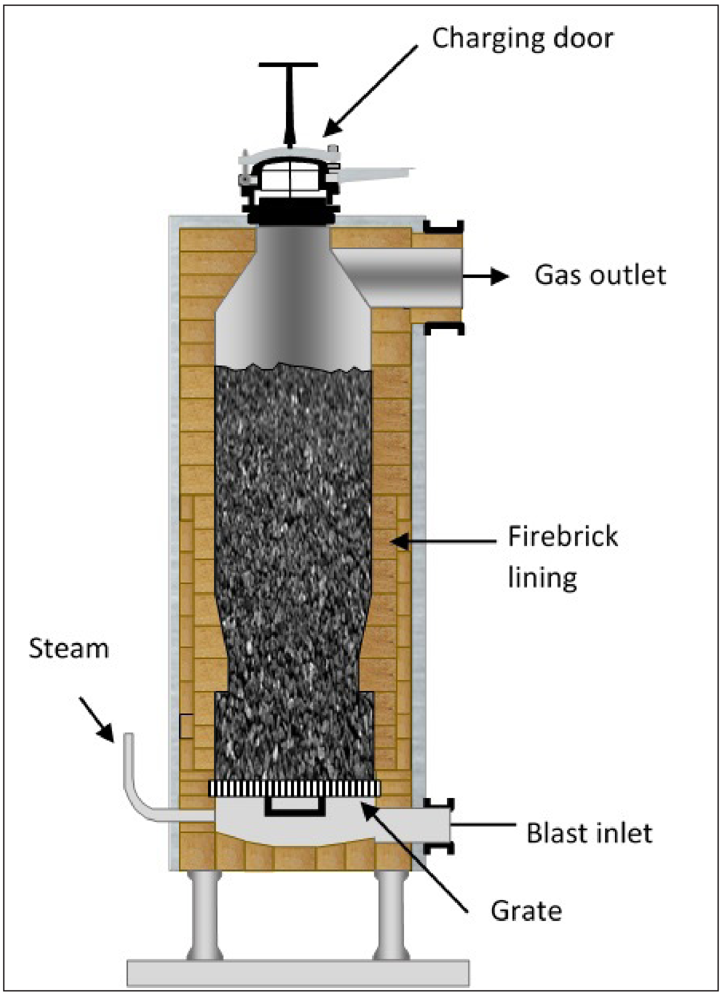


Figure 3.126 A hand-clinkered water gas generator, typical of those used on smaller gasworks. Source R. Thomas.

In Britain, water gas allowed the gas undertakings to meet peak gas demand whilst utilising by-product coke and enabling some control over the price of coke by reducing its supply. Most medium and large town gasworks in Britain operated water gas plant at some point during their operational history. The water gas process generated gas through the action of steam upon red-hot carbon (generally in the form of coke). The generator (see Figure 3.126) would be filled with fuel, ignited and brought to temperature through the 'blow' phase. Once brought to temperature, the system would enter the 'run' phase and steam would be admitted (Anon 1950).

The gas was produced on the principle that heated carbon acted as a reducing agent for the steam as it passed through, the oxygen in the water combining with the carbon and giving off hydrogen gas (the oxygen having a greater affinity for the heated carbon than for the hydrogen).

3.4.2.4 The 'Run' and 'Blow'

The 'run' and 'blow' were the principal components of the intermittent manufacture of water gas, each working in sequence to produce the water gas in a cyclical fashion. The object of the blow period was to store the maximum quantity of heat in the generator fuel bed. This hot fuel bed, which usually consisted of coke (coal could be used) was then used in the endothermic steam : carbon reaction during the run stage (Meade 1916 p469-511, Anon 1950).

During the blow, air was pushed by fans (Figure 3.127) into the base of the fuel bed, providing oxygen to allow the fuel to burn and heat the generator.

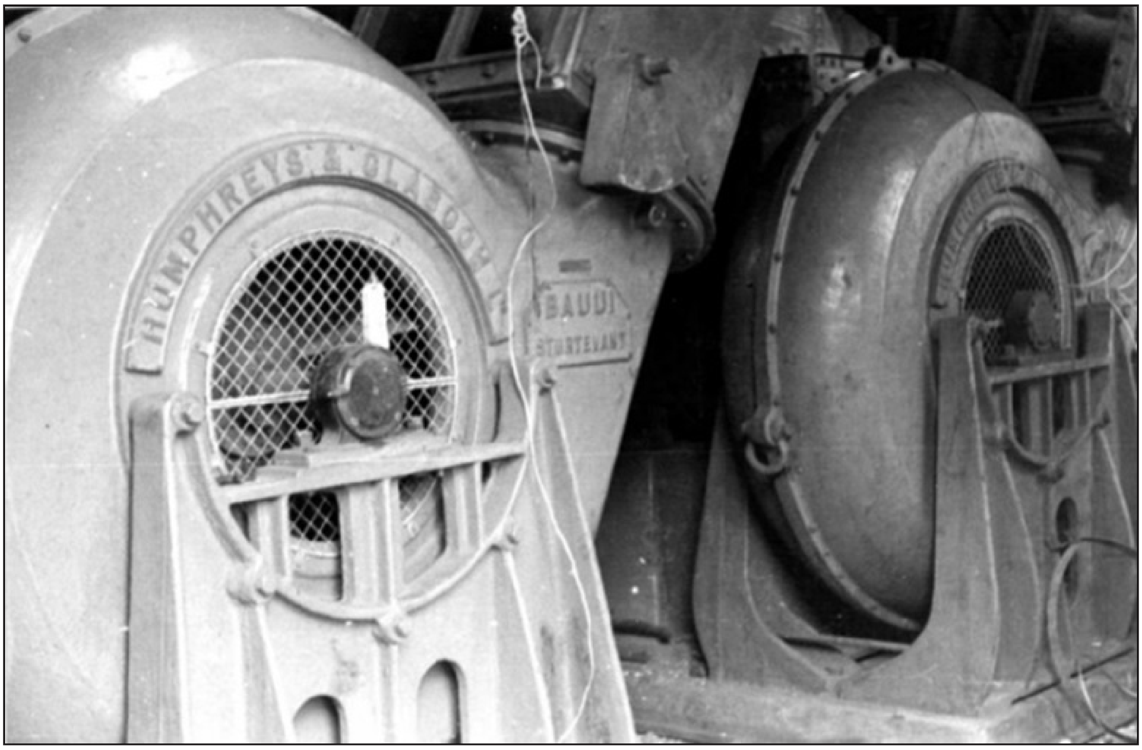


Figure 3.127 Blowers (fans) used to provide the blast air on an H&G Water Gas Plant. Image courtesy of the National Grid Gas Archive.

The following reactions occurred within the fuel bed, which overall were highly exothermic.

(i) $C + O_2 \rightarrow CO_2$ - exothermic

(ii) $C + CO_2 \leftrightarrows 2CO$ - endothermic

(iii) $2C + O_2 \rightarrow 2CO$ - exothermic

(iv) $2CO + O_2 \rightarrow 2CO_2$ - exothermic

This would form carbon dioxide in much larger proportions compared to carbon monoxide. As the carbon dioxide rich gas passed through the remainder of the hot fuel bed, some of it was partially reduced to carbon monoxide. This was formed by a secondary reaction between the carbon dioxide and hot carbon which was endothermic, in effect cooling the generator. For this reason, the presence of large amounts of carbon monoxide at this stage was not desirable (Meade 1916 p469-511, Anon 1950).

The gas exiting the generator was like a poor-quality producer gas which would be burnt in the subsequent carburettor and superheater, heating them. Burning carbon to carbon dioxide released about three times as much heat as when it was it was burnt to carbon monoxide only (Meade 1916 p469-511, Anon 1950).

As the blow proceeded, the temperature of the fuel bed increased, raising the amount of carbon monoxide in the gas leaving the generator. The blow had to avoid excessive combustion of the carbon (coke), so the amount of air supplied was carefully controlled. By the end of the blow phase, the generator, carburettor and superheater would all be sufficiently hot for the run to take place (Meade 1916 p469-511, Anon 1950).

During the run, steam was injected into the generator, which reacted with the hot carbon. As the run proceeded, the fuel bed started to cool, and gradually the proportion of carbon dioxide in the gas produced increased. This had the effect of increasing the amount of inert substances in the gas, reducing its heating qualities (Meade 1916 p469-511, Anon 1950).

During the run, within the lower part of the fuel bed, the water (steam) reacted with the heated carbon forming carbon dioxide, and some carbon monoxide as shown below.

(i) $C+2H_2O \rightarrow CO_2 +2H_2$ - endothermic

(ii) $C + H_2O \rightarrow CO +H_2$ - endothermic

The carbon monoxide generated could also react with the steam, forming carbon dioxide and hydrogen, which was an exothermic reaction:

(iii) $CO + H_2O \rightarrow CO_2 + H_2$ - exothermic

As the carbon dioxide formed passed up through the bed of coke, it was reduced by further hot carbon higher up the fuel bed forming carbon monoxide through an endothermic reaction:

(iv) $C + CO_2 \leftrightarrows 2CO$ - endothermic

This reaction was reversible, and the amount of carbon dioxide converted to carbon monoxide was highly dependent on changes in pressure and temperature. A decrease in pressure and increase in temperature made the formation of carbon monoxide preferential; whereas if this was reversed, the formation of carbon dioxide was preferential. At 850°C, the reaction forming carbon dioxide was found to proceed 166 times more rapidly than the reverse reaction (Meade 1916 p469-511, Anon 1950).

A schematic of the H&G water gas plant is shown in Figure 3.128.

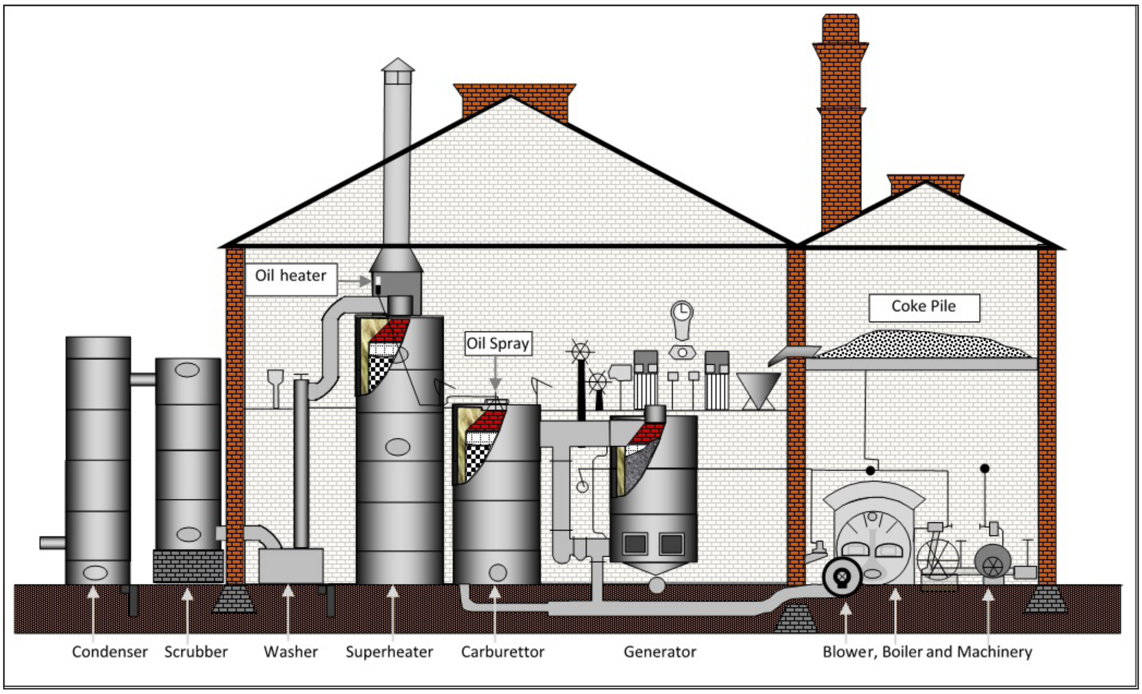


Figure 3.128 A schematic of a carburetted water gas system based on the Humphreys and Glasgow design. Source R. Thomas.

3.4.2.5 Down Run

If steam was continually admitted to the base of the generator, the lower portion of the fuel-bed (which had continually to perform the heaviest duty of decomposing the steam) became too cool and inactive over time, and the steam condensed instead of being converted into gas. The succeeding blow, therefore, further chilled the lower layers of the fuel bed instead of rekindling the fire (Meade 1916 p469-511, Anon 1950).

To rectify this, one of the developments introduced by Dr Humphreys was the ‘down run’. He discovered that the control of the water gas generator and the management of the clinker could be greatly improved if the operation of the generator was periodically reversed. After every few runs, the steam was admitted to the top of the generator above the fuel and it descended through the fuel bed and was withdrawn at the bottom. Following this, the gas flowed to the carburettor as usual (Meade 1916 p469-511, Anon 1950).

3.4.2.6 Types of Intermittent Water Gas Plant

A wide variety of water gas plants were developed and sold commercially. The main difference between these plants was whether they produced raw ‘blue’ water gas or enriched ‘carburetted’ water gas (CWG). The blue gas was purely an unenriched gas comprising primarily of carbon dioxide, carbon monoxide, hydrogen and nitrogen. It derived its name from the blue colour of the flame, which gave little light. Many plants originally built as blue-water gas plants were later retrofitted with a small carburettor, enabling them to yield enriched CWG gas (Meade 1916 p469-511) .

The CWG produced the same blue water gas initially, but it was then enriched by oil (and in some cases resin or tar) to improve its calorific value and illuminating power. This enriching process is described later.

Blue water gas had a calorific value of 290-300 British Thermal Units per cubic feet (Btu/ft^3) equivalent to 10.8-11.1 MegaJoules per metre cubed (MJ/m^3). The enriched CWG had a calorific value of approximately 380-500 BTU/ft^3 (14.1-18.6 MJ/m^3); by comparison, natural gas which is currently used in Britain has a calorific value of between 1009-1154 BTU/ft^3 (37.5 MJ/m^3 to 43.0 MJ/m^3).

Water gas was originally seen as a cheap and quick method of producing gas, but if CWG was to be produced, its economics became heavily reliant on the cost of oil. Whilst in the early years of its development a plentiful supply of gas oil was available, this later diminished when motor vehicles used this fuel. The oil-enriched CWG was more important when gas was predominantly used for illumination.

Later, when the illuminating properties of gas were not so important, unenriched blue water gas became more popular, especially at times when oil costs were high.

3.4.2.7 Blue Water Gas Plants

Two popular blue water gas plants were those built by Kramers and Aarts (K and A, Figure 3.129), and the Dellwik plant (Figure 3.130).

The K and A Plant (Figure 3.129) had two generator vessels as opposed to the single generator vessel used on the Lowe-type system. During the run, the generators were used in series, while during the blow they were used in parallel; this reduced the duration of the blow to a quarter of that used on a Lowe-type plant, allowing more gas to be produced (Meade 1916 p478-481).

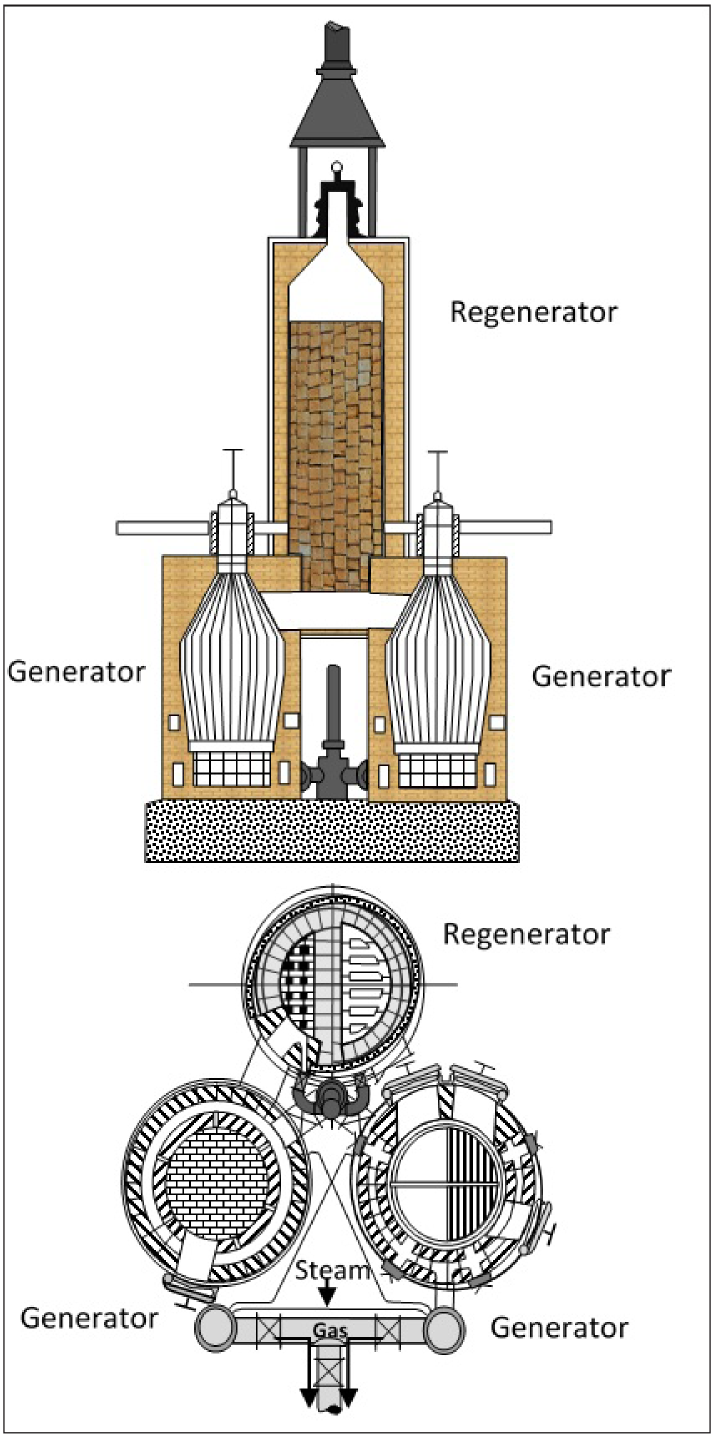


Figure 3.129. A Schematic of Kramers and Aarts Blue-Gas Plant. Source R. Thomas adapted from Meade 1916.

In addition to the two generators, the K and A plant also had a regenerator. During the blow phase, the regenerator was heated through the passage of hot gases from the generator. During the run phase, steam was introduced into one of the generators where it would undergo the water gas reaction, forming hydrogen, carbon dioxide and carbon monoxide and then entered the regenerator (Meade 1916 p478-490).

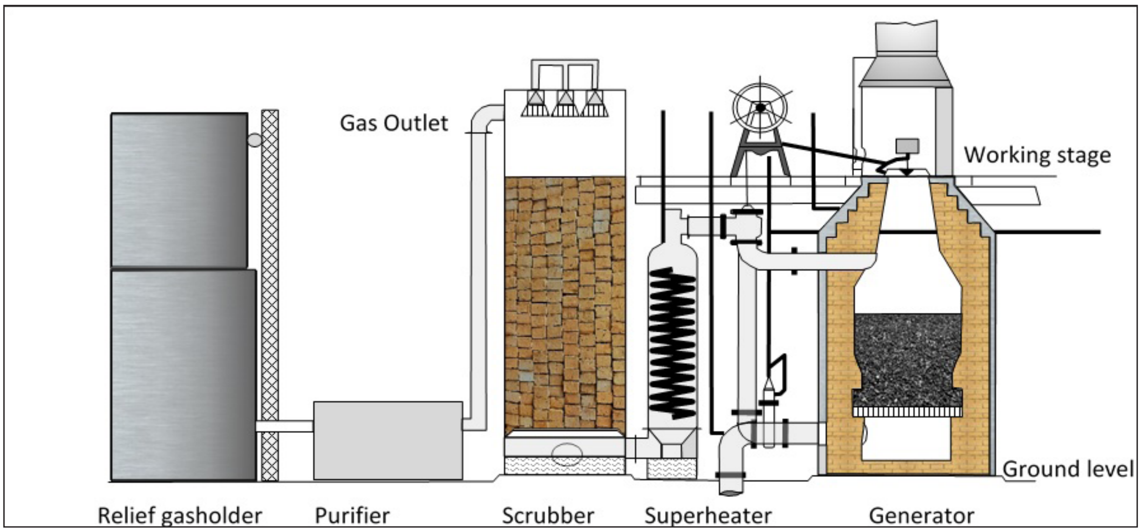


Figure 3.130 The Dellwik Blue-Gas Plant. Image produced by R. Thomas, adapted from Meade 1916.

Within the regenerator, any surplus steam was also converted into hydrogen and the gas superheated; from here, the gas passed through to the second generator where hot coke reduced the carbon dioxide to carbon monoxide.

When the plant was run again, the direction of flow through the system was reversed, making the final generator the first generator and *vice versa*. K & A plants were supplied in Britain by the K & A Water Gas Co. Ltd. of London. The Dellwik blue-gas plant developed by Karl Dellwik produced a gas which was very similar in composition to the K and A plant, but the plant was structurally very different, using a single generator preceded by a superheater. The latter heated the steam before it passed into the generator. The gas then passed directly from the generator to the superheater, and then through a coke scrubber. Karl Dellwik was known for his work in restructuring the air supply to the water-gas plant. This minimised carbon monoxide production during the blow, increasing the heat generated in the water-gas plant during the blow and maximising the amount of water gas production during the run. Dellwik plants were built by R & J Dempster of Manchester in Britain.

Another type of water gas plant was the Simplex plant. Designed as a low-cost method of producing gas quickly, it was primarily suitable for smaller gasworks (Meade 1916 p478-490).

Unlike other water-gas plants which used oil in the carburettor, the Simplex plant used tar. The Simplex plant was also built without an outer steel shell, just brickwork. These plants were produced in Britain by the Vertical Gas Retort Syndicate Ltd of London.

A variation of the water-gas plant was the single superheater plant (SSP) which varied significantly from the traditional layout shown in Figure 3.128 for the Humphreys and Glasgow plant. In the SSP, the carburettor and superheater were merged into a single large vessel, similar to the original plant developed by Lowe and shown in Figure 3.123. One of the benefits of this plant over the Lowe-type water-gas system was the reduced capital expenditure (Meade 1916 p469-511).

As CWG plants developed they were increasingly automated reducing the amount of labour required to operate them. Such an example of this design is shown in Figure 3.131, with the Humphreys-Glasgow Labourless CWG plant.

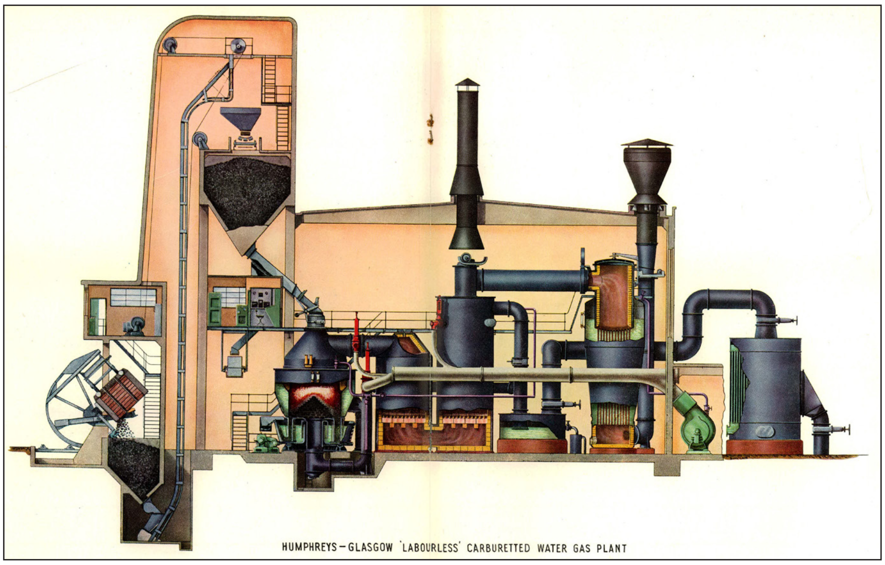


Figure 3.131 Humphreys-Glasgow Labourless Carburetted Water Gas Plant Circa 1950. Image courtesy of National Grid Gas Archive.

3.4.2.8 The Operation of an Intermittent Carburetted Water-Gas Plant

There were many different configurations of a CWG plant. The following section describes the key plant involved in the CWG making process.

A typical CWG apparatus is shown in Figures 3.128 and 3.135, consisting of a generator, carburettor, superheater, oil heater, washer and condenser. The cylindrical generator, carburettor and superheater all looked similar, the outer shell of the units constructed from steel plates and lined with firebricks. A more modern CWG plant from circa 1950 can be seen in diagrammatic form in Figures 3.131. A flow diagram of the CWG process can be seen in Figure 3.132.

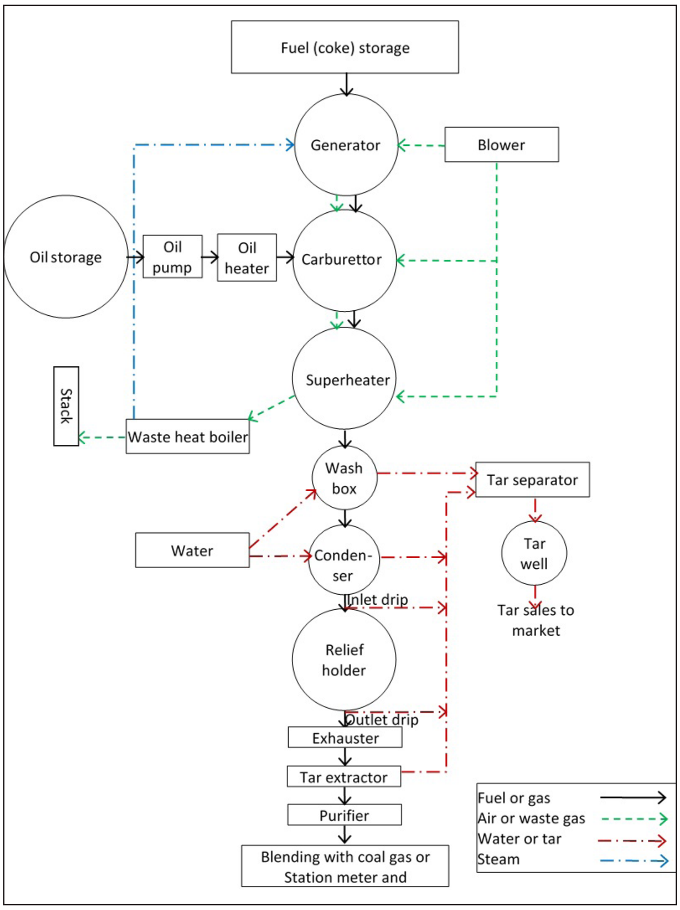


Figure 3.132 Material flow sheet for a carburetted water-gas plant. Source Lowry, H.H, Water Gas, Chemistry of Coal Utilisation, 1945. Adapted by the R. Thomas..

3.4.2.9 Generator

The function of the generator was to contain the fuel bed which, as described earlier, was used for heating the system and generating incandescent carbon to decompose the steam during the run. These processes and reactions have been described already so will not be described further here.

The generator was quite simple in design, being a circular vessel lined with firebricks. It contained a grate at its base supporting the fuel bed, underneath which were two pipes, one which supplied steam and one which supplied blast air.

At the top of the generator was a charging door through which fuel could be added. Below this was the outlet through which the gas was removed. The grate was a very important feature of the generator, as removing the ash could be problematic, especially if clinker formed instead of ash, as it often did. The clinker would affect the reactions in the fuel bed and reduce the amount of control which could be exerted on the system (Meade 1916 p469-511, Anon 1950).

Removal of clinker by hand was very arduous and could reduce the amount of time the generator was making gas by 10%, as well as giving rise to additional unwanted heat loss. A diagram of a simple hand-clinkered water-gas unit is shown in Figure 3.126. Most CWG plants producing over 28,000 m^3 (1m ft^3) of gas per day were mechanically operated with a self-clinkering grate. *Circa* 1948, mechanically operated plant with a capacity of 280,000 m^3 (10m ft^3) of gas per day were routinely being used at large gasworks (Meade 1916 p469-511, Anon 1950).

Whilst the grate in a hand-clinkered unit was little more than a set of iron bars, a Kerperley-type grate was used in a self-clinkering unit. These had the appearance of a pyramidal or cone shape (Figure 3.133). The grate was mounted eccentrically on the generator base. The base plate and the grate rotated slowly and, as this happened, the clinker and ashes were crushed in the annulus between the grate and generator wall. The crushed ash was removed by a stationary plough dipping into the outer water seal. The base of the generator had water lutes internally and externally, providing a water seal (see figure 3.133). The depth of the water seal was dependent on water pressure. Where high blast pressures were used, a dry seal (Figure 3.134) was preferable as deep water seals could surge under high pressure (Meade 1916 p469-511, Anon 1950).

The dry grate used a revolving motion of a different design to sweep ash into compartments for its collection (clinker pocket). On dry grates, the base of the generator was surrounded by a water jacket which prevented clinker sticking to the lower part of the generator and blocking the fuel bed, whilst serving as a boiler for steam production. Given the available fuels for gasmaking, the wet seal was preferred for use in British water-gas plants.

The firebricks within the generator were prone to wear and tear, therefore generators would have an inner lining (to take the wear and tear) and an outer lining (to act as an insulator) of fire bricks. This double layer often only extended two thirds of the way up the fuel bed, to avoid disturbing the latter (See Figure 3.126).

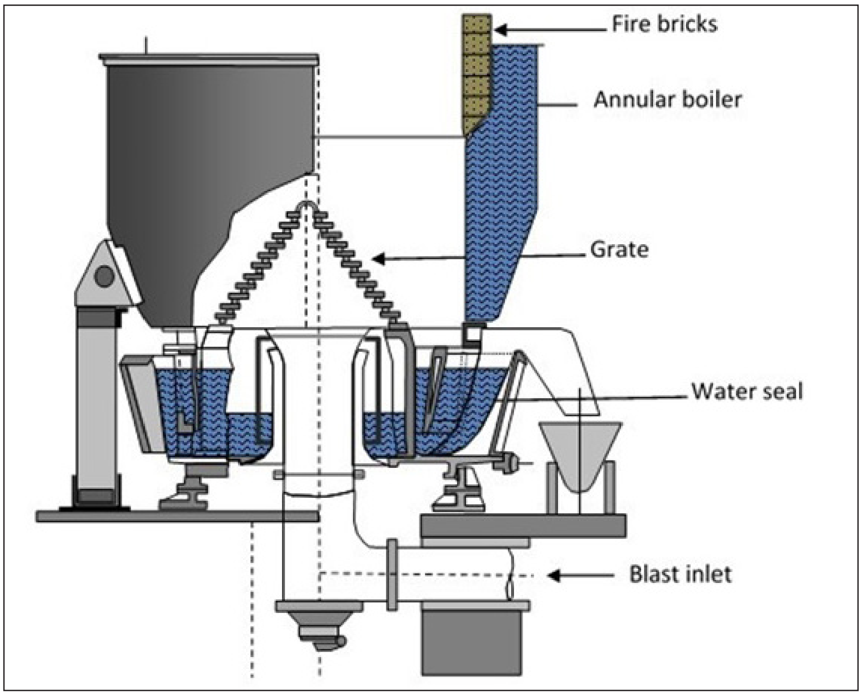


Figure 3.133 A Water-Sealed Self-Clinkering Grate. Source R. Thomas - adapted from Anon 1950.

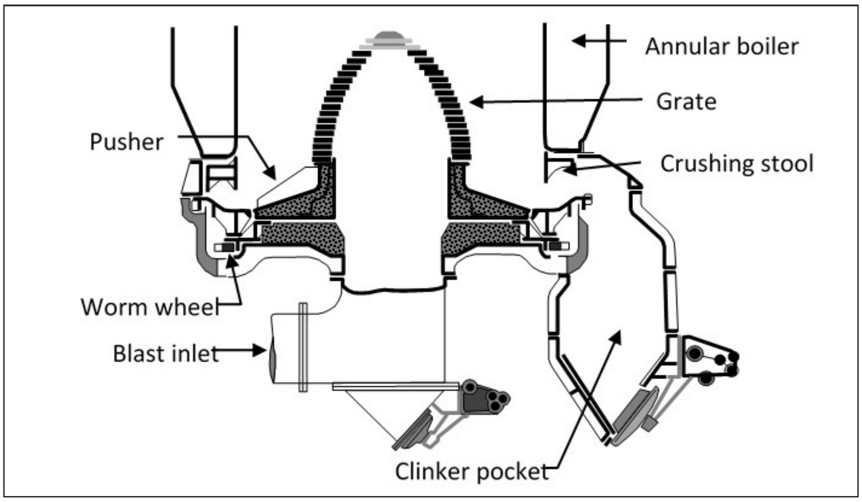


Figure 3.134 A Humphreys and Glasgow Dry-Sealed Grate. Source R. Thomas.

There was a gap of between 2-5cm (0.8-2 inches) between the outer firebricks and the steel outer shell. This was filled with asbestos, slag wool, silocel or celite and it allowed the lining to expand on heating. If possible, large bricks were used to reduce the number of joints required. Joints were areas where clinker would more readily adhere to the walls of the generator. There was, however, a limitation to the size of the brick, as above a size of approximately 22cm (9 inches) they had a tendency to crack and spall (Meade 1916 p469-511, Anon 1950).

A layout of the upper floor of a CWG plant can be seen in Figure 3.135, which shows the upper floor of the former CWG plant built at the St. Martins at Palace gasworks in Norwich.

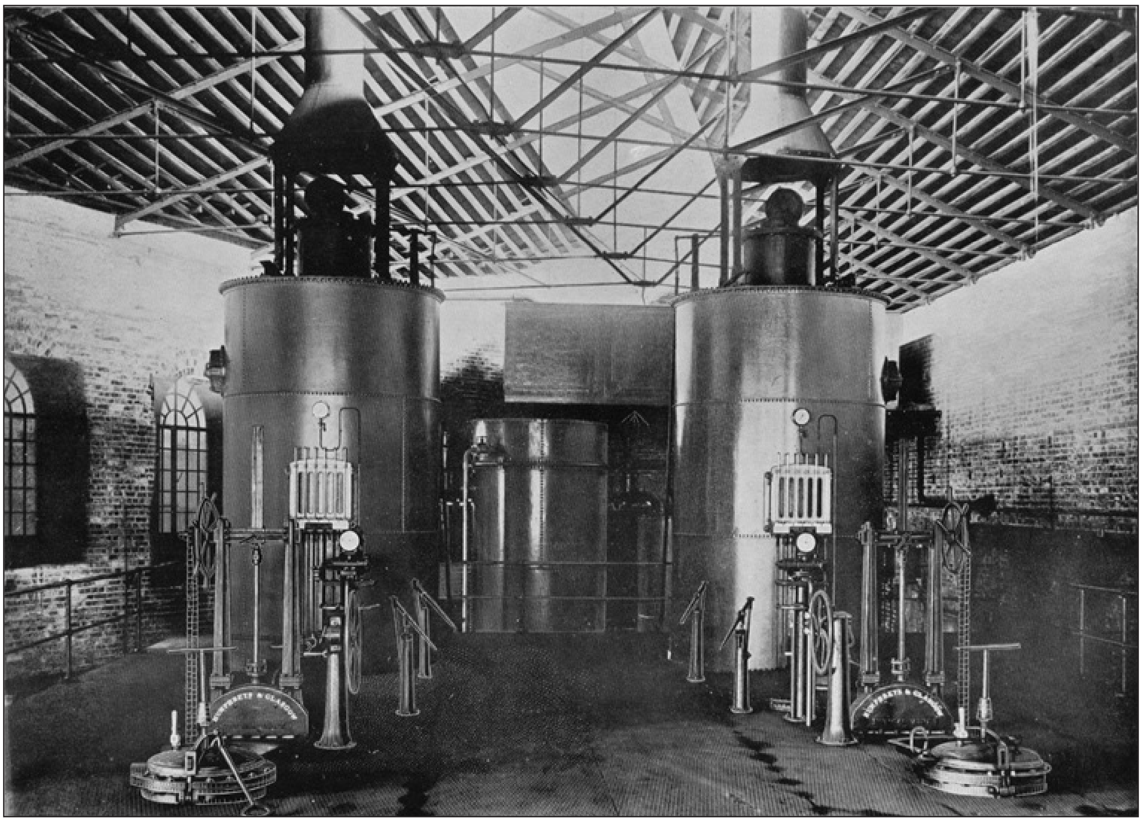


Figure 3.135 A Humphreys and Glasgow CWG plant, Norwich, St. Martin at Palace gasworks. Image courtesy of IGEM Archive.

3.4.2.10 Carburettor

Both the carburettor and superheater were filled with firebricks arranged in a chequerboard pattern. During the blow, the firebricks in both were heated by the hot gases carried over from the generator and from the combustion of any gases which were not burnt in the generator. A centrifugal oil spray was fitted in the top of the carburettor. Oil was supplied from a tank using a steam pump and passed through an oil heater located in the outlet pipe from the superheater. The carburettor was responsible for heating and vapourising this oil and the extensive brick surface aided the cracking of the oil into smaller gas phase molecules which would remain in a permanent gaseous state (Meade 1916, Morgan 1931, Anon 1950).

It was important that both the generator and subsequent superheater were operated at the correct temperatures, the chequerboard firebrick was maintained in good condition, and the rate of oil spray and its distribution in the generator was such that the gasification of the oil was maximised.

3.4.2.11 Superheater

The superheater fulfilled a similar function to the carburettor, thermally cracking as much as possible of the remaining oil into a gas. Although the carburettor was designed to maximise the amount of superheater as oil, especially if heavy oil was used.

At the top of the superheater was a stack valve which was opened during the blow. The gas escaping the valve would be between 600-750°C and could contain unburnt carbon monoxide gas. In 1916, waste heat boilers were introduced in Britain; these could recover this escaping energy by using it to heat water and raise steam.

This valve was closed during the gasmaking run phase, and the gas made its way through the remainder of the purification plant. Benefits could be gained by injecting the oil at multiple points in the carburettor and superheater and against the flow of gas. This caused the most volatile components of the oil to vapourise immediately into the gas. The higher molecular weight oils, which would be thermally cracked, descended to the base of the vessel before being carried on the flow of gas from the base to the top of the superheater (Meade 1916, Morgan 1931, Anon 1950).

3.4.2.12 Water Gas Purification.

Water gas required processing and purification, this depended on the type of process operated. The non-carburetting water-gas plant, where no oil was used to enrich the gas, were relatively ‘clean’ when using coke, producing little or no tar and placing a limited burden on the purification plant. The CWG plant (Figures 3.128 and 3.131) required a specialised purification plant, due to the burden of tar and oil which had to be removed from the gas. The difficulties and amount of tar produced were dependent primarily on the type of oil used and whether coke or coal was used as the fuel (Meade 1916, Morgan 1931).

The plant used to purify water gas (Figure 3.132) was similar to coal gas, but additional plant was used to attempt to separate the CWG tar from water, e.g. tar separators and settling tanks. Containing up to 85% water, CWG tar could have a similar density to water and could readily emulsify, making its removal very difficult (Meade 1916, Morgan 1931).

Due to the similarity of some of the plant used in water gas purification to that of coal carbonisation, only brief details are given where the same plant was used. Where plant was substantially altered or unique to water gas or CWG production (which would also be used for later oil gas production) then more detail is provided.

3.4.2.13 The Washer/Seal/Wash Box

The first part of the purification process was the washer (also known as the seal or wash box). This piece of equipment was specialised for used with water gas plants. The role of the washer was to provide a safety seal which prevented the gas from being pushed back into the superheater (by the pressure exerted by the relief holder) during the periods of the blow. Another role for the washer was to remove considerable amounts of tar formed from the CWG plant. The amount of tar formed from blue water gas plants using coke as a fuel would have been negligible. As the gas bubbled through the washer, some of the residues from the gas were removed. Certain washers (e.g. Western seal tar batter) were designed with baffles and water sprays to aid tar removal (Stephenson 1916, Russell 1917, Anon 1950).

Whilst operational, the water within the washer was kept hot by a continuous flow of water from the boiler. Tar condensing out would leave the washer by the effluent overflow and via the seal pot to the tar separator (Figure 3.136). During the run (up-run and back-run), gas would exit through the washer (Stephenson 1916, Russell 1917, Anon 1950).

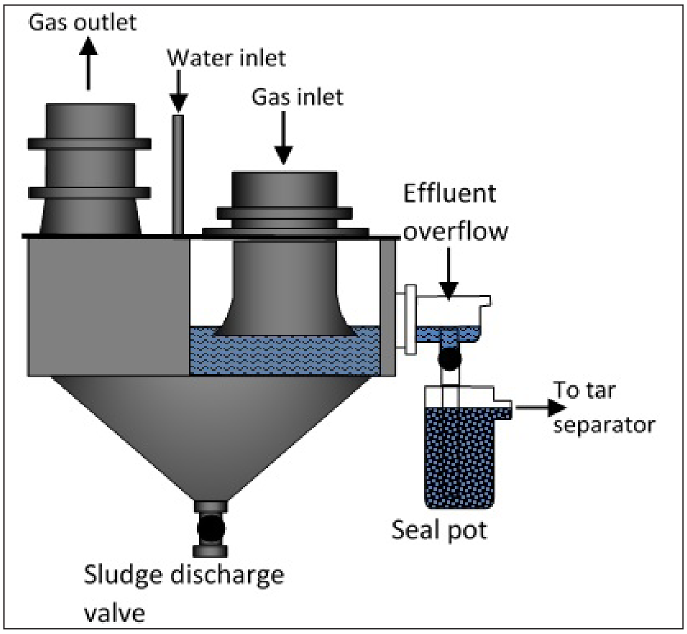


Figure 3.136 A cut-through diagram showing a Conical-Bottomed Washer. Source R.Thomas, adapted from Anon 1950.

3.4.2.14 The Scrubber and/or Condenser

Similarly to coal carbonisation, scrubbers and condensers were used to process the gas. For water gas the purpose of both the scrubber and condenser was to cool the gas and remove tar, oil and any dust/free carbon which remained suspended in the gas. A scrubber alone tended to be used on plants which produced below 28,300 m^3 (1m ft^3) of gas per day; above this figure a condenser was used with the scrubber or alone. If only a condenser was used without a scrubber, there was a risk that the sudden cooling would remove more light oil from the gas reducing it's calorific power (Meade 1916, Anon 1950).

Figure 3.137 Condensers used on an H&G Carburetted Water-Gas Plant. Image courtesy of National Grid Gas Archive.

The scrubber similar to the tower scrubber described previously in section 3.3.5, was a cylindrical tank fitted with trays made from wood, containing coke or other inert material; this provided a large surface area, kept moist by a spray of water. Most of the tar residues were removed here and drained to the base of the scrubber. The scrubber also cooled down the gas to a normal temperature prior to condensation (Meade 1916, Russell 1917).

If coke was used in the generator, the water gas was generally free from ammonia, but occasional traces existed and would be removed by the scrubber. Within the scrubber, the water directly cooled the gas, creating problems for the disposal of the large amounts of potentially polluted water generated (Meade 1916).

Condensers were used with large water-gas plants (Figure 3.137) These operated as described in section 3.3.1. The cooled gas was temporarily stored in a relief gasholder.

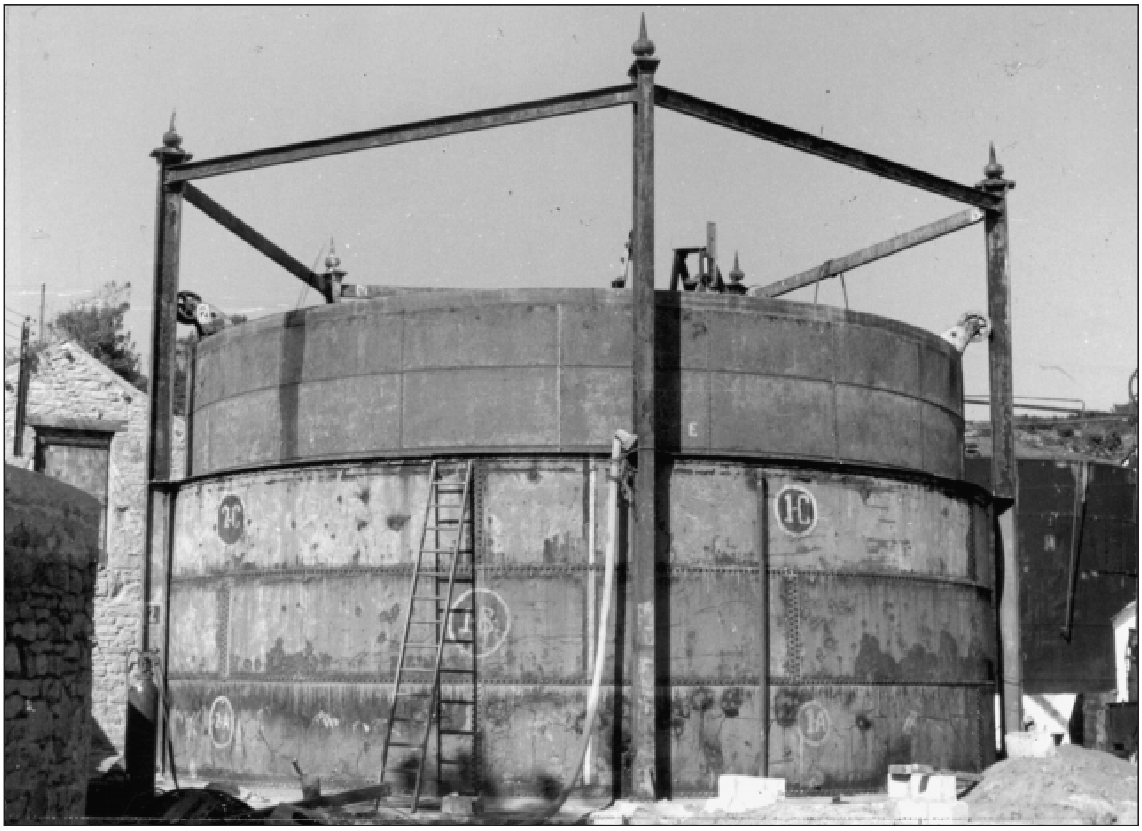


Figure 3.138 A gasholder typical of the type employed as a Water Gas Relief Holder. Image courtesy of the National Grid Gas Archive.

3.4.2.15 Relief Holder

Although constructed in the same way as other gasholders, a relief gasholder, an example shown in Figure 3.138, had a different function: to buffer the cyclical run and blow phases of gas production, providing a more even flow of gas. Due to the tarry nature of the gas entering the gasholder, the relief holder often became filled with tar.

The relief holder was often (but not always) an old gasholder which had become too small for general gas storage requirements. Alternatively, new gasholders were purpose built. It was possible to replace a relief holder with a much smaller compensation holder, if there was insufficient space (Anon 1950).

3.4.2.16 Exhauster

The exhauster was a gas- or steam-driven pump which would draw the gas from the relief holder and push it through the tar extractor and purifiers until finally being mixed with coal gas in the gasholders. The different types of exhauster were described in Section 3.3.2. Water gas was not used in its raw form but was instead mixed with coal gas at a proportion of approximately 30% water gas to 70% coal gas.

3.4.2.17 Dry Scrubber

The gas coming from the relief holder could contain an excessive amount of tar, this could readily block the purifiers and ruin the iron oxide used. The gas was sometimes passed through dry scrubbers also known as filter boxes. A simple solution to remove this was a dry-shavings scrubber. This simple device was developed for use on American gasworks. An iron or steel box could be used which would be arranged to contain two trays inside to carry 3-ft. layers of shavings (Russell 1917, Anon 1950).

Another version of this system, which was employed at the Garston Gasworks in Liverpool used a box filled with layers of coke. The coke would remove any heavy tar which remained trapped within the gas.

3.4.2.17 Tar Extraction

A range of tar extraction systems were developed, but the most popular was a Pelouze and Audouin tar extractor. This was described in Section 3.3.3. the Tar Extractor was later replaced on some larger gasworks post 1930 with the Electrostatic detarrer. It removed tar using an electrostatic attraction. As the gas passed through the electrostatic detarrer (See Figures 3.69 and 3.70), it was exposed to a very high negative voltage, giving the tar particles a negative electrical charge. As the gas continued through the detarrer, it was exposed to a high positive voltage. The negative charge obtained by the tar particles would then attract them to the positive electrode, where the tar would be removed.

Further processing was not normally required for tars produced from coal carbonisation; it was, however, required for CWG tars, as their neutral density, made them very hard to separate from water and they could emulsify. The following two sections describe plant used specifically for the treatment of water-gas tars.

3.4.2.18 Tar Separator

Tars from the processing plant described above would be passed to the tar separator. The latter was a relatively simple device operating on the principle of gravity separation. Tar separators used on gasworks would typically be installed at least 1.8m below ground, so the top of the separator was at ground level.

The separator was built from concrete and the top was covered by planks. If not built robustly, tar and liquor could escape from cracks in the separator wall. If volumes of tar were too great, it could escape over the top of the separator. Separation was achieved by gravity across a drop of about 0.3m (1ft), with wooden planks inserted to increase the flow path across weirs to encourage separation. The separator was usually adjacent to the point of discharge for the gas-liquor waste water. Tar separators were not effective for all tars and some required further treatment (Stephenson 1916, Morgan 1931, Hatheway 2011).

3.4.2.19 Tar Settling Tanks and Lagoons

The tarry emulsions which could form under certain conditions required a large storage capacity to allow the tar emulsions to settle. The tank of the relief holder often provided part of this storage capacity, but specific tanks were also constructed. These tanks allowed the tarry emulsions to very gradually settle into the constituent tar and water, so the tar could be decanted off (Stephenson 1916, Morgan 1931, Hatheway 2011).

Difficult tar emulsions could be treated by heating, reducing the viscosity of the tar, and making it easier for the water droplets to coalesce. High temperatures were required to produce very fine particles of water. These tanks were heated indirectly by steam, and the tar and water decanted off. Heating could also be undertaken at high pressures to aid separation. Some CWG plants used lagoons for tar settlement; including unlined lagoons constructed as a temporary measure to deal with large volumes of tarry emulsions. Being unlined, they also operated as soakaways and could be a major source of pollution (Stephenson 1916, Russell 1917, Hatheway 2011).

Such lagoons have been well documented in the USA, however their use in other countries is less well understood. On larger gasworks' centrifuges, distillation units or spray baths would have been used. The former Tottenham gasworks (UK) used both centrifuges and cyclones to separate waste-gas tars. Post 1945, chemical treatment (e.g. surfactants) to separate the tar and water phases became a regular practice.

3.4.2.20 Purifiers

Water gas contained hydrogen sulphide and organic sulphur compounds (e.g. carbon disulphide), which required removal. This was achieved by using a purifier, a square cast-iron box supported on wooden grids and containing layers of iron oxide mixed with wood shavings. If tar reached the purifiers it was filtered out of the gas by the wood shavings. These operated the same as described in Section 3.3.6.

3.4.2.21 Waste Heat Boiler

The blast gases from the blow phase exited the plant via a waste-heat boiler. This recovered some of the heat and energy from the exiting blow gases, which would otherwise be lost. This was a common feature of plant which could manufacture in excess of 1m ft^3 (28,000 m^3) of gas per day. This equipment was very similar to that described in section 3.3.14.

3.4.2.22 Operation

Early water gas plants were manually operated. Given the cyclical nature of the process, this was time consuming and could be prone to error. To minimise the risk of mistakes, interlocking gears were developed to prevent operation at the wrong time or out of sequence. This allowed all operations (except removal of clinker) to be controlled mechanically from the raised floor at the top of the generator (Figures 3.135 and 3.139). Later, the removal of clinker also became mechanically automated.

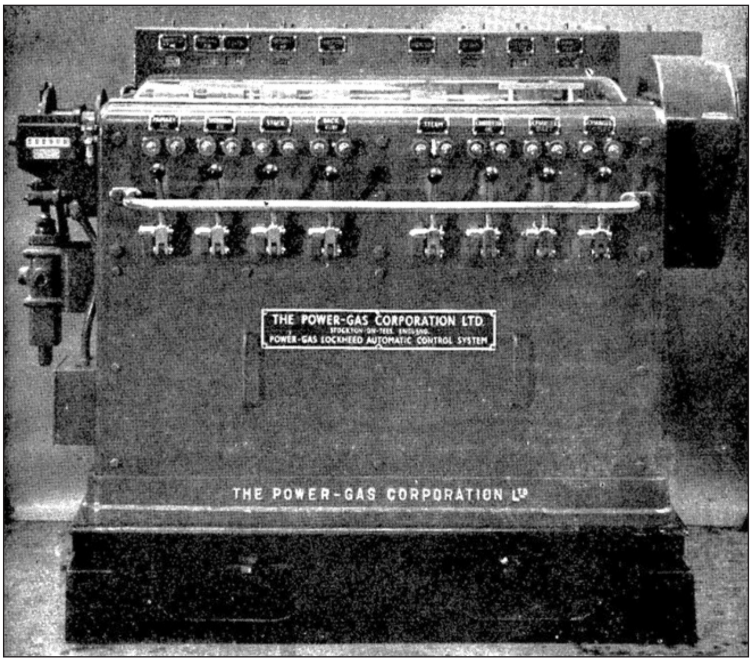


Figure 3.139 A Power Gas carburetted water-gas plant hydraulic operator. Image courtesy of National Grid Gas Archive

As water gas plants increased in capacity, the manual effort required to operate them became so great that, in 1915, hydraulic operating systems (Figure 3.139) were introduced. These systems had progressed so much by 1921 that a single centralised operating unit was introduced, automating the whole process. In the early 1920s, automatic coke-charging units were introduced, allowing continuous operation of the plant (Meade 1921).

3.4.2.23 Up-run and Back-run

As the water gas process became more advanced and sophisticated, the run became split into two separate phases: the up-run and the back-run.

The up-run was the phase during which all the enriching oil was added to the gas. It was the main gasmaking phase, analogous to the ‘run’ described earlier.

After reaching a temperature of approximately 1200°C during the blow phase, steam was admitted to the base of the generator forming blue-water gas as it passed upwards through the fuel bed (by the processes described earlier). As gas passed through the carburettor, oil was sprayed; this vapourised in the chamber and on the chequer brick, becoming fixed in a gaseous state in this chamber and the superheater. The gas then passed through the washer and other auxilary processing plant (Meade 1921).

During the back-run, the plant was run in reverse. Steam was admitted to the top of the superheater, travelling down and up through the carburettor, and absorbing heat in the process. It then entered the fuel bed (generator), returning the heat and also producing blue-water gas.

3.5.3 Types of Fuel used

Coke and anthracite (a high rank coal) were the fuels most commonly used in Britain for the water-gas process. When these fuels were in short supply, unavailable or very expensive, other forms of coal were used. The fuel type affected the design of the water-gas plant, so adaptations needed to be made. Fuel use varied from region to region, depending on availability.

3.4.3.1 Coke

Coke was the preferred fuel source for water-gas plant in Britain. Coke used for gasmaking would be egg-sized lumps of uniform coke and free from fines. If the coke was produced on a gasworks to make water gas, it would be screened to remove breeze below 2cm diameter size. Denser coke would allow more fuel to be stored in the generator, but less-dense coke was thought to be more reactive. The important factor was a low sulphur content and low ash content.

3.4.3.2 Anthracite

Anthracite was the most dense form of carbon that could be used in water-gas plant. It was also used at an egg size, with minimal fines,and contained approximately 10% ash, although the lowest possible ash content was preferred.

3.4.3.3 Bituminous Coal

Bituminous coal could be used in water-gas production but was avoided where possible given the complications it would cause within the generator and in the gas purification. It was not until 1917-18 that war restrictions on coke supplies in the USA led to alternative fuels being tested. In states such as Illinois, where the availability of coke or anthracite was limited, cheaper sources of bituminous coal were available and could be sourced locally. The USA continued to use this coal after 1918. It presented three main problems:

i) Reduced plant capacity due to problems associated with maintaining the burning fuel bed.

ii) The checker brick in the carburettor and superheater became covered in fine fuel from the generator.

iii) Smoke generation from the incomplete combustion of the tarry matter from the coal when freshly charged.

When used in the water-gas plant, bituminous coal would act in a similar way to coking coals in a coke oven. Most of the activity would be confined to the peripheral edges of the fuel bed; the latter would then shrink away from the wall, forming a plastic mass in the centre of the fuel bed. This was more resistant to both the blast air and the steam and minimised the areas of activity in the generator. This could be overcome be a modified design called the pier design, in which the generator would contain one or two central piers. Further reference to this method can be found in Lowry 1945, listed in the Bibliography.

Coal was rarely used in British gasworks to fuel water-gas plants, as coke was generally available. When used in CWG production, bituminous coal was found to increase the formation of emulsions within the tar produced, although this was more dependent on the type of oil used.

3.4.3.4 Oil Feedstocks used to Enrich Water Gas

The choice of oils used in CWG production was originally limited to gas oil as prescribed by Lowe. Given the fluctuations in the availability and cost of oil feedstocks, a variety of oils were eventually used, ranging from light fractions such as Naphtha to heavy fuel oils such as Bunker C or #6 fuel oil.

In the early development of CWG technology, the preferred oils for use in the carburettor were in the range between naphtha and gas oils. Their specific gravity was between 0.845 and 0.865, their colour varied from yellow to green, and they were viscous in appearance. These light distillates produced little or no tar when used with coke or anthracite.

Across the world, and in the USA, different practices developed in operating water-gas plants, largely because of the availability and cost of generator fuels and oils. Gas oils became more expensive as they became in greater demand for motor vehicles. At the same time, demand for oil opened new fields in the US Mid-Continent and Gulf coast. These new fields contained oils with much greater asphaltic content than the previously used paraffinic oils from Pennsylvania.

In Britain, early supplies of oil came from Russian/Azerbaijani oil fields, Romania or Scottish oil shales. Oils from the USA and Middle East became available later. As oils with greater asphaltene content and higher carbon-to-hydrogen ratio were used, more tar was formed. For heavy oils, as much as 30% of the volume of the oil could be converted into tar. Some plants became specifically designed for use with heavy oils, such as the UGI heavy-oil process.

There was therefore a great deal of variation in the oil feedstock used in CWG plants, regionally and internationally, based on the availability of supply and economics.

3.4.3.5 Storage of Gas Oil

Gas oil was almost always stored in above-ground cylindrical tanks constructed from steel. These tanks were generally placed vertically (Figure 3.140) but could also be horizontal. Some later tanks were built from reinforced concrete, and special paints were developed to make the tanks impervious to oil.

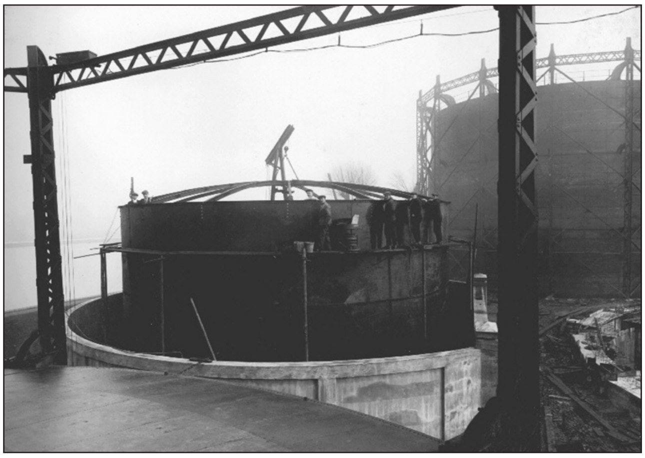


Figure 3.140 Construction of a traditional above-ground oil storage tank at Brentford Gasworks in 1929, showing the perimeter wall protecting the tank and the construction of the tank roof and walls. Image courtesy of National Grid Gas Archive.

These tanks often had minimal or no bunding, although the example in Figure 3.140 can be seen with a circular concrete bund. Logically, the oil tank would have been located near the CWG plant, but often this was not the case. This was due to site space constraints, the practicality of importing oil to the site from roads or rail sidings, or the historical development of the site using oil tanks from previous builds of CWG plant.

It should be highlighted that, as an added point of complexity, some water-gas plants were adapted to undertake fuel bed reforming, a common practice in some parts of Britain, such as South Wales. These processes would have also produced tars where heavy oils were used.

Water gas was seldom used as a sole source of gas in the UK, but instead was mixed and blended with coal gas at a rate of approximately 30% water gas to 70% coal gas prior to distribution. In some areas of Britain (e.g. Newport, South Wales and parts of West and South Yorkshire) where coke oven gas was available, the local gasworks stopped coal-gas production, but maintained the ability to produce CWG gas for periods of high demand.

3.4.4 Complete Gasification and the Lurgi Process

3.4.4.1 Complete Gasification

Complete gasification was a concept developed were by which low-grade coal, typically unsuitable for gas making, was used to manufacture gas in a process which gasified the coal completely, except for the ash (Williams, 1981). The process combined conventional carbonisation with subsequent water gas production, using solid fuel into which air was blown (BP 1965). These types of plants were also known as 'Double Gas' plants. There were many different types of this plant developed. The earliest forms were developed by Dr. Hugo Strache in Vienna and Cornelius Britiffe Tully in the UK. The latter form which was used extensively in the UK is described.

Cornelius Britiffe (C. B.) Tully and Vivian Lewes (Anon 1907) developed the concept of a complete gasification plant as early as 1898 when a 'Methane-Hydrogen' plant was developed by Tully.

Tully was born and educated in London, he followed his father in to the Gas Industry, working firstly at the Nine Elms Gasworks for the London Gas Company, south of the River Thames, where he oversaw all the mains laying. Tully left to join Dixon & Company working on several important ironwork projects. Tully returned to the Gas industry joining the Liverpool United Gas Company. In 1888 after two years at Liverpool, he left to become the engineer and manager of the Sligo Gaslight and Coke Company in Ireland a job he held for 15 years. It was at Sligo that he developed his notion of the "methane-hydrogen" plant (Figure 3.141) which was later to become the Tully gas plant (Anon, 1930).

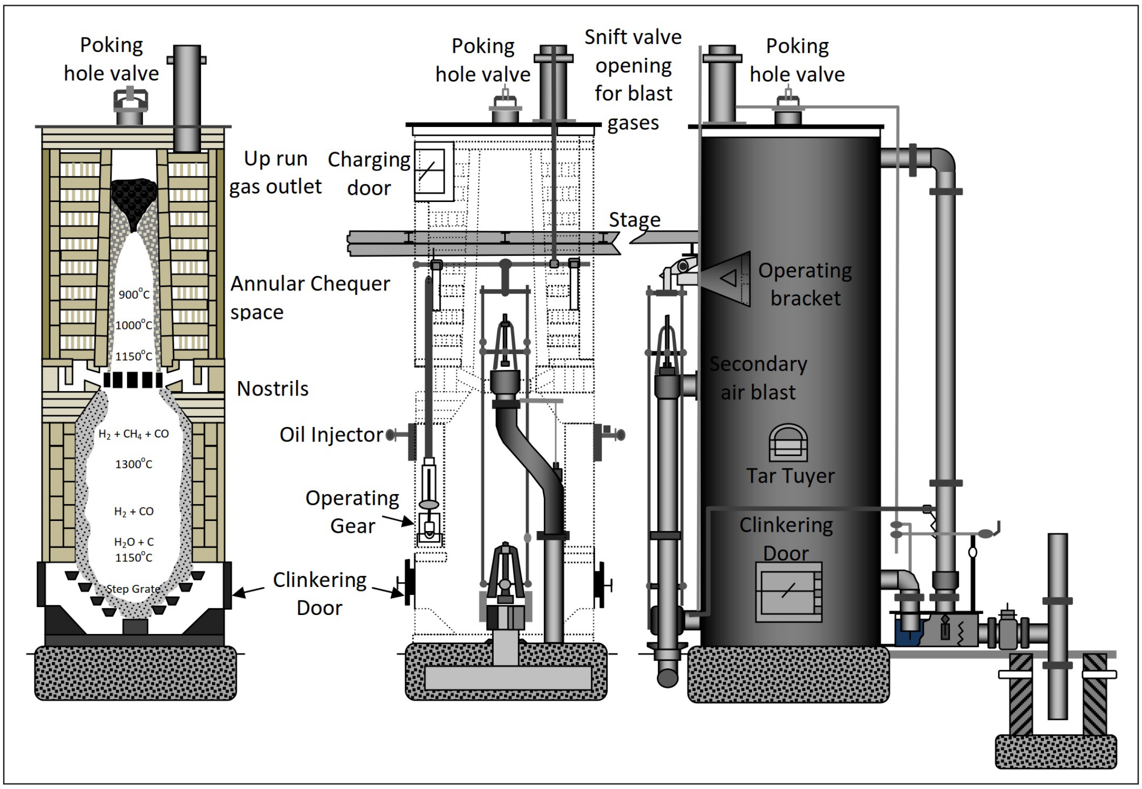
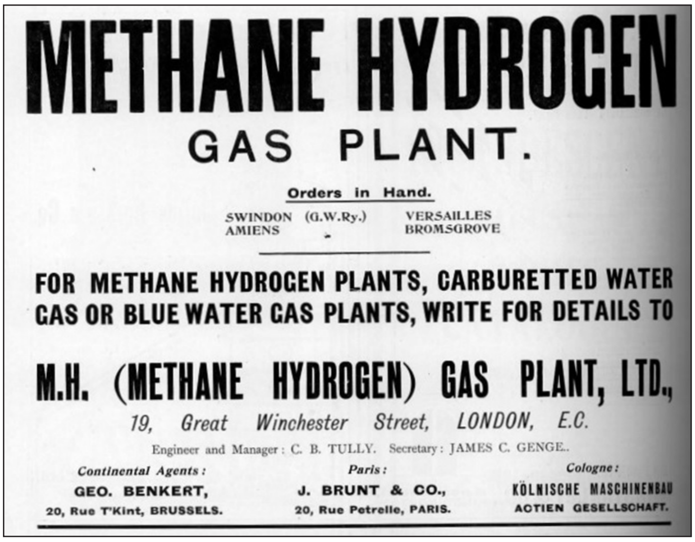


Figure 1.141 A Schematic of a Tully Gas Plant. Source R. Thomas.

The original 'Methane-Hydrogen' gas plant (Figure 3.142) was developed by between Cornelius Tully and Messrs Biggs, Wall and Co. with whom he started working in 1903. It was a hybrid of other gas manufacturing plant and considered in practical terms to be a vertical retort fixed over a water gas producer. It worked on the principal of complete gasification, i.e. it converted both the coal and coke to gas, leaving just ash. It was a forerunner of a range of complete gasification plants which could make gas from lower quality coals. Like water gas, the Tully Gas plant produced a mixture of hydrogen and carbon monoxide. A key aspect of the plant was that it used coal tar and later oil as a carburetting medium in the modified water gas generator (Williams 1981). A key difference with a water gas plant was that the methane-hydrogen plant produced a very different composition gas. It contained considerable proportions of methane and hydrogen and considerably less carbon monoxide.



METHANE HYDROGEN

GAS PLANT.

Orders in Hand.

SWINDON (G.W.Ry.) VERSAILLES
AMIENS BROMSGROVE

FOR METHANE HYDROGEN PLANTS, CARBURETTED WATER GAS OR BLUE WATER GAS PLANTS, WRITE FOR DETAILS TO

M.H. (METHANE HYDROGEN) GAS PLANT, LTD.,

19, Great Winchester Street, LONDON, E.C.

Engineer and Manager: C. B. TULLY. Secretary: JAMES C. GENGE.

Continental Agents: GEO. BENKERT, 20, Rue T'Kint, BRUSSELS.

Paris: J. BRUNT & CO., 20, Rue Petrelle, PARIS.

Cologne: KÖLNISCHE MASCHINENBAU ACTIEN GESELLSCHAFT.

Figure 1.142 Early advert for a Tully type Methane Hydrogen Plant (Circa 1910). Source Journal of Gas Lighting, March 8, 1910. Image courtesy of IGEM Archive.

The operation of the Tully gas plant was more complex than that of a conventional water gas plant, a brief description of the process is given below: The fuel would pass down the upper chamber of the plant (akin to a vertical retort), undergoing the various stages of carbonization with increasing temperature as the coal fell downwards by gravity. It would drop down into the producer in the form of coke which was then converted to gas as it would be in a water gas or produce gas generator (Anon, 1907).

The producer was filled with hot fuel up to the bottom of the retort, it was then blown with air to incandescence, the blast entering below the grate and leaving at special nostrils at the bottom of the retort, at which point secondary air is admitted, making a combustible mixture, and heating the chequer work round the retort (Anon, 1907).

After one or two runs the plant would then be charged with coal to a point about 2 feet from the top of the retort. The blast air was admitted until a flame appeared at the snift valve, indicating excess producer gas production. The blast air and snift valve were then shut off. Steam was introduced to the bottom of the producer and the outlet to the washbox was opened, allowing the gases to pass up through the producer, through the retort, down the top outlet pipe, through the washbox, then to the scrubber and relief holder. After 5 or 6 minutes, air was injected into the producer until the coal became incandescent again. The air valves and snift valve were then closed, the bottom outlet lever on the washbox was opened, which admitted steam in the chequer work at the top of generator. The gases travelled down and out the bottom of the producer, then away through washbox and scrubber to the relief holder (Anon, 1907).

The gas produced by the Tully Gas Plant could also be enriched by the injection of coal tar or oil as it would be in a carburetted water gas plant. The gases produced would travel out of the Tully plant at the bottom of the producer, they would then be passed through a washbox and scrubber to the relief holder (Anon, 1907).

The first small Methane-Hydrogen plant was built at Truro Gasworks in Cornwall, this was followed by a larger plant built at the Swindon Works of the Great Western Railway by Messrs Biggs, Wall and Co. This plant was designed to supplement the coal gas production at the railway gasworks which produce over 300 million cubic feet of gas per year. On completion their early gas plants success, enough orders were received to set up a separate company, the M. H. (Methane Hydrogen) Gas Plant, Ltd Company in London. This operated until 1913 when C.B. Tully set up in partnership with Oliver Yeo in Westminster manufacturing Tully's Complete Gasification Plant under the name of Bale and Hardy Ltd. In 1921 the company moved to Newark (Nottingham) and became known as Tully Gas Plants Ltd, they produced gas plants for gasworks across the UK and the world, with their largest plant constructed in South Africa. Between 1918 and 1921 Tully built some 150 small complete gasification plant in Britain, they also produce water gas plants (Marsden, 1955).

The Tully gas plants popularity stemmed from its relatively low capital costs. They did however, require a very high level of precision to operate what was a complex process, often greater than that able to be provided by the operatives, and as a result they fell out of favour.

3.4.4.2 Gas Integrale

The Gas Integrale was another form of complete gasification plant developed from the original work Austrian scientist, Dr Strache. A trial plant was built at Kensal Green gasworks in the 1950's, it had similarities to the concept of the Tully gas plant that it was a carbonising retort superimposed on a carburetted water gas generator. The plant was suitable for use with low grade and cheap coals. Like the Tully gas plant, it used the 'Run' and 'Blow' cycles as described for in an earlier section. As with a CWG plant, oil was injected into a hot carburettor chamber to enrich the gas. The plant was in many respects a larger and more modern form of the Tully gas plant (Barash and Gooderham 1971).

3.4.4.3 Lurgi Gas

The Lurgi process was developed in 1927 in Germany to look at the complete gasification of the brown coal deposits in the East Elbe (Wilson, 1969). The Lurgi process differed from previous complete gasification plants through: (1) its gasified the coal with a mixture of superheated steam and oxygen; (2) it was a high-pressure process and; (3) it was a continuous process.

The first plant was built in Hirschfelde in 1936 and further plants were built in Germany and Czechoslovakia, where a plentiful supply of low-grade brown coal was available.

As the process was originally designed for brown coal it required some modification to make it suitable for British black coals, but with the work of Tully and others previously the concept of using oxygen and steam in gas production was not new (Anon, 1907, Braunholtz, 1963) .

The Lurgi process combined both the producer gas and water gas reactions (described earlier).

The raw gas produced by the process consisted mainly of hydrogen, with about 25% carbon monoxide and small amounts of methane formed from secondary reactions. With the Lurgi gas process being a high pressure process it enabled the use of a catalyst at 800°C which enabled the water gas shift reaction to occur, where the carbon monoxide would react with steam to produce hydrogen and carbon dioxide, enriching the hydrogen content. The carbon dioxide could then be removed by treatment with an alkaline solution (Anon, 1967, Hebden and Brooks, 1976, Williams 1979).

Like other coal-based gas manufacturing processes the Lurgi process also produced coal tar, light oil and ammonia rich water. Benzol was also scrubbed from the gas. These by-products were removed from the raw gas before catalytic conversion and carbon dioxide removal (Williams, 1979, Hebden and Brooks, 1976).

The Lurgi gas generator had similarities to a conventional gas producer or water gas generator but was surrounded by a water jacket. It had a fixed fuel bed fitted with a stirring mechanism on a rotating grate (Figure 3.143). As a pressure vessel, the coal was added, and ash was removed via a system of pressure locks, with the ash removed in a solid state (Anon, 1967)

The Lurgi gas after processing provided a high-pressure gas with a considerable quantity of hydrogen, which gave it both a low calorific value and a very low specific gravity (Williams, 1979, Hebden and Brooks, 1976). For this reason, its composition needed to be amended prior to distribution. Its low calorific value was amended by the

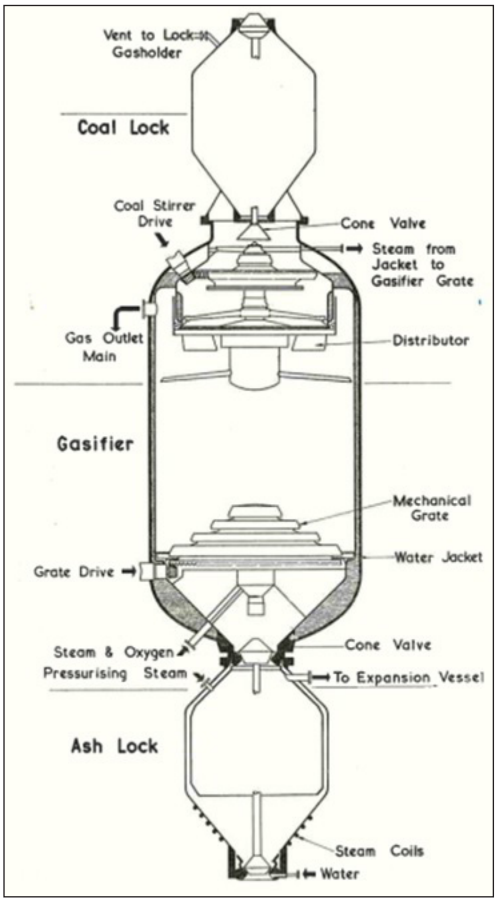


Figure 3.143 A diagram of the Lurgi Gasifier, Westfield, Fife, Scotland. Image Courtesy of the National Grid Gas Archive.

addition of a Liquid Petroleum gas (LPG) such as butane or natural gas. To amend the specific gravity to the correct amount involved the mixing of a ballast gas such as nitrogen or limited carbon dioxide removal from the gas (Anon, 1967, Hebden and Brooks, 1976).

Two Lurgi gasification plants were built in Britain, one built by the Scottish Gas Board at Westfield, Fife in Scotland (Figure 3.144) and the other built by the West Midland Gas Board at Coleshill, Warwickshire (Figure 3.145) in England (Anon, 1967, Hebden and Brooks, 1976).

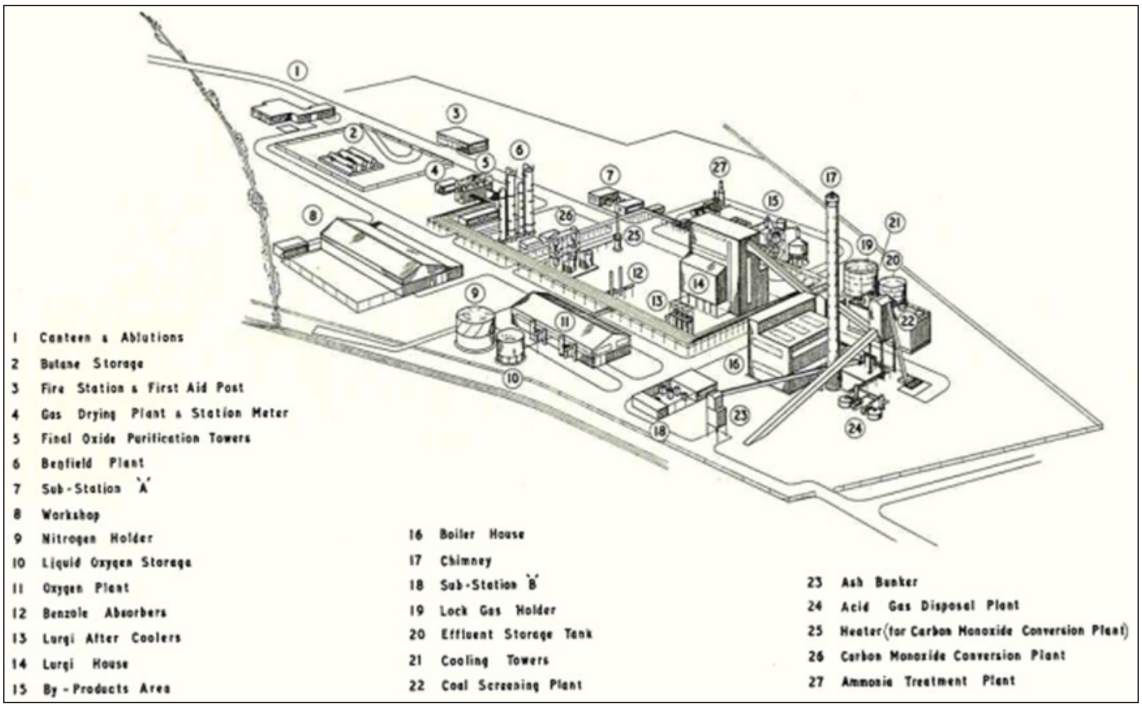


Figure 3.144 An artist impression of the Lurgi Plant built at Westfield, Fife, Scotland. Image Courtesy of the National Grid Gas Archive.

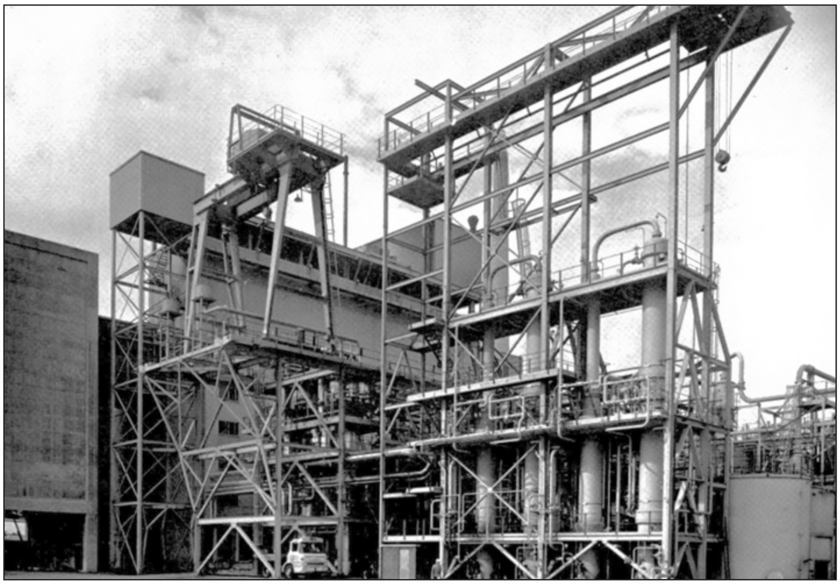


Figure 3.145 The gas cooling and carbon monoxide conversion plant, Coleshill Lurgi gas plant. Image Courtesy of the National Grid Gas Archive.

Both Lurgi plants were built adjacent coal mines, the Westfield plant was built next to Westfield open-cast coal mine and became operational in 1960. The Coleshill plant was built near to the Kingsbury Colliery and became operational in 1963 (Anon, 1967, Hebden and Brooks, 1976).

The Coleshill Lurgi gas plant produced high pressure gas at 24 bar (355 pounds per square inch). The Westfield Lurgi Gas Plant produced high pressure gas at 20.6 bar (300psi) and supplied a high-pressure grid system in the Fife and central areas of Scotland.

Both plants were conventional dry-ash Lurgi gasification plants. The Coleshill plant was in operation until 1969, by which time an oil gasification plant installed at Coleshill had proved more economic (Williams, 1981).

The Westfield plant was in operation until 1974, when the area it served converted to natural gas (Hebden and Brooks, 1976).

The story did not end there. From 1972 onwards, the Westfield site was used as a development site for the British Gas-Lurgi (BGL) slagging gasifier. During the development programme, two of the original Lurgi gasifiers were converted to slagging gasifier operation. The BGL technology was never used commercially in the UK (Williams, 1981, 1967, Hebden and Brooks, 1976).

A comparison of the composition of gas manufactured by the processes described in the previous sections is given in Table 3.1.

Table 3.1 The composition of various manufactured gases

	% composition							
Gas Component	Coal Gas	Carburetted Water Gas	Blue-Water Gas	Dellwick Fleisher gas	Tully gas Methane-hydrogen plant	Lurgi gas Westfield Fife	Producer gas made from coke	Producer gas made from US soft Coal
H_2	47.0	30.3-35.0	52.0	50.8	42.4	39.8	6	10
CO	7.75	29.1-32.0	38.0	39.65	28.8	24.6	25	27
CO_2	3.5	3.4-4.5	4.5	4.65	2.8	24.6	5	4
CH_4	27.5	21.3-13.0	1.0	0.82	19.2	8.7	1	3
Hydrocarbons	3.5	10.0-12.3	0	0.95	0.8	1.1	-	-
N	10.5	3.1-5.3	4.3	3.83	-	1.2	63	55
O	0.25	0.2-0.5	0.2	0.2	0.2	-	-	0.5
Candle Power								
MJ/m³	13.5	18.0	0	N/A	N/A		-	-
BTU/ft³	19.3	21.6	11.1	N/A	N/A		-	-
BTU	520	580	300	N/A	357		-	-

3.4.5 Manufacture of Gas from Oil

3.4.5.1 Early Oil Gas Making Processes

As described in the first volume of this report, the manufacture of gas from the gasification of oil was first practiced in the early 19th century. Gas made from these processes was produced from resins, tar by-products and whale, fish and vegetable oils. It was manufactured by heating the oil in an iron retort, producing a gaseous mixture of hydrocarbon vapours resulting from the direct conversion of oil into gas by thermal cracking. The oil gas would have an illuminating power of 60 to 70 candles.

This early type of oil gas led to a number of public oil gas companies being established in Liverpool, Bristol, Colchester, Taunton, Norwich, Hull, Plymouth and Whitby as well as at Edinburgh and Leith in Scotland and Dublin in Ireland. They struggled because of oil shortages and became uneconomic to run due to the much cheaper cost of coal gas. Many soon failed and those that survived switched to coal gas production. Oil gas companies were established on the European continent and were longer lived in areas where supplies of coal was not easily available as in Britain (Stewart 1958).

3.4.5.2 Oil Gas on the Railways

The use of oil for gas lighting was revived on the railways. It was first reintroduced in Germany, where along with other countries up until the year 1870, railway carriages were lit by candles or oil-lamps. The light from candles or oil lamps proved to be insufficient and petroleum could not be used on account of the risk of fire. Interest was then drawn to gas lighting.

To store enough gas on a railway carriage required it to be compressed into a smaller volume at pressure. Coal gas was unsuitable, as its illuminating power decreased under pressure, however, as had been proven much earlier in the gas industry, oil gas was suitable for compression, even at a pressure of 10 atmospheres without showing any appreciable reduction in lighting power and could therefore be carried in small cylinders. So even though it was more expensive, the ability to compress oil gas and store it at high pressure within cylinders on railway carriages made it popular (Stewart 1958).

The Pintsch oil gas process devised by the German engineer Julius Pintsch (Figure 3.146), it was the most widely adopted by the rail industry. Other rival processes, which included the Pope's system of oil gas manufacture and Keith's apparatus were also adopted by railway companies and operated in a similar way (Butterfield, 1904).

Stettin 1865. **Paris 1867.**

Fabrik für Gasmesser und Apparate
zur Gasfabrikation.
Mechanische Werkstatt
von
JULIUS PINTSCH
in
Berlin
Andreas-Str. 72, 73.

Filiale **Dresden**
Friedrich-Str. 9.

Filiale **Breslau**
Friedrich-Wilhelm-Str. 37 a

empfiehlt seine **Gasmesser** von 2—150 Flammen in Gehäusen von starkem, selbst verzinntem Blech, ebenso seine **patentirten Gasmesser** gleicher Grösse ohne Preiserhöhung. Die Stärke des Materials gestattet mir, eine Garantie von **4 Jahren** zu übernehmen.

Stationsgasmesser mit gusseisernem Gehäuse für 500—100,000 c' Durchgang per Stunde, von welcher letzteren Grösse in den hiesigen Anstalten 1 Stück und à 80,000 c' 2 Stück in Thätigkeit sind; bis 3000 c' per Stunde halte Stationsgasmesser in so weit fertig, dass ich dieselben in 8 Tagen zu liefern im Stande bin. **Stadtregulatoren** in jeder Grösse und eigener Construction. **Regulatoren** für kleinere Leitungen, **Exhaustoren** nach Beal'schem System 12—24', **Wechselhähne**, **Waschapparate**, **Schieber**, **hydraulische Hähne**, **Ventile**, neu und praktisch, **Manometer** jeder Art, wie **sämmtliche Blecharbeiten** als Condensatoren, Scrubber, Reinigungskastendeckel, Wechselhahnhauben etc. liefere ich zu soliden Preisen von bestem Material. **Strassenlaternen** in grösserer Auswahl und solider Arbeit. (5/21)

Figure 3.146 German advert for gas apparatus made by Julius Pintsch, which featured in Journal für Gasbeleuchtung in 1872.

In the Pintsch process the oil was gasified in a double retort, directly fired from below. This double retort system had one retort stacked above the other. The oil was dripped onto trays in the upper retort and passed along the tray for three feet before falling on to the cast iron retort which vapourised and cracked the oil into gas phase hydrocarbons. The gas then passed into the lower retort where it was subjected to a high temperature, where the gas would be fixed into a permanent gas phase. Each retort was about 6 feet long, 10 inches wide, and nearly 10 inches high, similar to that visible in Figure 3.147. The oil gas produced was a form of vaporised and cracked naphtha.

The oil gas produced was stored in the rail carriages in special high-pressure cylinders (Anon, 1900a). In 1892 there were 31,335 Pintsch gas lit carriages in Germany, by comparison there were 16,854 cars lit with Pintsch gas in (Hill & Sinclair, 1892).

The first British Railway to adopt gas lighting of carriages was the Metropolitan Railway closely followed by the Great Eastern Railway in 1877 who erected an oil gasworks at Stratford, London.

By 1895 all the rail carriages which left the South-Eastern Railway works at Ashford were fitted with gas lighting instead of oil lamps. At this point some 800 carriages were already fitted with gas lighting, the gas being manufactured at the Company's works in London. Each coach carried a pair of gasholders underneath, capable of containing a supply for 25 hours. The gas was replenished at different depots along the line. Flexible hoses (Figure 3.148) were used to transfer gas from the gas plant to the onboard carriages (Anon, 1895b).

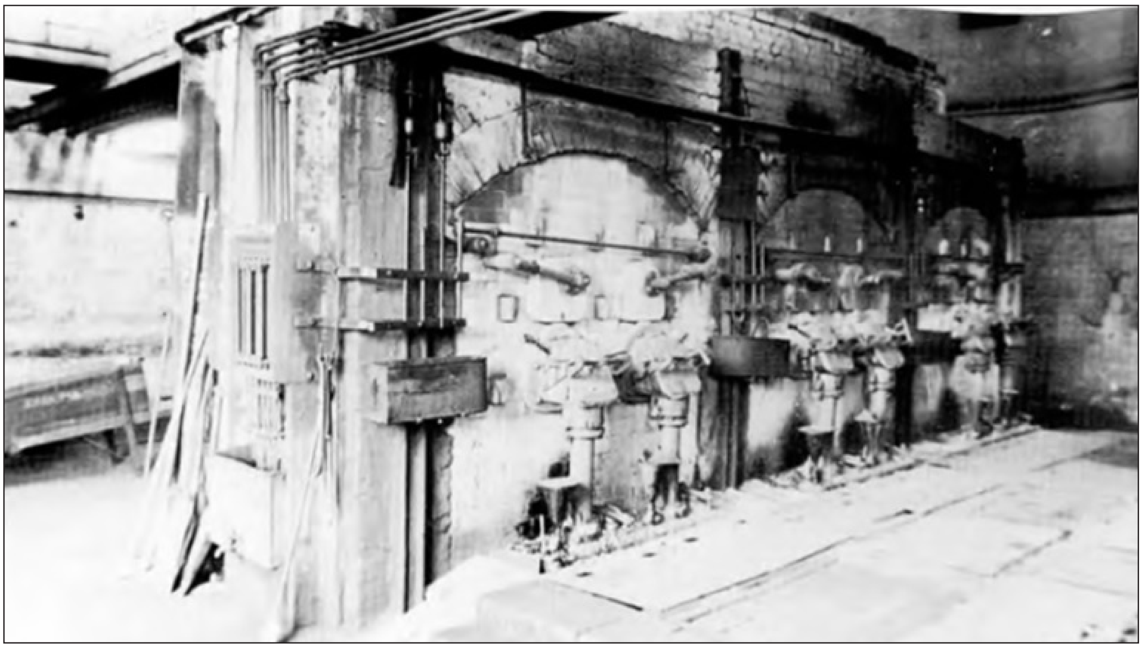


Figure 3.147 Three double sets of oil gas retorts, probably at Darlington. Image courtesy of North Eastern Railway Association Archive.

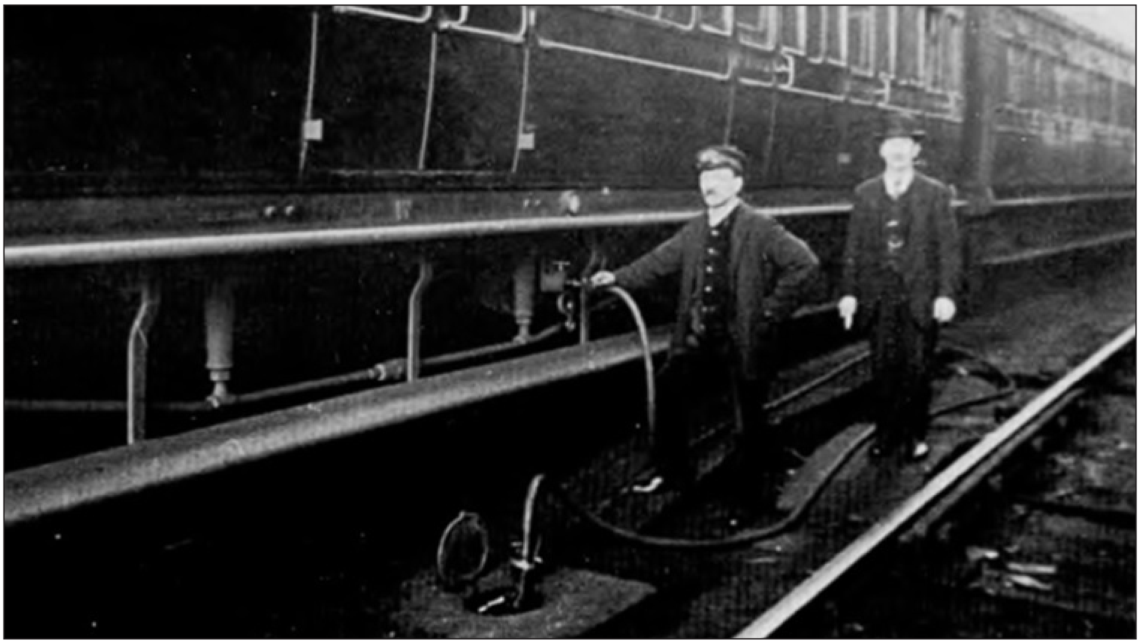


Figure 3.148 Charging gas cylinders on a coach using a flexible hose. Image courtesy of North Eastern Railway Association Archive.

Gas was produced by all the main railway companies to light the railway carriages and the works. For more general use, the railways produced coal gas and at larger works have operated both coal and oil gas plants. This included the Great Northern Railway, who had a large gasworks at their works in Doncaster and Great Western Railway who had a large gasworks at their works in Swindon. Such companies would also have smaller coal or oil gasworks which supplied, stations and junction. Most of these locations appear in the Gazetteer in Volume 3 of this report.

3.4.5.3 Re-Emergence of Oil as a Gas-Making Feedstock

As the available coal resources for gas making became more expensive and of lower quality, the gas Industry looked at alternative feedstocks. Liquid feedstocks such as petroleum oils and its derived distillate fractions were becoming available in abundant amounts from the growing number of oil refineries built in the 20th C. These oils became a cheaper alternative feedstock for gas production.

In the US where abundant sources of locally produced oil were available, oil gas production started to replace traditional coal gas production. This was particularly true on the West coast of the US, where oil was plentiful but coal was not. Here oil gas processes such as the Jones Process and Hall Process, used carburettors for a similar function to the CWG process: to crack the oil into gas-phase hydrocarbons.

Substantial native oil supplies had not been found in the British Isle, until James "paraffin" Young had developed a process from extracting oil from oil shale. Similar to the gas making process the oil shale was heated in a retort to release the oil vapour. James Young first used Cannel Coal, but later switched to the the oil shale found in West Lothian and parts of Midlothian and Fife in Scotland. With the first oil being produced about 1860 at "Young's Paraffin Light and Mineral Oil Company" which was based in Broxburn. The Broxburn Gas Company was established in the same town and made gas from the local oil shales. This form of gas making was localise to this area of Scotland and did not spread wider across the UK. Similar attempt were undertaken to create an oil shale industry in Dorset and Norfolk in England, some companies were established in Dorset but it was a small and short lived industry by comparison to Scotland.

Oils could range from being highly paraffinic to highly aromatic. The greatest difference in gas-making efficiencies of liquid feedstocks was the relative size of the constituent molecules. The light distillate fractions had the highest efficiency and the heavy fuel oil the lowest.

From the 1950's a significant development of oil based gas making technology was introduced into the British Gas Industry. this included many technologies developed overseas. The Hempsted gasworks in Gloucester (Figure 3.149) were rebuilt by the South Western Gas Board with four new gas making processes in addition to the continuous vertical retorts, these included the Koppers-Hasche Process, the Gas Integrale Process, the Hall process and Jones process.

Figure 3.149 The Hempsted Gasworks Gloucester, where a range of oil gasification processes were operated, including the Hall, Jones, Koppers-Hasche and Gas Integrale processes. Image courtesy of National Grid Gas Archive.

Later, catalytic oil gas plants such as the SEGAS and ONIA-GEGI (Both Described later) were introduced at gasworks across Britain. These plants used a hot catalyst to crack the oil into gas-phase hydrocarbons.

The combustible components of a typical oil gas would be composed of 48.6% hydrogen, 26.3% methane, 12.7% carbon monoxide, and 3.8% illuminants.

Gasmaking from oil and refinery by-products became more popular with the introduction of cyclic and continuous catalytic reforming processes. Reforming was a more intensive process than the previous cracking process, and would require greater heats and the use of catalysts. Reforming processes were generally ‘clean’ as can be seen from the site shown in Figure 3.150, and did not produce significant quantities of tar as a residual by-product.

An additional benefit of oil gas manufacture over coal gas was the lack of ammonium and cyanide produced; this reduced capital costs as well as the amount of land required to operate the process. If oils were used which were rich in unsaturated, naphthenic or aromatic compounds, then there would be a much lower gas yield, especially methane and ethylene, and an increase in tar and/or free carbon produced. To reduce tar formation, it was possible to introduce oxygen and hydrogen in the form of steam, enabling combustion, hydrocarbon hydrolysis or water gas reactions to occur. This could also be achieved by increasing the pressure at which the process operated.

Figure 3.150 Oil Reforming Plant at the Former Tipton Gasworks. Image courtesy of National Grid Gas Archive.

3.4.5.4 Non-Catalytic Cyclic Method of Gas Production

3.4.5.4.1 G.L.C. Process

The GLC Process was developed by Dr. M. McCormack of the Gas Light and Coke Company, who had developed this from the American Dayton Oil Gas Plant. The oil was partially burned in this process to produce a cool flame used to crack oil into smaller gas phase molecules. The gas produced by the process was composed of a mixture of hydrocarbons, carbon monoxide, carbon dioxide, hydrogen and nitrogen and had a calorific value of 400-540 btu/ft^3 (14.90- 20.11 MJ/m^3). This gas contains about 60% nitrogen and had a high specific gravity which differed from town gas, so the gas had to be mixed with other gases to achieve the requisite properties before distribution. The process was used as a peak load plant and was known to have been used at Southend and Southall gasworks (Barash and Gooderham 1971).

Several later processes used a similar principal to the GLC process in that some of the feedstock was used to heat the remainder of the feedstock in the manufacture of gas, these processes were referred to as auto-caloric or auto-thermic processes and included the ONIA Auto-Caloric, Shell-Texaco and Topsøe-S.B.A Autothermic Process are described later (Barash and Gooderham 1971).

3.4.5.4.2 Jones Process

The Jones oil gas process introduced in California by E. C. Jones in 1899. It was the most popular of a group of processes referred to as the 'Pacific Coast Oil Gas Processes'.

The Jones process created severe cracking conditions to produce a gas with a calorific value (CV) of 500 British Thermal Units per cubic foot (Btu/ft^3) equivalent to 18.6 Megajoules per cubic metre (MJ/m^3). It gave a gas composed of approximately 40% water gas, but the efficiency was poor, with only 50% of the oil converted to gas. The rest of the oil was converted to carbon black (otherwise known as lamp black) and small amounts of viscous tar, which was rich in naphthalene and carbon black content (BP 1965).

This process was later extended to a wider range of oil feedstocks and was adapted to enable increased carbon black production, a useful by-product which could be sold. In this case, a gas with a lower energy density of 350 Btu/ft^3 (13 MJ/m^3) was produced, forming little or no tar. The carbon black could be sold at a price which made such a lower calorific value viable (BP 1965).

The Generator Unit consisted of four vessels, the two smaller outer vessels contained chequer bricks and were only used as heat exchangers. Gasification took place in the two larger main generator units. These larger vessels contained oil sprays and vaporiser spaces located at the top of the vessels. The two larger generator vessels were heated, and oil was injected into them for five minutes; air was then blown into them, allowing them to reach between 870-925°C. Steam would then be added into the first generator for one minute, then oil injected with steam into both main generators for roughly seven minutes. Steam alone would then be injected into the generators for two minutes (BP 1965).

Air was blown into the generators to burn off the carbon, cleaning the unit and reheating it at the same time and the cycle was repeated. This process produced about 1,000 ft^3 or 28 m^3 of gas from about 7 gallons (32 litres) of oil (BP 1965).

Under sever cracking conditions the flammable component of the gas produced was primarily hydrogen and as a result had a low calorific value of 360 btu/ft^3, in such cases the gas was used as a diluent with richer gases such as butane (Barash and Gooderham 1971).

A similar method called the straight shot was carried out within a single generator unit; the latter was divided into sections, with heating undertaken at the base of the unit. This method produced about 1,000 Cuft^3 (28 m^3) of gas from about 8.6 gallons (39 litres) of oil (BP 1965).

In both processes, the oil gas would exit the generators through the carbon recovery unit and gas washing unit. The manufacture of oil gas produced a significant amount of naphthalene, requiring the gas to be passed through a naphthalene scrubber. The remaining purification process was like that of Carburetted Water Gas except for the removal of carbon black which was achieved using cyclone extractors. The water from the scrubbers and the wash box was passed to the lampblack separator. The carbon black was removed from the separator and dewatered, or else it was filtered, dried and briquetted. It could then be used as either boiler or Carburetted Water Gas fuel or sold for other industrial purposes including the production of tyres, paint and ink (BP 1965).

A Jones gas plant was built in England at the former Gloucester Hempsted gasworks (*See Figure 3.149*) in the 1950's (Barash and Gooderham 1971).

3.4.5.4.3 Hall Process

The Hall process was developed by the American Gas Association from the water gas process. The process was originally undertaken on specially adapted water gas plants. Later plants were specifically designed for this purpose. Distillates, crude oil or residual oil could be gasified, although efficiency would decline with heavier oils and could fail because of the deposition of carbon and pitch within the generators. The gas making efficiency of the Hall process varied from 82% of the thermal value of the feedstock on light distillate, to only 50% on heavy fuel oil. The tar produced would range from less than 5% of the thermal value of the feedstock for light distillate to 20-30% for heavy fuel oil. The process operated in a cyclical fashion, shown in Figure 3.151. In (1) air and oil were passed down into both vessels and steam was passed upward in the second vessel. In (2) oil was injected downwards into both vessels and steam upwards in the second vessel. In (3) air was blow upwards into the first vessel and oil downward into the second vessel whilst in the final step (4) oil was injected into both vessels and steam upward into the first vessel. The cycle was then repeated (Barash and Gooderham 1971).

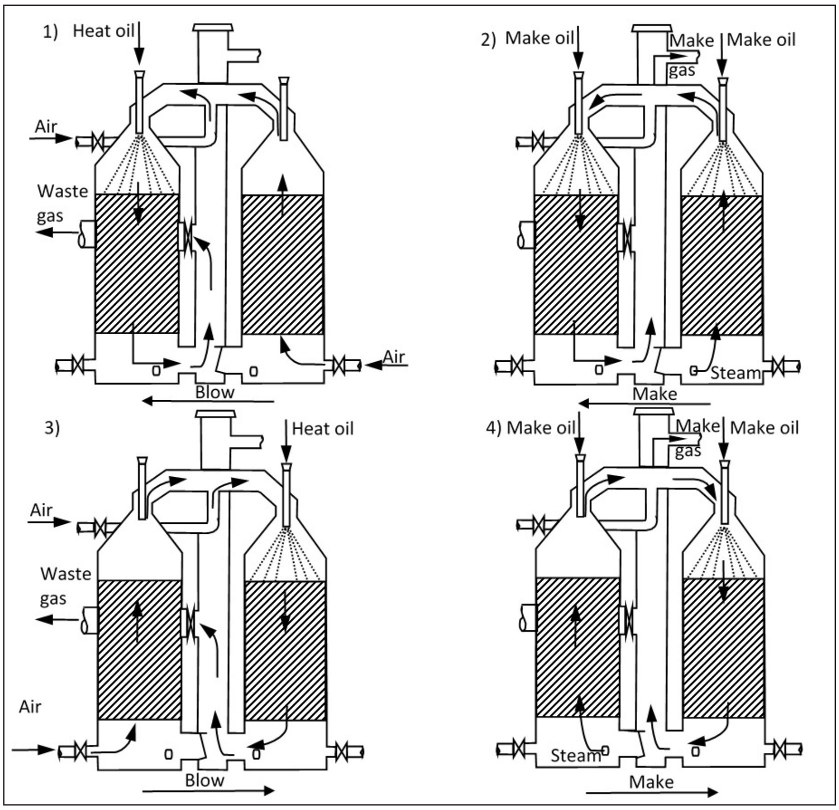


Figure 3.151 A schematic of the operation of a Hall Plant. Source R. Thomas.

A Hall plant was built by the South-Western Gas Board at the Hempsted gasworks in Gloucester in the 1950's (*See Figure 3.149*). It produced a high calorific value gas of 37.2 MJ/m^3 (1,000 Btu/ft^3) which was equivalent to natural gas (Barash and Gooderham 1971).

The Woodall-Duckham Gasmaco plant and Power-Gas Semet-Solvay were both adaptations of the Hall plant. Other types of non-catalytic oil gas plant were also developed (BP 1965).

3.4.5.5 Cyclic Catalytic Processes

Catalytic gas manufacturing processes were also more common on former gasworks sites in Britain. These plants would operate at a low pressure and their design was influenced by the type of feedstock being processed into gas.

The process used a catalyst to convert the oil to gas and this was dependent on the feedstock being used. Lime catalysts were used for the range gas oil to medium fuel oil; nickel catalysts were best suited to light distillate.

If oil had a high content of naphthalene and aromatic compounds, then provision would have to be made to remove the naphthalene and tars using a naphthalene washer and electrostatic detarrer.

3.4.5.5.1 SEGAS Process

The SEGAS process was developed by research teams within the South-Eastern Gas Board to produce a gas similar to town gas from oil. The plants constructed were primarily unhoused as can be seen in Figure 3.152 and therefore only a few buildings were used to house such plant.

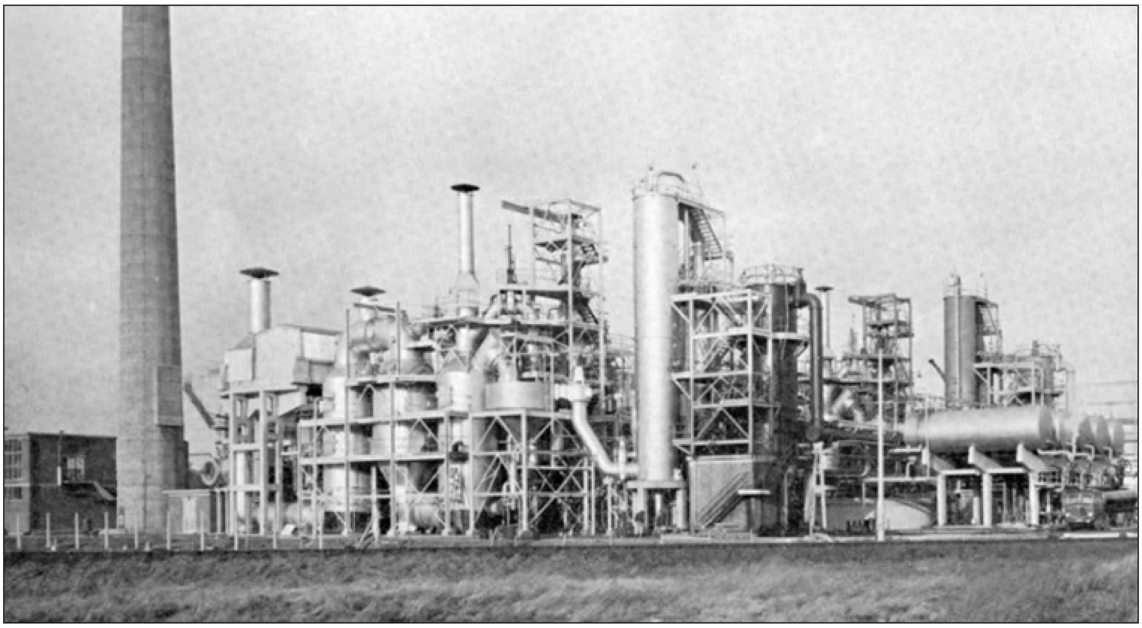


Figure 3.152 SEGAS Plant Isle of Grain. Image courtesy of National Gas Grid Archive..

The plant had a regenerative design, using a catalyst in the form of cylindrical pellets, which were 1 ½ inch in diameter and 1 ½ inch in length. These pellets were composed of calcined magnesia which was impregnated with free lime and would last for three years. The reactor vessel contained a 6ft depth of the catalyst. (Barash and Gooderham 1971).

The catalyst was used at a temperature of 800-900°C when using heavy fuel oil or 715-920°C when using light distillate as a feedstock. The process was cyclic and operated on a run and blow principal like the previous oil gas plants described (Barash and Gooderham 1971).

A gasification efficiency of 70% was achieved, giving a CV of 500 Btu/ft^3 (18.6 MJ/m^3) compared to the catalyst-free Jones process which only achieved 50%. If higher throughput, gasification efficiencies and a cleaner gas were required, then a nickel catalyst could be used instead of lime. The gas exiting the SEGAS plant would pass through a wash box, a direct contact cooler known as a Lymn washer, and an electrostatic detarrer before entering a relief holder. The SEGAS process was robust, could gasify a range of oil feedstocks, and could start producing gas quickly. It was one of the most economical processes for gasifying residual oils and several such plants were built across the UK, a notable example being on the Isle of Grain (Figure 3.152) (Barash and Gooderham 1971, BP 1965).

3.4.5.5.2 Onia-Gegi Oil Gas Process

The Onia-Gegi process was developed by the French ‘Office National Industriel de lAzote in co-operation with the Gaz à lEau et Gaz Industriels, hence the name Onia-Gegi. Originally developed to produce synthesis gas, it was later used to produce town gas. Synthesis gas consists primarily of hydrogen and carbon monoxide, and is used to produce ammonia and methanol.

The Onia-Gegi plant was designed to produce a gas like town gas with a CV of 500 Btu/ft^3 (18.6 MJ/m^3) and used a nickel impregnated catalyst. The system operated on a blow-and-run cyclic principal at atmospheric pressure and between 650-850°C to promote reaction by the nickel catalyst with steam, carbon and hydrocarbons. This produced a higher gas content and a lower tar/carbon yield than the Jones system. The Onia-Gegi system produced similar amounts of tar to the SEGAS process under the same conditions. The plant was very flexible as it could be started very quickly and use refinery gas, distillate and fuel oil as feedstocks (BP 1965, Barash and Gooderham 1971).

One of the first Onia-Gegi Plants was built in 1958 at Romford in Essex by Humphreys and Glasgow for the North Thames Gas Board. A pipeline was built to this gasworks directly from the Shellhaven and Coryton Refineries, which were located nearby (Barash and Gooderham 1971).

3.4.5.5.3 Micro Simplex Process

The micro-simplex (MS) process (Figure 3.153) was developed jointly by Gaz de France and Messrs Stein and Roubaix to reform hydrocarbon and liquefied petroleum gases. The process used a nickel catalyst. Later MS plants were developed to operate on light distillates including naphtha and primary flash distillate. It produced a gas with a low CV of 320 Btu/ft^3 (11.9 MJ/m^3), producing small amounts of tar which could be removed by electrostatic precipitators or deposited in dry purifiers (BP 1965). Microsimplex plant were built at several gasworks in England including the former gasworks in Exeter and at the Cremorne Lane gasworks in Norwich (Eastern Gas 1965).

Figure 3.153 Microsimplex reforming plant Crewe Gasworks. Image Courtesy of the National Grid Gas Archive.

3.4.5.5.4 UGI/CCR Process

The Cyclic Catalytic Reforming Process (CCR) was developed by United Engineers and Constructors and the United Gas Improvement Company (UGI) of America. One of the earliest cyclic reforming processes developed using a nickel catalyst, it was used to produce a lean gas with a CV of 11.1-13.0 MJ/m^3 (300-350 Btu/ft^3). It was later developed to use light distillate and kerosene as a feedstock and would be enriched by natural gas or liquid petroleum gas. The gas yields and by-products produced were similar to those plants mentioned above. A wide range of other oil gas processes were developed (BP 1965).

3.4.5.5.5 H.T.R. Process

The North-West Gas Board developed their own cyclic catalytic oil gas process at the Research Centre in Stretford Manchester. The process was named the H.T.R process after the surnames of the engineers who developed it, namely N. Hare, C. H. Taylor and D. M. Robinson. The process features in the Gazetteer and was used on several plants by 1971. It used a catalyst composed of corundum (mineral aluminium oxide) mixed with the nitrates of nickel and uranium.

3.4.5.6 Partial Combustion processes

As mentioned earlier other gas making processes developed on a similar principal to the GLC process in that some of the feedstock was used to heat the remainder of the feedstock in the gas making process. These processes were referred to as auto-caloric or auto-thermic processes (Barash and Gooderham 1971).

3.4.5.6.1 Onia Auto-Caloric

The Onia Auto-Caloric process was developed by M. Patry and E. Dol of the French 'Office National Industriel de l'Azote' (Onia). The process depended on controlling the combustion of methane and other hydrocarbons with air or oxygen within a bed of catalyst on a continuous (non-cyclical) basis. A plant was built at Bromley by Bow, by Humphreys and Glasgow based on the Onia design, following the construction of plant previously in France. The process flow diagram can be seen in Figure 3.154. Air was blown through a low-temperature heat exchanger which heated the air to about 260°C. Steam from a waste heat boiler was added and then the mixture was heated again to about 400°C in a second hot gas heat exchanger. Liquefied Petroleum Gas (LPG) entered a mixing vessel where it was mixed with steam and air and entered the base of a reactor vessel where it passed up a two-layer bed of catalyst. The catalyst was magnesite based either with platinum (1st layer) or nickel (2nd Layer) and heated to 700-750°C (by partial burning of the LPG), which generated a gas with a low calorific value of 190 Btu/ft^3 which had to be enriched with LPG to bring the calorific value back to the required 500 Btu/ft^3(BP 1965, Barash and Gooderham 1971).

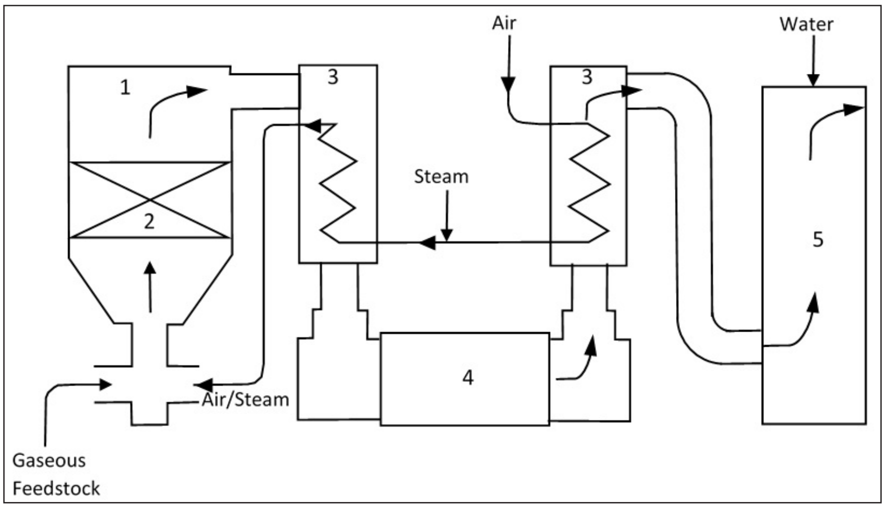


Figure 3.154 Process flow diagram for the Onia Auto-Caloric (Autothermic) gas plant, showing the various component units: 1) Reactor; 2) Catalyst; 3) Heat Exchangers; 4) Waste Heat Boilers; and 5) Cooler. Source R. Thomas.

3.4.5.6.2 Shell and Texaco Gasification Process

The process was first used in England at the Isle of Grain gasworks in Kent (Figure 3.155), where it was used to manufacture water gas from oil. It used a heavy fuel oil mixed with steam and oxygen which was passed under pressure (10 to 40 atmospheres) through a reactor lined with refractories which was heated to 1300°C. The plant constructed at the Isle of Grain had 4 such reactor vessels each of which produced 6 million ft^3 of gas per day.

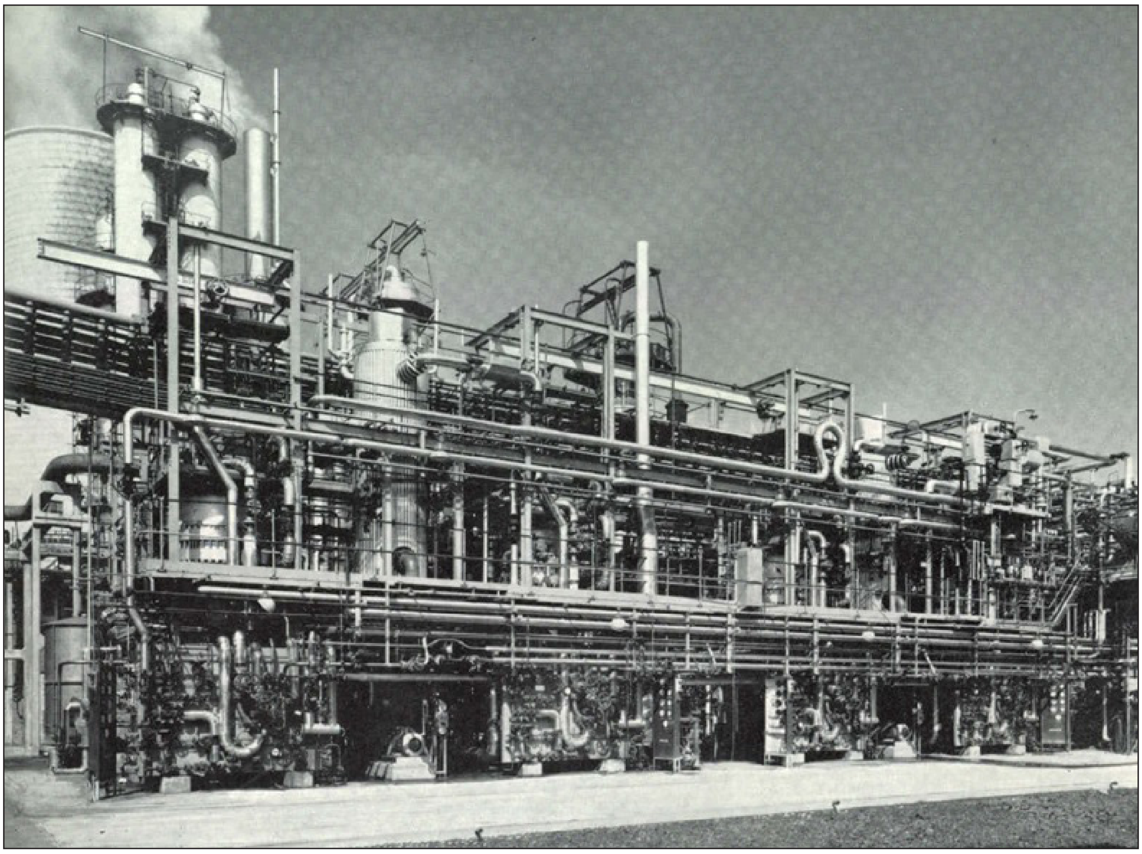


Figure 3.155 The Shell Gasification Plant built at the Isle of Grain. Image courtesy of National Grid Gas Archive.

The Plant was fitted with carbon separators and scrubbers to treat the gas before it was passed to alkazid plant where hydrogen sulphide was removed. The carbon monoxide in the gas was converted to carbon dioxide and this was then removed leaving a gas primarily consisting of hydrogen. (BP 1965, Barash and Gooderham 1971).

3.4.5.6.3 Koppers-Hashe Process

This process was another partial combustion process developed from the Dayton oil gas process. It was designed to operate at atmospheric pressure and only with hydrocarbon gases. The plant consisted of a vaporiser vessel, venture ejector and a reforming vessel. The latter which consisted of two banks of alumina grooved chequer tiles separated by the reaction space. The process efficiently converted a high calorific value mixture of LPG/air to a high calorific value “town gas” containing carbon oxides and nitrogen. But the economics were not favourable (BP 1965). Such a plant was built at the Hempsted gasworks in Gloucester.

The Topsøe-S.B.A Auto-Thermic Process was developed by Haldor Topsøe of Denmark and Societe Belge de l’Azote of Belgium. It also used Catalytic conversion (Barash and Gooderham 1971).

3.4.5.7 Continuous Catalytic Reforming of Petroleum Gases and Light Distillate

A range of continuous catalytic reforming processes were developed. These varied in the temperature (700-950°C), pressure (1-40 atmospheres) and whether steam was used, the reaction was carried out in externally heated in nickel chromium steel tubes, usually in the presence of catalyst.

The gases produced usually consisted of hydrogen, carbon monoxide, carbon dioxide, some methane and undecomposed steam. These processes did not produce tar, however some (Power Gas/ICI continuous reformer with enrichment by the gas recycle hydrogenator) did produce small amounts of benzol which were recovered and could be burnt to heat the reformer (BP 1965).

3.4.5.7.1 ICI ‘500’ Process

This process was developed by the Imperial Chemical Industries (ICI). Plants were built at major gasworks across the country including sites at Bromley By Bow and East Greenwich (Figure 3.156) in London. The ICI process used external heating of two reforming furnaces each containing about 66 tubes, each 21 ½ foot in length and 5 inches in diameter. The tubes were filled with ICI 46/1 a specially design catalyst manufactured by ICI which contained a nickel catalyst on a ceramic base. The hydrocarbon feedstock would be preheated, vaporised, desulphurised and passed along with steam through the tubes where in the presence of the catalyst the hydrocarbon reacted with the steam to form hydrogen, carbon monoxide and methane. The gas produce was then passed through a waste heat boiler where steam was added to convert carbon monoxide to carbon dioxide in the presence of an iron oxide chrome oxide catalyst. The carbon dioxide could then be removed. The gas was then purified and enriched to produce a 500 btu/ft^3 gas (BP 1965, Barash and Gooderham 1971).

At East Greenwich the ICI tubular continuous reformed (Figure 3.156) converted feedstocks such as Light Distillate Fraction (LDF) or sometimes methane feedstock to a lean gas which was then subsequently enriched by methane and/or butane (Anon, 1965).

A different catalyst (ICI 53/1) was used by the ICI 500 plants operated by the North Western, Eastern and Southern Gas Boards.

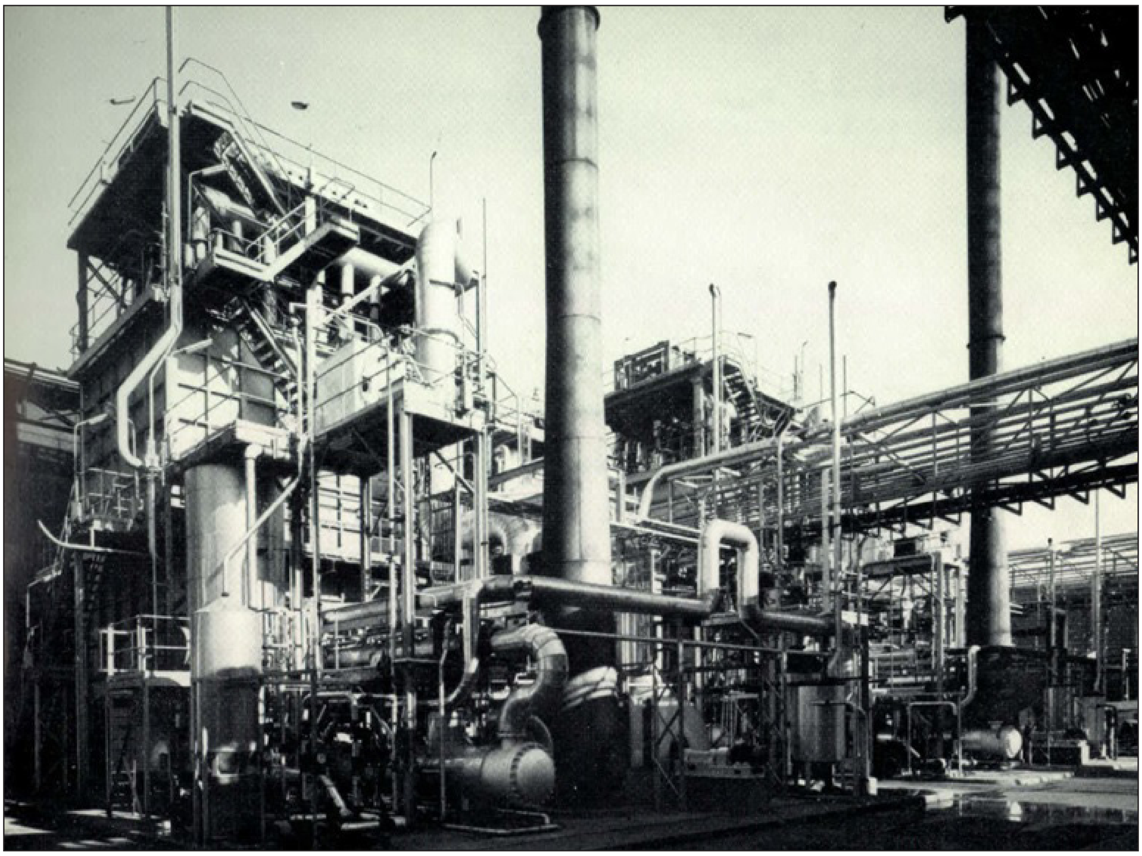


Figure 3.156 An I.C.I Tubular Reforming plant built at the East Greenwich Gasworks Image Courtesy of the National Grid Gas Archive.

3.4.5.7.2 Power Gas – Continuous Catalytic Reforming Plant

This process developed by Power Gas was designed to continuously catalyse LPG. It used furnaces containing rectangular tubes arranged in rows which were heated by LPG. The LPG was gasified in steam, sulphur removal was achieved by admixing the LPG with a small volume of hydrogen recycle gas and vaporising it, then passing it through a cobalt-molybdenum catalyst.

The sulphur compounds were converted to hydrogen sulphide and removed by passing the gas over zinc oxide pellets. The steam and LPG then passed into the reformer tubes heated to 700°C (Anon. 1965). The lean gas produced was collected and cooled in direct-air heat exchangers. The gas would then be passed through an absorption scrubber (Figure 3.157) in which with an absorption reagent, a form of aqueous amine (monoethanolamine) was passed counter current to remove CO_2 and produce a hydrogen rich recycle gas (Anon. 1965).

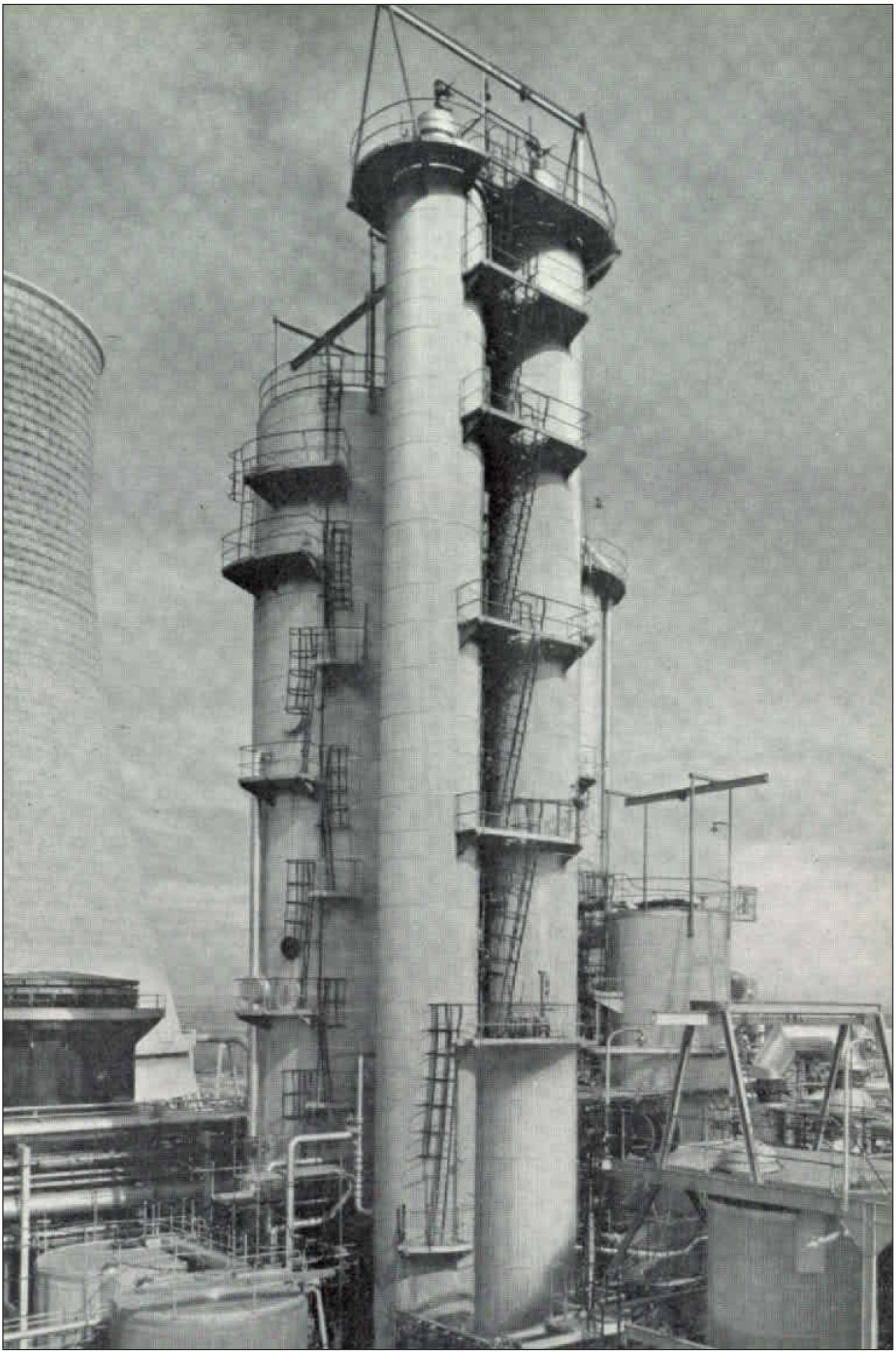


Figure 3.157 Carbon Dioxide Absorption Plant used on a Power Gas Continuous Catalytic Reforming Plant. Image Courtesy of the National Grid Gas Archive.

3.4.5.7.3 Otto Process

A plant of this design was built by Simon Carves Ltd under license from the German Otto company at the Cremorne Road site (Figure 3.158) in Norwich. This plant produced a 500 btu/ft^3 gas at a pressure of 6.8 atmosphere (100 psig). The propane used in the process was transported by pipeline from Felixstowe to Norwich. The propane was desulphurised by passing it through a solution of specially activated sodium oxide a process known as the Otto Degussa System. The gas was then passed into an externally heated Otto reforming furnace, the reforming tubes were filled with a pelletised nickel based catalyst with aided the breakdown of the propane. The gas from the reformer was composed of carbon dioxide 12.4%, methane 6%, carbon monoxide 13.3% and hydrogen 68.3% and had a calorific value of between 280-310 btu/ft^3 (Eastern Gas 1965).

Figure 3.158 Otto High Pressure Reforming Plant Cremorne Lane, Norwich. Image courtesy of National Grid Gas Archive.

The carbon monoxide was then converted to carbon dioxide by reaction with water in a vessel which contained ferric oxide/chromium oxide catalyst. Hydrogen sulphide was then removed from the gas by using the Stretford process (described in the section on gas purification). The gas was then ballasted with inert gas and enriched with propane to ensure the gas had the correct composition for distribution (Eastern Gas 1965).

3.4.5.7.4 Topsøe Plant

The Topsøe plant was developed by Haldor Topsøe of Denmark. It was a gas reforming process which used high pressure and feedstock of methane or light distillate to directly produce town gas of the correct calorific value. Five plants were built in England, these were at Northampton, Slough, Staines, Fulham and Poole (Barash and Gooderham 1971).

3.4.5.7.5 Koppers-Kontalyt Process

This process manufactured a town gas from naphtha reformed with steam within a tubular catalyst filled reformer. Such a plant was built by Woodall-Duckhams under license from Koppers at the Killingholme works of the East Midland Gas Board (Barash and Gooderham 1971).

3.4.5.8 Gas Council Processes

The Gas Council funded the development of four related processes. These processes came to dominate gas production during conversion to natural gas. The most popular of the processes were the Catalytic Rich Gas (CRG) Process and the Gas Recycle Hydrogenator (GRH) processes.

3.4.5.8.1 Catalytic Rich Gas Process

The Catalytic Rich Gas (CRG) process was developed by Dr F. J. Dent and his team at the Midland Research Station at Solihull. The process produced a non-toxic gas with a Calorific Value of about 650 Btu/ft^3.

The CRG could produce gas from LPG or naphtha by reaction with steam under pressure within a medium-temperature reactor. Depending on how the gas was processed, the rich gas produced was then either used as a fuel gas, to enrich lean gas or as a substitute “town gas” or natural gas. A process flow diagram is shown in Figure 3.159 of the CRG process.

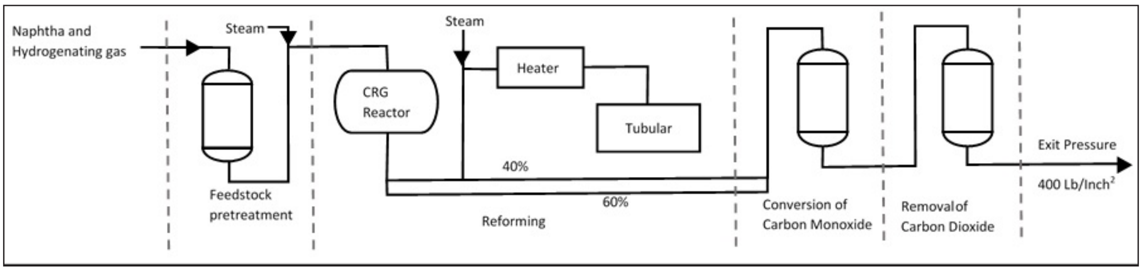


Figure 3.159. Process Schematic for the CRG Process. Image Courtesy of R. Thomas.

There were four main parts to the CRG process. These were:

(1) The feedstock was treated with a catalytic hydrogenator, which turned any sulphur compounds into hydrogen sulphide, which could then be removed by iron oxide;

(2) The conversion of naphtha and steam in the CRG reactor vessel using a catalyst followed by the reforming of 40% of the gas in a tubular reformer;

(3) The conversion of the carbon monoxide to carbon dioxide by passage of the gas over an iron catalyst containing chromium oxide; and

(4) The removal of carbon dioxide, aided by passage of the gas through a packed tower through which potassium carbonate flowed.

The process was more complex than described as each of the parts were composed of several processes.

A key aspect of the pre-treatment was the use of a catalytic hydrogenator to turn any sulphur compounds into hydrogen sulphide which could then be removed by iron oxide. The CRG reactor was packed with 'B' catalyst, whereas the tubular reformers were composed of vertical tubes of an alloy steel containing chromium and nickel.

The process became popular because it was economic and flexible and required no external heating as the process was exothermic. Dr Dent was made a fellow of the Royal Society because of the work and the Gas Council Awarded a Queens Award to Industry (Barash and Gooderham 1971).

3.4.5.8.2 Gas Recycle Hydrogenator

The Gas Recycle Hydrogenator (GRH) process was non-catalytic and used a hydrogen rich gas to preheat the hydrocarbon feedstock prior to entering a specially designed insulated reactor vessel. The reactor vessel was heated to between 700-750°C, within which the hydrocarbon feedstock was broken down into smaller molecules and partially hydrogenated.

The first installation of the GRH was installed at the Seabank Gasworks of the South-Western Gas Board and integrated with an existing ICI gas reforming plant (Barash and Gooderham 1971).

3.4.5.8.3 Lean Gas Process

The lean gas process required pre-treatment of the feedstock to remove sulphur compounds. The feedstock was then mixed with steam and preheated to between 400-500°C prior to entering a tubular reformer which was heated to 740°C and composed of tubes between 20-40ft long and 5-6 inches in diameter filled with an inert corundum support impregnated with Nickel and Uranium oxides (Barash and Gooderham 1971).

The final gas produced was carbon dioxide 17%, carbon monoxide 10%, hydrogen 56% and methane 17%. The Carbon monoxide could be converted to carbon dioxide and the carbon dioxide could be removed (Barash and Gooderham 1971).

3.4.5.8.4 The Preheat-Reheat Process

This variant of the Gas Council Process produced town gas by reforming rich gas produced via the CRG reactor (described previously). The rich gas was mixed with steam and heated to 740°C before entering two vessels placed in series containing a nickel enriched aluminium oxide catalyst to affect the reforming process. A plant of this design was built at a site at Whitehill Point by the Northern Gas Board (Barash and Gooderham 1971).

3.5 Gas Storage

3.5.1 Introduction

This section has been written slightly differently to other parts of the report. This is because an extensive body of work "London Gasholder Survey" was previously commissioned for English Heritage and produced by Malcolm Tucker, a recognised authority on gasholders. This document focusses on the gasholders of London and contains detailed descriptions of gasholder which used guide frames. The survey contains valid information applicable to these types of gasholders found across England and most importantly it includes the Tucker Typology, a system for classifying gasholders based on their design, further reference is made to this within the document.

The ability to store gas was vital for the efficient operation of a gasworks and this function was provided by the gasholder.

The consumption of gas always fluctuated during the day and night (diurnal) dependent on use. The production of gas using retorts could not be readily increased or decreased. This was due to the time taken to get the plant operational being measured in days. The gas making plant operated best when it was run at a constant rate of production. Greater flexibility was introduced when carburetted water gas manufacture was introduced in the 1890's and again when oil gas was introduced in the 1950, but the requirement for gas storage was always an integral part of the gas industry (Sturt 1981).

Without the buffer of supply provided by gasholders, the gasworks would have needed to balance gas production with the consumption of gas, this could then have only been achieved by always producing more gas than required and flaring or venting the excess. The industry would have been considerably less cost effective and probably not economically viable. For this reason, the gasholder dates to the creation of the gas industry, being used in the earliest of gasworks constructed (Sturt 1981).

The diurnal fluctuations in gas demand changed through the history of the industry. During the period where gas was used primarily for lighting (up to about 1880), the consumption of gas was greater in the evening, when gas lighting was required. As gas became more widely used for heating and cooking, then greater demand developed in the morning and evenings especially at meal times. Gas use also fluctuated on a seasonal basis, with greater gas use in the darker and colder months of the year. Gasholders evolved through the history of the gas industry, however, they were primarily low-pressure storage vessels, this was until the advent of high pressure gasholders, such as bullet tanks and Horton spheres, which appeared from the 1930s onwards (Stewart 1958, Clements 1968).

Gasholders are one of the last distinctive features remaining from the manufactured gas era to be found on former gasworks sites. They were retained after the manufactured gas era had ended because they remained an integral part of the gas distribution system in the natural gas era. Even after the manufactured gas era and the construction of National Gas Transmission System, a demand for low pressure storage still existed in 1981, when this amounted to about 15% of the daily supply (Sturt 1981). This requirement gradually declined until it was finally phased out in 2015.

The requirements of diurnal storage have since been met by alternative solutions. As natural gas is compressible, it can be held within the gas transmission and distribution systems under higher pressures, this creates a storage capacity within the pipelines, known as linepack, which is released by the gradual depressurisation of the high-pressure grid mains (Sturt 1981).

Some large-scale gas storage is provided at below ground facilities such as depleted oil and gas fields (e.g. Humbly Grove) and within salt caverns (e.g. Holford). Gas storage is also provided by the giant Liquefied Natural Gas (LNG) storage tanks built at LNG importation facilities, such as the Isle of Grain.

Gasholders are characterised by a single or series of large interconnected (telescopic) cylindrical vessels (lifts) which would rise and fall from a water filled tank, depending on the volume of gas stored.

It was estimated that over 3000 gasholders were in operation across Great Britain in 1958, which varied in capacity from 5,000 to 12,000,000 cubic feet (Stewart 1958). By 1981 it was estimated that there were between 1600-2000 gasholders remaining within the gas network located on 850 sites (Sturt 1981). Since then the number of operational gasholders gradually declined until 2015 when the last operational gasholders on the gas networks in England, were taken out of service. A few high-pressure bullet gasholders remain in service, but all the low-pressure telescopic gasholders in England associated with the gas network have been decommissioned. Those which have not been listed, are awaiting demolition.

The oldest surviving gasholder in the world is located at the former gasworks site in Fulham, London and has Grade II* listed status, a photograph of the gasholder dating to 1951, whilst still operational as a relief gasholder is shown in Figure 3.160.

Figure 3.160 No.2 Gasholder Fulham whilst still operational in 1951, built circa 1830 and attributed to John Kirkham and Samuel Clegg. Image courtesy of IGEM Archive.

Four listed former gasholders at Kings Cross have recently been incorporated into a new development at the site. The gasholders which consisted of a single gasholder and three interconnected gasholders were removed refurbished and reassembled elsewhere on the site and are now a park (the single gasholder) and three blocks of apartments located within the frames of the gasholders.

Whilst most above ground features of gasworks were removed during demolition and redevelopment. Below ground features such as the tanks of former gasholders can still be present on many former gasworks sites. This is due to the size and depth of such structures which may extend below the water table. Historically during demolition, the tank void formed a ready-made repository for demolition rubble and other materials on site.

3.5.2 Gasholders and Gasometers

The word ‘gasometer’ is commonly found on historical Ordnance Survey maps dating back to their first editions. The term can even be found on older tithe maps.

The term gasometer originates from the instrument developed by the French chemist Antoine Lavoisier for use in his pneumatic chemistry experiments. Lavoisier who termed the instrument the Gazomètre, and used them to store and supply a uniform stream of oxygen for his experiments and is shown in Figure 3.161.

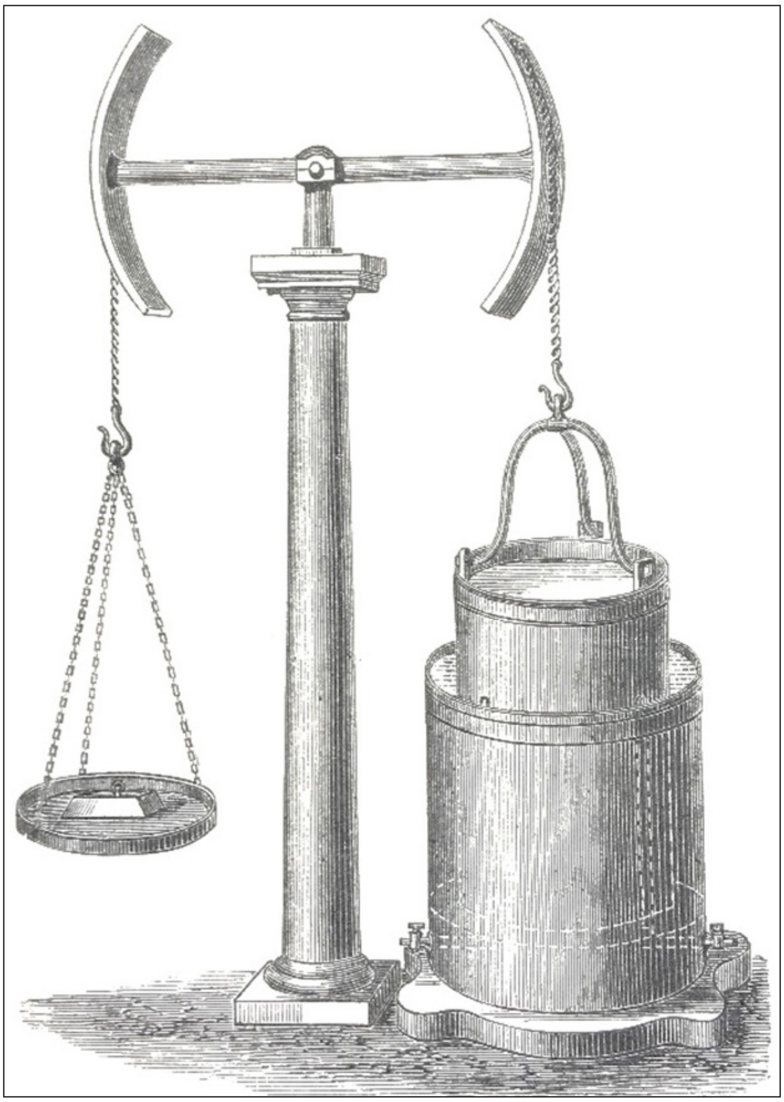


Figure 3.161 A drawing of Lavoisier's Gasometer. Source Fewtrell and Newbigging 1878, Vol 2.

The application of the gazomètre to the gas industry, was an excellent example of the close ties which had existed within the community of natural philosophers, engineers and scientists in the late 18th century. This was a time when there was considerable interest in pneumatic chemistry, the study of the chemistry of gases (Thomas 2018).

At this time a mixture of friendship, rivalry and cooperation existed between British scientists, most notably Joseph Priestley and their European counterparts, most notably in the case of the gasholder, Antoine-Laurent Lavoisier. Priestley was a prominent member of the famous Lunar Society, this was a dinner club and informal learned society of prominent figures based in the Midlands. Its original members included such notable figures as Erasmus Darwin, Josiah Wedgewood, Matthew Boulton and James Watt. The society still meet today (Hunt, 1907, Tomory, 2012, Newbigging and Fewtrell, 1878).

French chemists had adopted an empirical approach to their work, developing accurate tools for the collection, weighing and measurement of gases. Key amongst these was Lavoisier's Gazomètre (Figure 3.161). This simple instrument was composed of a counter-balanced cylindrical metal vessel (Grand Cloche), which was sealed at the top, but open at the base. It was placed in a tank of water, open side down. The water acted as an air-tight seal, which kept the gas in the vessel whilst it's base was submerged (Lavoisier 1787, Newbigging and Fewtrell 1878).

The gazomètre featured in Lavoisiers important book Traité Élémentaire de Chimie and some of the original equipment survives today in France, thanks to his wife. Lavoisiers career and life were cut short when he was executed during the French Revolution (Hunt, 1907, Tomory, 2012, Newbigging and Fewtrell, 1878).

Lavoisier's gazometre had been adopted by Boulton in his unsuccessful collaboration with Thomas Beddoes developing equipment used in pneumatic medicine. It was the realisation by Boulton and Watt engineers that the gazomètre could be scaled up considerably for the storage of gas on an industrial scale, which enabled the gas industry to manage the its problem of balancing supply and demand (Tomory, 2012).

Throughout the history of the gas industry, gas storage evolved, but the principals of the gazomètre were used in England for over 200 years for low pressure gas storage. Clegg used a rectangular version of the gasometer for the gasworks he built for Rudolph Ackerman shown in Figure 3.162.

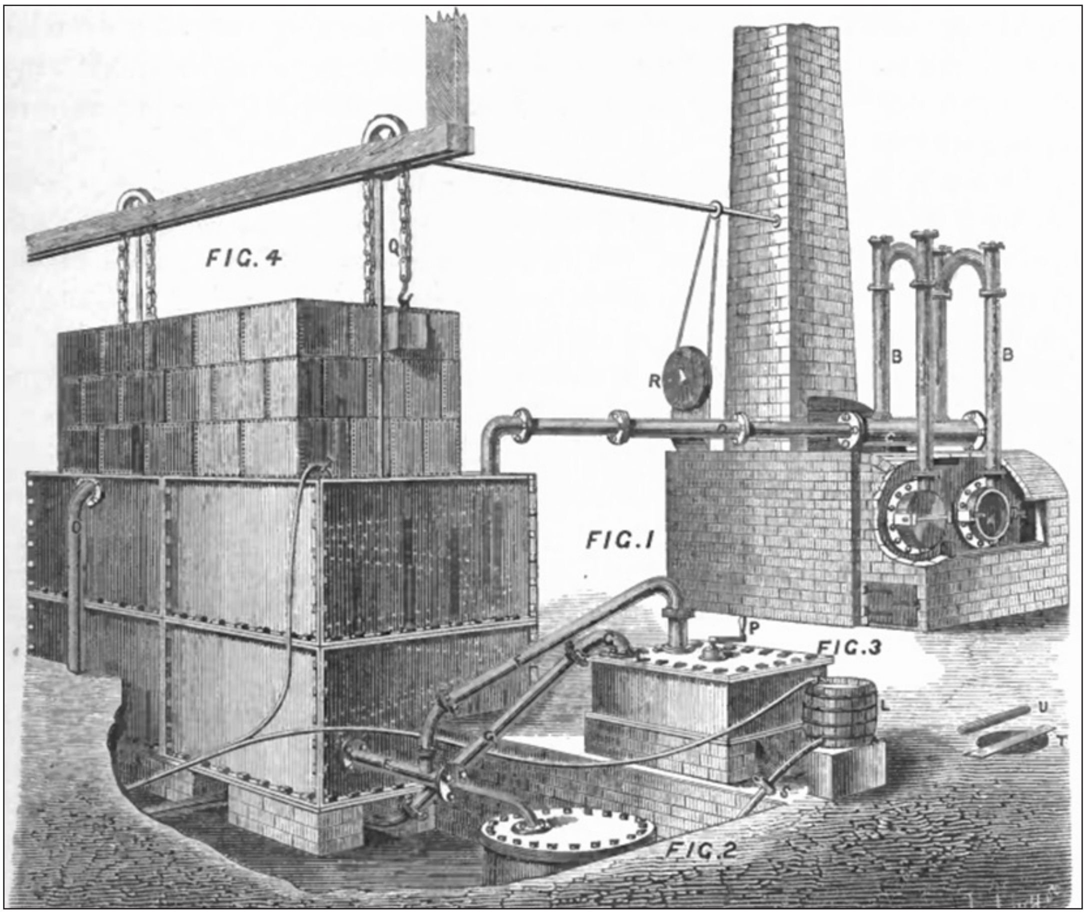


Figure 3.162 A Print of the Gasworks Built by Samuel Clegg for Rudolph Ackerman, a famous London printer, Indicating the Retort Setting (FIG. 1), Tar Receiver (FIG. 2), Lime Purifier (FIG. 3) and Gasholder (FIG. 4). Source Accum 1815.

In terms of gas storage and supply, the term gazomètre or its English derivation gasometer was an incorrect term. They were not used to measure gas, which was the role of the gas meter, although they provided a crude visual indication. They were constructed for storing or 'holding' gas, hence the name gasholder.

The term gasometer is found in early gas texts, such those written by Accum (1815), Peckston (1819) Clegg (1841) and even as late as Richards (1877). The term survived on Ordnance Survey (OS) maps until the 1970s.

Gasometers marked on early OS or tithe maps which were not located on gasworks, but located adjacent to mills, factories, hospitals and country houses, were typically associated with small gasworks serving the establishment, which itself was not specifically marked on maps.

Some sites were only ever established as gasholder stations, where gas was stored but not manufactured. These were often on the periphery of the gasworks distribution network, areas of high demand or sites where insufficient land existed at the gasworks to store the gas (e.g. the Kennington Oval and Battersea Gasholder Stations). Some gasworks evolved into gasholder station, when they obtained a supply of gas from a bigger more efficient gasworks. This led to the closure of their gas manufacturing plant, but often the retention of the gasholders. After gas manufacture ceased in England, all remaining gasholders effectively became gasholders stations.

3.5.3 Evolution of the Gasholder

Gasholders have been a feature of gasworks ever since they were first constructed. Examples of such early gasholders can be seen in figures 3.160 and 3.612-3.164. The rectangular gasholder design shown in Figure 3.162 was used by Murdoch and Clegg in early gas installations.

Like Lavoisier's Gazomètre, the first gasholders consisted primarily of two parts: a tank which contained water, and a cylindrical vessel or lift which was sealed at one end and inverted over the tank, which would contain the gas (Sturt 1981). The function of the water was primarily to provide an elastic gas-tight seal in which the vessel could rise or fall. The water also received the whole of the pressure exerted by the weight of the vessel and, in this way, the water formed the necessary resistance to raise the vessel or expel the gas. The gasholder operated on the basic principle of a gas-filled floating vessel, rising and falling in a seal of water (Fewtrell and Newbigging 1878, Stewart 1958, Sturt 1981).

As well as storing the gas, the gasholder acted as a crude visible 'meter', it acted as a buffer between production rates and the more unpredictable consumption rates, and until boosters were introduced it provided the pressure in the gas mains for the distribution of the gas (Stewart 1958).

It was very important that the weight of the gasholder vessel was calculated correctly so that it would provide sufficient pressure to the gas in the mains with which it was connected. It was not unusual for weights to be placed on the top of a gasholder to increase pressure. If the weight of the gasholder was too great, it would put increased back-pressure on the exhauster. If an exhauster was not used, the weight thrown by the gasholder would restrict the flow of the gas leaving the retorts, and the quality of the gas and tar released from the coal would be degraded.

The first gasholders were rectangular and over-engineered, being constructed of iron with a heavy wooden frame, and holding about 500 ft^3 (14 m^3) of gas (Richards 1877 p160). Figure 3.163 shows a rare example of an early American gasholder c1820, which had wooden framing.

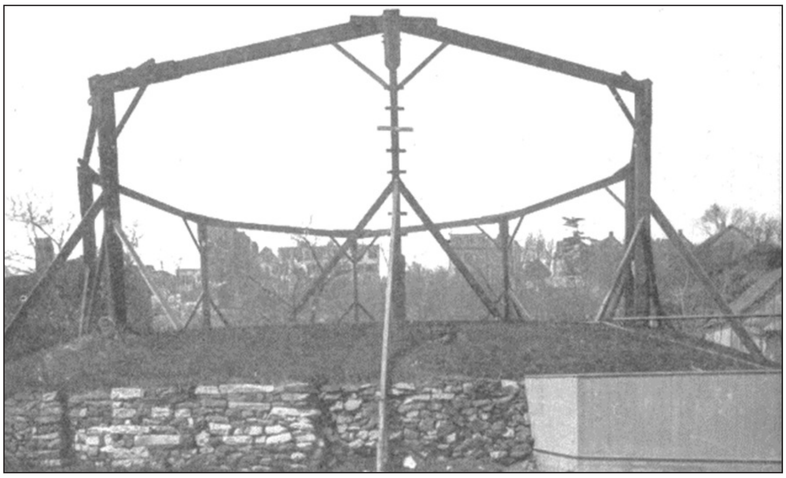


Figure 3.163 An early example of a gasholder with a wooden framing, from New York, circa 1820s. Source Journal of Gas Lighting 1909.

Initially the gasholder tank was also used to condense the tar from the gas, and could be used to partially purify sulphur from the gas by the addition of lime to the water in the tank. This early use of lime was ineffective due to the settlement of the lime. Rectangular gas holders continued to be built until 1816 when they were replaced by the cylindrical design (Richards 1877 p160).

The cylindrical gasholders (e.g. Figures 3.160, 3.164 and 3.165) were bigger and had a greater capacity than the rectangular tanks they replaced, two early examples are shown in Figures 3.164 and 3.165. The biggest problem with the new gasholders was the construction of suitable tanks. With the tanks being built above ground and constructed from wood. However, they were not particularly robust and were prone to leaking, the ammonia and hydrogen sulphide which dissolved in the water, which corroded the iron hoops and could lead to the tanks collapse. The last of these wooden tanks was removed from the Gas Light and Coke Company's Brick Lane gasworks in 1843 (Richards 1877 p160-161, Sturt 1981 p233).

Early safety concerns over gasholders expressed by Sir Joseph Banks and members of the Royal Society, led to gasholders being limited in size to 6000 ft^3 and constructed in strengthened buildings (Clegg 1841 p.18). These buildings were known as a gasometer or gasholder houses. They were a separate superstructure built around the gasholder to protect it from explosions and the weather, wind shear, show loading and lightning in particular. The benefit against the risk of explosion was not sound, as gas could leak from the gasholder into the air surrounding the gasholder within the house, forming a potentially explosive atmosphere (Sturt 1981).

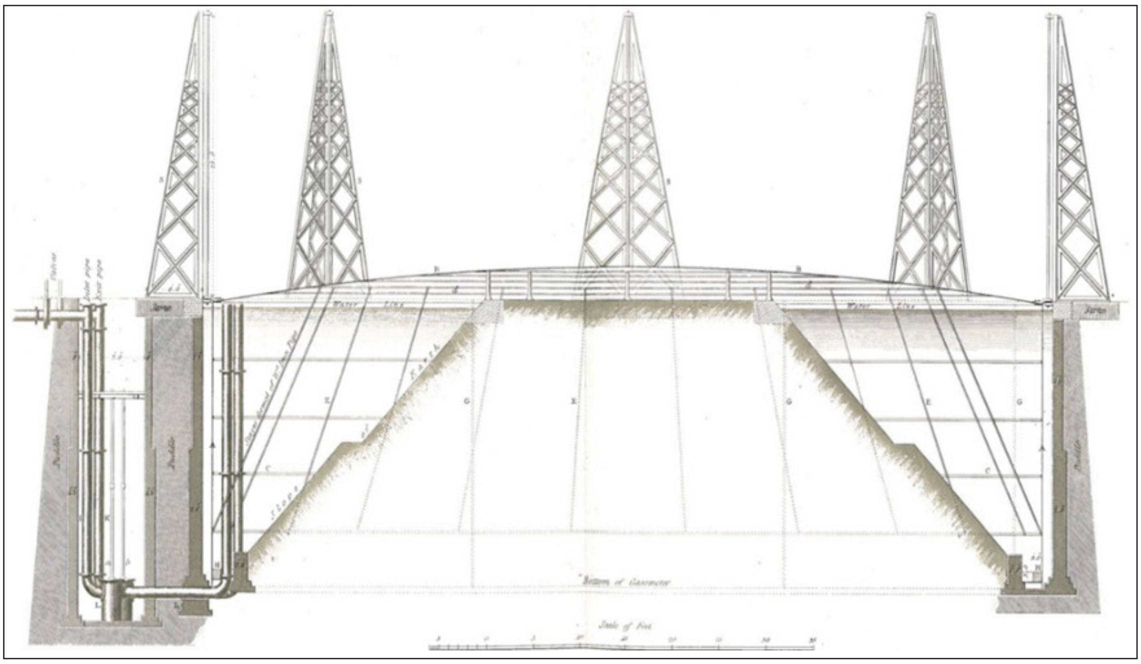


Figure 3.164 Design of an early gas holder taken from ‘A practical Treatise on the Manufacture and Distribution of Coal Gas’ by Samuel Clegg Junior. This simple design shows many of the features common in later gasholders. Note the basic guiding of the gasholder vessel by metal brackets with eyelets running on cylindrical metal bars; these were later replaced by guided rollers. Source R. Thomas.

Figure 3.165 The primitive gasholder at the former Soho factory of Bolton and Watt, when under the ownership of Avery in 1903, still being used to store producer gas. Although an early design, is not believed to be directly attributable to Murdock. Image courtesy of National Grid Gas Archive.

Numerous gasholders houses were built, for example at the original gasworks in Northampton, Leamington Spa and Warwick, the latter of which are the only surviving example in England. These structures were phased out in the UK, but in parts of Europe and North America, where cold weather brought the risk of freezing and high snowfall, ornate brick-built gasometer houses were constructed. Examples in Helsinki (Finland), Copenhagen (Denmark), Leipzig (Germany), Vienna (Austria) and Warsaw (Poland) are preserved.

Whilst employed at the Gas Light and Coke company, the great gas engineer Samuel Clegg developed some alternative forms of gasholder but none of these were an effective replacement. Clegg developed a revolving gasholder (Figure 3.166), which worked with greater regularity and less friction than other types of gasholder, but still required a water tank, was no cheaper to build than a gasholder with an iron tank and more complicated and difficult to repair. A few were built including one at the Peter Street Gasworks of the Gas Light and Coke Company. Clegg also developed a tent shaped collapsing gasometer in 1818. These designs and another which involved storing gas in a canvas bag or balloon, were never successful, the latter design being too easy to catch fire (Stewart 1958 p32-33, Clegg 1841 p17-18).

By 1819, gasholders had reached capacities of about 566 m^3 (20,000 ft^3) using iron or wooden tanks. John Malam, a gas engineer of the famous Malam gas-engineering dynasty, did much to improve cylindrical gasholder design by reducing the weight of the internal framing and using counterbalance weights and chains. Malam also developed a system where the gasholder was guided by a central rod and tube. This rod and tube system was used extensively on small gasholders, many such examples surviving until at least the 1870s (Richards 1877 p162, Sturt 1981 p232).

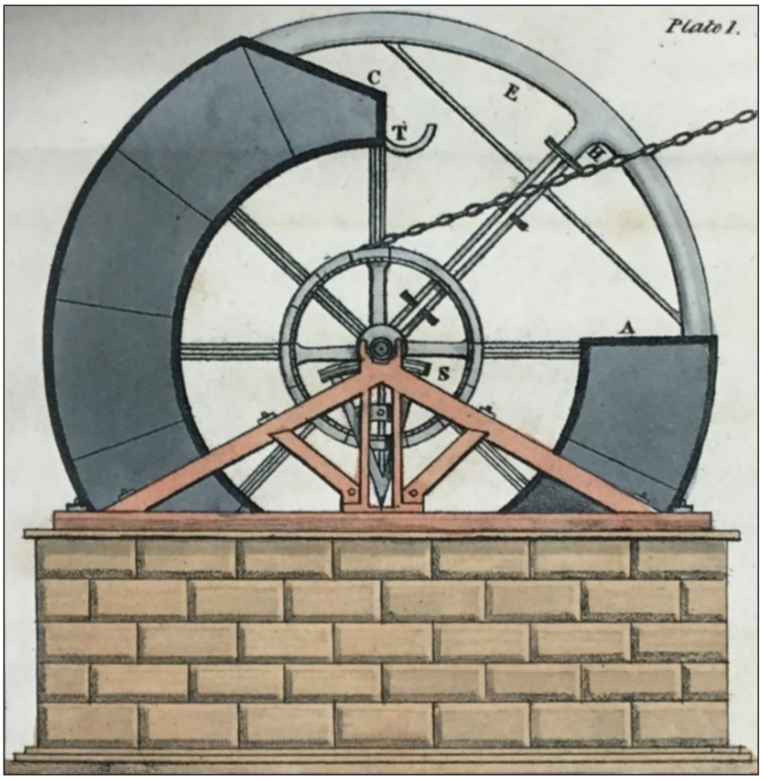


Figure 3.166 Clegg's rotating gasholder. Taken from Accum 1819. Image courtesy of National Gas Grid Archive.

Brick tanks were introduced in 1818, with stone and concrete tanks coming later (Richards 1877 p162). By 1823 there were 47 gasholders in use in London, Sturt 1981).

Their simple design and reliability saw the gasholder concept remain in use for over 200 years. Almost all gasholders worked on the same principle. The vessels or piston would rise and fall depending on the quantity of gas stored. It was the method employed to guide the movement of the vessel or piston that differed as the gasholder technology developed. There also became a fashion in the early years of the gas industry to name gasholders, the first gasholder designed for the Bristol gas company by Samuel Clegg was known as "Aladdin" (Sturt 1981).

Originally, gasholders contained only a single vessel (lift) suspended within the tank; later, multiple-lift (telescopic) gasholders were developed (Figure 3.167). William Nicholson attempted to patent a telescopic holder, with two or more lifts, in 1827, but had to give up his claim for the patent in 1836 due to the prior unpatented design of Tait from 1824. The first telescopic gasholder was built in Leeds in 1826, and early examples were also constructed at Mile End in London (Sturt 1981).

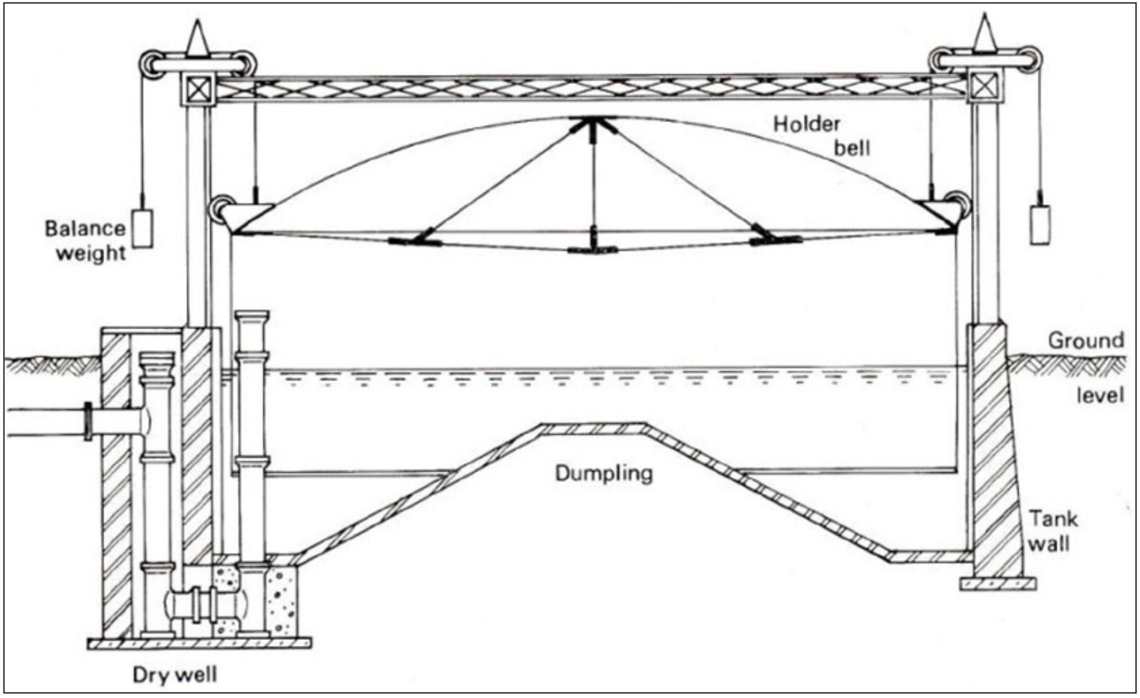


Figure 3.167 A schematic diagram of a guide-framed gasholder with a below-ground tank. Source Sturt 1981. Image courtesy of IGEM Archive.

In Tait's unpatented design the gasholder bell or otherwise known as an inner lift, was fitted all along its base with a U-shaped cup. The outer lift had a similar but inverted u-shaped grip fitted around its top. As the inner lift filled with gas and rose, the cups interlocked into the grips and then the two sections would rise together. As gas was removed from the gasholder the lifts would decouple in the reverse fashion. The gas tightness in the cup and grip joint between the lifts was secured by the presence of water in the U-shaped cup forming a seal. All subsequent telescopic designs used the same general design although the different forms of cup and grip were developed (Stewart 1958, Sturt 1981).

When Samuel Clegg Junior wrote his treatise in 1841, he commented that telescopic gasholders were an expensive exception to be used only in highly constrained sites. They eventually became commonplace, with many earlier single-lift gasholders being extended to multiple-lift (Clegg 1841, Richards 1877, Sturt 1981).

In 1852 an unsuccessful attempt was made to construct a three-lift gasholder at the Rotherhithe gasworks. This was followed, in 1861, by the first successful example built by the City Gas Company at Blackfriars, shown in Figure 3.168. A four-lift gasholder was built by the South Metropolitan Gas Company at East Greenwich in 1886 (Sturt 1981).

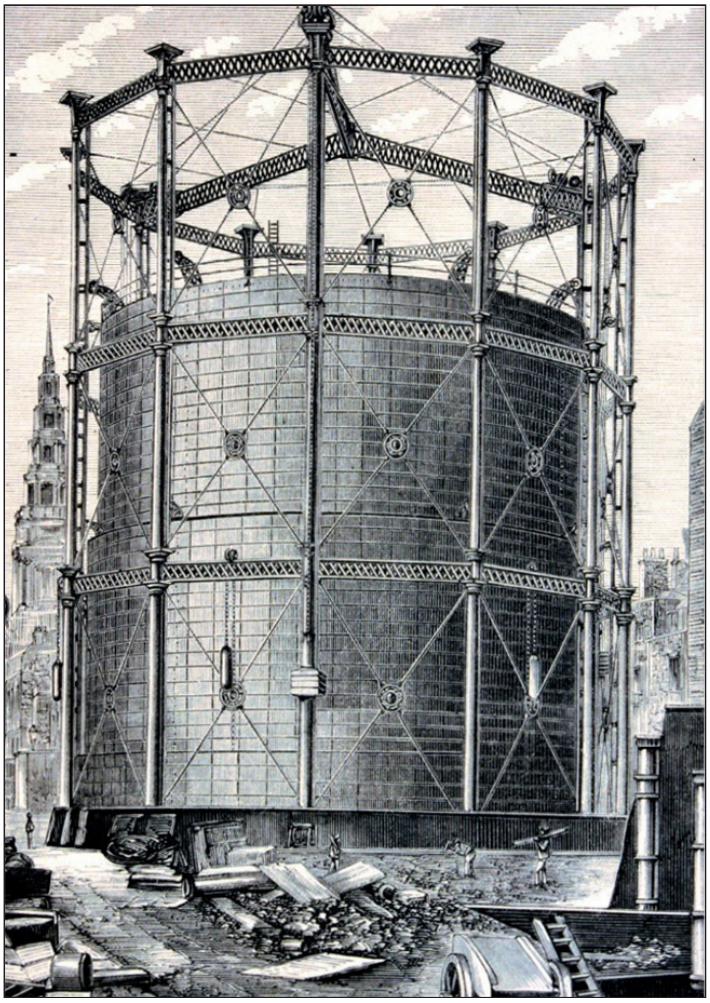


Figure 3.168 The three-lift column-guided gasholder designed by William Mann and built by Westwood & Wright for the City of London Gas Company's works at Blackfriars, London in 1861. The holder is shown ready for demolition in about 1878. Source from King's Treatise, Vol II (Fewtrell and Newbigging 1878). Image courtesy of R. Thomas.

Telescopic gasholders shown in Figures 3.167-3.169, allowed a much greater volume of gas to be stored in roughly the same footprint of land, making them more cost effective (Sturt 1981, Richards 1877).

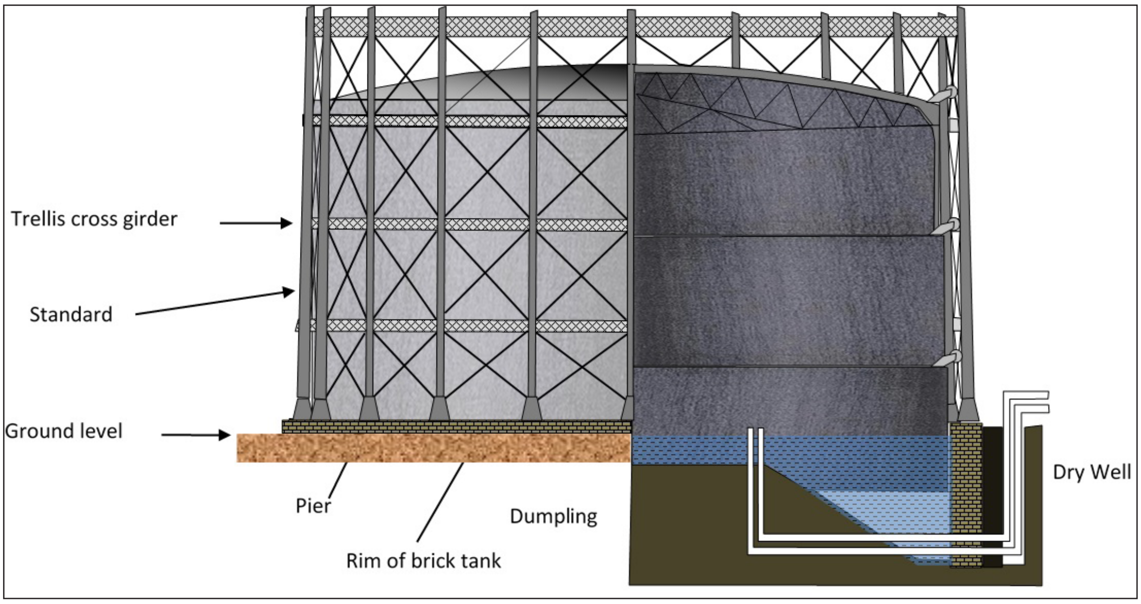


Figure 3.169 A schematic diagram of a guide-framed telescopic gasholder with a below-ground tank. Source R. Thomas.

Whereas a single lift gasholder would exert a constant pressure from the downward pressure created by the weight of the gasholder. The effect of adding additional lifts was that when the next lift was engaged and filled with gas it increased the pressure exerted by the gasholder. This caused additional problems with the supply of gas as the gas pressure was not constant but variable, which required control via the governor. The inner lift would typically exert a higher pressure than the subsequent outer lifts, as it was heavier because it incorporated the weight of the crown (Cripps 1889).

The evolution of column or frame guided gasholders through the 19th century can be seen in Figure 3.170, with St. Pancras station provided as a point of reference for comparison.

During the 1880's two forms of gasholder developed which used no guide columns or frame. These were the wire rope guided gasholder and spirally guided gasholder, the latter became an industry standard whose design prevailed in 20th century.

The waterless holder was first developed in the 19th century. The effective designs were not however introduced into England until the 1920's, with two German designs being imported. A later waterless gasholder design, the Wiggins was introduced into England in the 1950's (Stewart 1958, Sturt 1981).

Low Pressure Gasholders could generally be classified under four main headings, namely:

- Gasholders with guide-framing, which could be single-lift or telescopic, with or without 'flying lifts'.

- Gasholders guided by wire ropes or cables (could be single- or multiple-lift or used as an additional flying lift).
- Spiral-guided gasholders (could be single- or multiple-lift or used as an additional flying lift); the guide rails could be left-hand, right-hand or both, and either internal or external attachments to the lifts.
- Waterless or 'dry' gasholders which stored gas beneath a floating piston.

Another later form of gas storage was the application of high-pressure static vessels, which had no water tanks or moving parts, and received and stored gas at much higher pressure than those listed above. In addition, in more recent years, gas has been stored within high-pressure gas mains, as liquified natural gas (e.g., Isle of

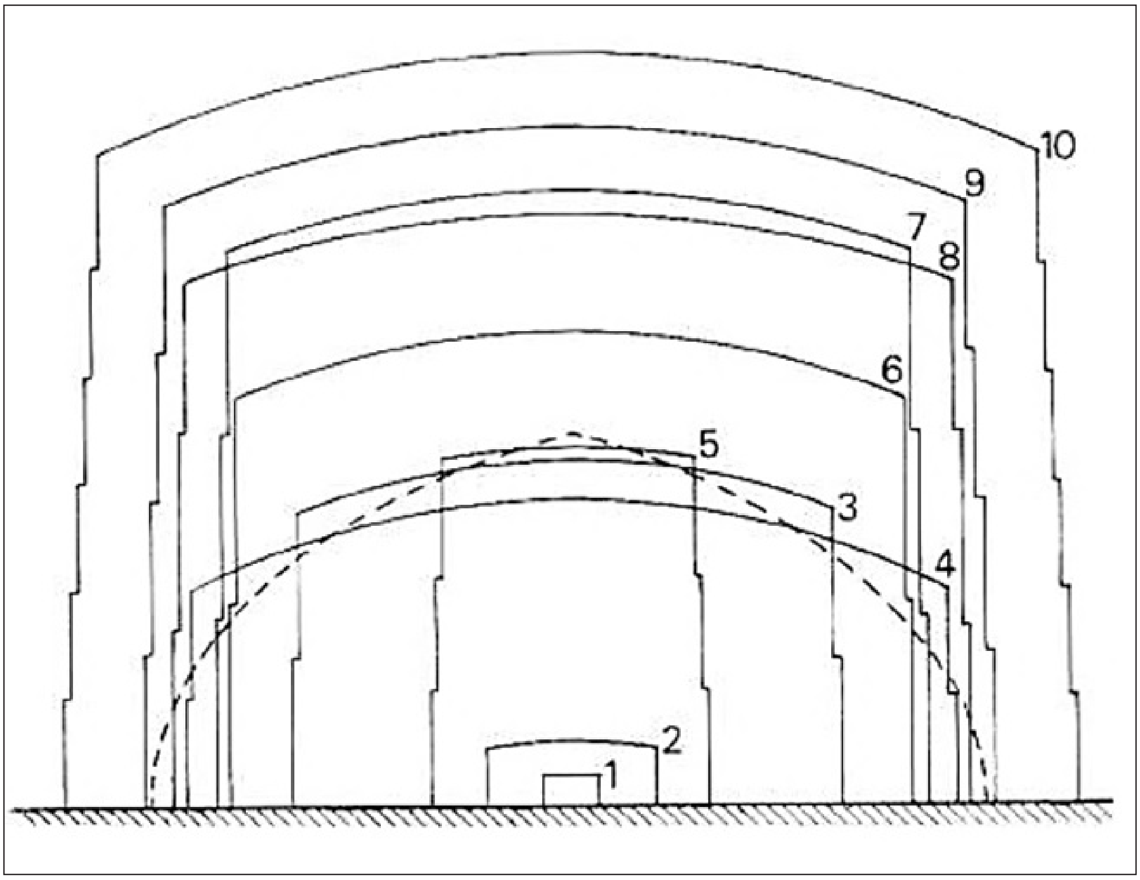


Figure 3.170 Growth of the gasholder from 1,200 to 12,000,000 ft^3 capacity, from a diagram by George Livesey, 1905. 1) Typical chartered single holder (1200 ft^3, 1812), 2) First South Metropolitan single holder (30,000 ft^3, 1832), 3) William lnnis's Kennington double holder (1,400,000 ft^3, 1854), 4) Robert Jones's Stepney and Nine Elms double holders (2,000,000 ft^3, 1860), 5) William Mann's Blackfriars three-lift holder (500,000 ft^3, 1861), 6) Corbet Woodall's Kennington double holder (3,100,000 ft^3 1897), 7) Old Kent Road three-lift holder (5,500,000 ft^3, 1881), 8 Charles Hunt's Birmingham three-lift gasholders (6,000,000 ft^3, 1883), 9 East Greenwich four-lift holder (8,000,000 ft^3, 1887), 10 East Greenwich six-lift holder (12,000,000 ft^3, 1892), To indicate scale, the dashed tine represents the roof span of St. Pancras Railway station, London. Source Sturt 1981. Image courtesy of IGEM Archive.

Grain) and within depleted gas fields (e.g., rough gas storage) or salt caverns (e.g., Holford, Cheshire).

3.5.4 Gasholder Tank

The gasholder tank was the part of the gasholder which would house the lifts when empty of gas. It contained the water in which the lifts would rise and fall, depending on the volume of gas stored, with the water functioning primarily as an elastic gas-tight seal.

By 1818 the three principal designs of gasholder tanks had been standardised, these were:

- Buried or below ground;
- Semi—buried or partially below ground and;
- Above-ground.

The below ground type can be seen in Figures 3.164,3.167 and 3.169 the above ground type can be seen in Figures 3.180 and 3.181. The form of tank chosen very much depended on the ground conditions at the gasworks. If the site was located in an area with high groundwater, especially if the ground was composed of granular material such as gravel, then above ground gasholders would be preferred. This was because it would be costlier and more dangerous to remove the water from the ground to construct the gasholder tank than build the tank above ground from cast iron plates.

Where there was a low ground water table, or the ground consisted of a higher impermeable material such as London Clay, then below ground tanks would be favoured.

A partially below ground tank would have been constructed where the ground water was a few meters below ground level, a level to which the gasholder tank base could be constructed and then the remained of the gasholder tank would extend above the ground level, but with would be supported by a bank of earth on the tanks outer face. The No.1 and No.2 gasholder tank at East Greenwich were constructed on these principals.

The size and form of the excavations required to build a below ground gasholder tank were dependent on ground conditions. The safe angles of repose varied depending on the type of below ground strata encountered, with compact earth offering the steepest and wet clay the shallowest angle of repose.

The material from which a gasholder tank was constructed was dependent on the available local building materials. Where a local source of good quality building stone was available, then this would have been used to build the tank. The most commonly used material for building below-ground gasholder tanks was brick (preferably low-porosity hard-burnt bricks).

To construct a below ground tank, a circular trench was excavated in which the tank wall was built. The wall, typically built of well-burnt brick or other material as described above, would not be waterproof, to remedy this the outer facing walls and base of the tanks were backed with puddle clay. The puddle could be pure clay, but it was thought preferable to mix clay with one-third sand, silt, or soil free from plant matter; this was firmer in texture and less liable to crack when dry. The puddle would be prepared outside of the trench and built up in thin layers as the wall of the tank was built; it was kept moistened, punned well, and backed up with carefully pounded earth (Hughes and Richards 1880 p182-190, Meade 1916 p454-456).

An alternative method of waterproofing was through the application of an inch (2.5cm) render of Portland cement to the internal face of the tank. Applied successfully, this would make the needle for puddle clay redundant. Tanks built from waterproof concrete did not require rendering or puddle (Meade 1916 p454).

The interior of the tank was excavated to the full depth just inside the tank wall, providing room for the bell of the holder and any additional lifts. Where ground conditions were favourable, it was more economical to leave a conical mound known as dumpling, within the centre of the gasholder tank. The dumpling was either faced with brick, stone, rendered or, where suitable clay was available, was left as puddled clay. (Sturt 1981).

In tanks whose diameters did not exceed about 60ft (18m), it would be more economical to remove all the material if it required waterproofing, such tanks would then have a flat base, unless they were constructed in rock, stiff clay or chalk.

The benefits of leaving the ‘dumpling‘ in place were that it reduced the volume of water required within the tank and provided a readymade foundation for the framework to support the crown of an untrussed holder when deflated. Without the dumpling, the volume of water required to fill the tank was very large (Sturt 1981)

Occasionally, tanks were built by excavating a circular trench in the ground and constructing an iron, brick or concrete annular channel to contain the water, with the intervening central space also being covered with a shallow layer of water. A few examples existed where gasholder tanks were hewn out of bedrock as circular annular trenches. The gasholder tanks at the original gasworks in Chester designed by Samuel Clegg and the Garston gasworks in Liverpool were constructed this way in the sandstone bedrock. These tanks still needed water proofing which could be achieved using puddle, render and achieved by painting the rock with tar (Sturt 1981.

For gas to enter and leave the gasholder, inlet and outlet pipes were built into the tank through a shaft excavated outside of the tank wall, known as the dry well. If the pipework was large enough then an airlock was placed at the top of the pipework giving access to the interior of the holder for maintenance when the gasholder was decommissioned (Sturt 1981).

Large gasholder tanks required wall-strengthening methods which included layers of thick Portland cement, at 60-90cm intervals, into which the brick or stone was placed. As an alternative, hooped-iron or flat-iron rings were built at intervals into the wall. In 1871 George Livesey built a composite tank for No. 11 gasholder at the Old Kent Road using concrete to replace the outer layer of brickwork. The tank was still lined with puddle clay to ensure it was water tight, but this new design saved the South Metropolitan Gas Company £1700. (Richards and Hughes 1880 p190-191, Sturt 1981).

The next gasholder tank built in 1875, for the South Metropolitan Gas Company at the Old Kent Road gasworks, was built using mass concrete alone. This method had been first used to build a gasholder tank at Portsea gasworks in Portsmouth by the works Engineer Mr Douglas (Richards and Hughes 1880 p191-192, Sturt 1981).

The construction of the tank for No.12 gasholder proved a considerable challenge as groundwater was encountered at a depth of 11 feet below ground level and between 60,000-70,000 gallons per hour of water had to be removed. This tank saved the company £5000, but the tank later developed vertical cracks through which water escaped. Future tanks built this way by the South Metropolitan Gas Company incorporated iron bands in the walls. As larger gasholders were built, it became standard practice to included layers of thick Portland cement, at 60-90cm intervals, into which the brick or stone was placed, or hooped-iron or flat-iron rings were built at intervals into the wall, whether they were constructed from brick, stone or concrete (Richards and Hughes 1880 p193-195, Sturt 1981).

It was not unusual for gasholder tanks to develop leaks; traditional remedies were to throw dung or spent hops from the local brewery into the holder tank to fill the cracks and reduce the leakage (Sturt 1981).

Below ground column or frame guided gasholders required that the gasholder tanks included brick, stone or concrete piers, to provide foundation for the columns or frame guides. The piers were placed at equal intervals around the gasholder tank and extended from the tanks walls outwards. The columns or frame standard were attached to the piers by holding down bolts (Hughes and Richards 1880 p185-196, Meade 1916, Sturt 1981).

If ground conditions made it very difficult or expensive to construct a below ground gasholder tank, for example ground water not be far below ground level, then a partially below ground tank or an above-ground tank would be the preference (Sturt 1981).

When the first gasholder tank was built at the East Greenwich gasworks in 1886, the poor ground conditions encountered led to the adoption of a partially below ground tank. This gasholder which had originally been planned to be a three-lift gasholder with a 60 foot deep below ground tank, had to be modified to a partially below ground tank 45 feet deep, with the top 13 feet extended above ground level. Even at this reduced depth a massive volume of water (240,000 gallons/hr) had to be removed. The resulting shallower tank required the gasholder to have an additional lift to retain the same capacity, which resulted in the construction of the first four-lift holder in the world. The portion of the tank which extended above ground was then supported by a bank of earth (Sturt 1981). Both the No.1 and No.2 gasholder at the former East Greenwich gasworks are shown in Figure 3.171.

Above-ground tanks were typically constructed from flanged cast or wrought iron plates, bolted or riveted together. Each tier of plates was strapped with a wrought-iron band. These tanks were relatively light in weight and could, with proper precautions, be built on soils with poor load-bearing properties. The cost was, however, three to four times that of a conventional tank, and the average size of this form of tank was restricted to about a 60-foot diameter. These tanks could be easily dismantled and reused elsewhere (Meade 1916 p453, Sturt 1981).

As above ground tanks got larger and heavier, then they were built on concrete slabs which in some condition would require piled foundations. As steel plate became available, riveted or later welded tanks were adopted, especially with spirally guided holders. The relatively low-cost of steel in the 20th century led to the re-emergence of above ground gasholder tanks (Sturt 1981, Thomas 2014, Tucker 2014).

These tanks had the advantages of lower cost, easier overall maintenance and lighter weight, but placed the gasholder in a more elevated position than if an underground tank had been used. It also placed the gasholder in a higher position which made it more prominent visually and put it at greater risk from wind shear damage when inflated (Sturt 1981).

Figure 3.171 No.1 (left) and No.2 (right) gasholders at the former East Greenwich gasworks London, circa 1900. Image courtesy of National Grid Gas Archive.

3.5.5 Gasholders Using Guide Frames

As described earlier the first gasholders were housed in buildings. The roof trusses of the buildings were used to support the pulleys of the counterbalance system. The first type column guided holders were developed by John Mallam. These relied on single a central cast iron column with guide rollers (Sturt 1981).

As larger unhoused gasholders were built, cast-iron tripods, *as seen in Figures 3.160 and 3.164* were constructed to support the gasholder. These tripods were isolated from each other and used for small gasholders of 40-50 feet (12-15 meters) diameter by gas engineers such as John Kirkham. When larger gasholders were required, Kirkham connected the tripods together using iron girders. The gasholder vessel moved up and down on brackets with a pierced eyelet which ran on cylindrical metal bars (*See Figure 3.164*). This feature is still retained on the lower guides within Fulham No.2 gasholder in London (*See Figure 3.160*).

These early tripods and subsequent columns and standards were secured by retaining bolts to reinforced piers, which were built into the gasholder tank.

The use of eyelets running on cylindrical metal bars was replaced by the use rollers running on guide rails mounted on the inside of the columns (facing the lift). The guide rails were attached to ensure the rigid guiding of the lift. The rollers were attached to arms extending from the lift called carriages (Figure 3.172), which were located at the top and bottom of the bell (or outer lift) and the tops of the additional lifts. The early rollers had flanges on both sides loosely fitting the T section rails for lateral guidance. In the later gasholders the rollers were flangeless and the rails were channel shaped. Channel section rails were typically used in the gasholder tanks (Sturt 1981, Tucker 2014).

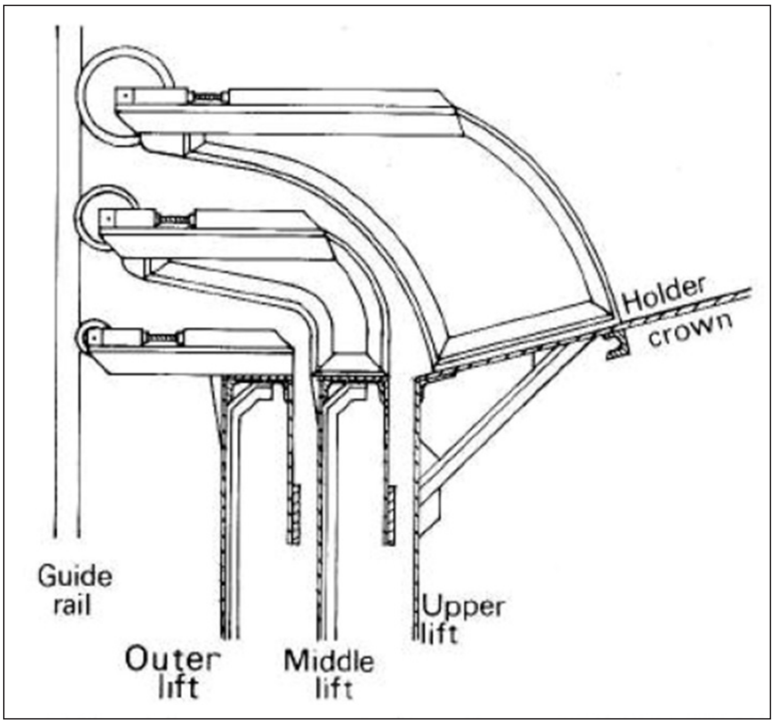


Figure 3.172 Typical arrangement of the carriage rollers on a three-lift gasholder. Source Sturt 1981. Image courtesy of IGEM Archive.

The rollers could be set radially, tangentially or on an angle, running on the standards or column guides (Figure 3.173). As well as guiding the direction of the gasholder bell and lift, the rollers and accompanying carriages also transferred the stresses on the holder due to wind shear and uneven snow loading to the frame (Cripps 1889, Sturt 1981).

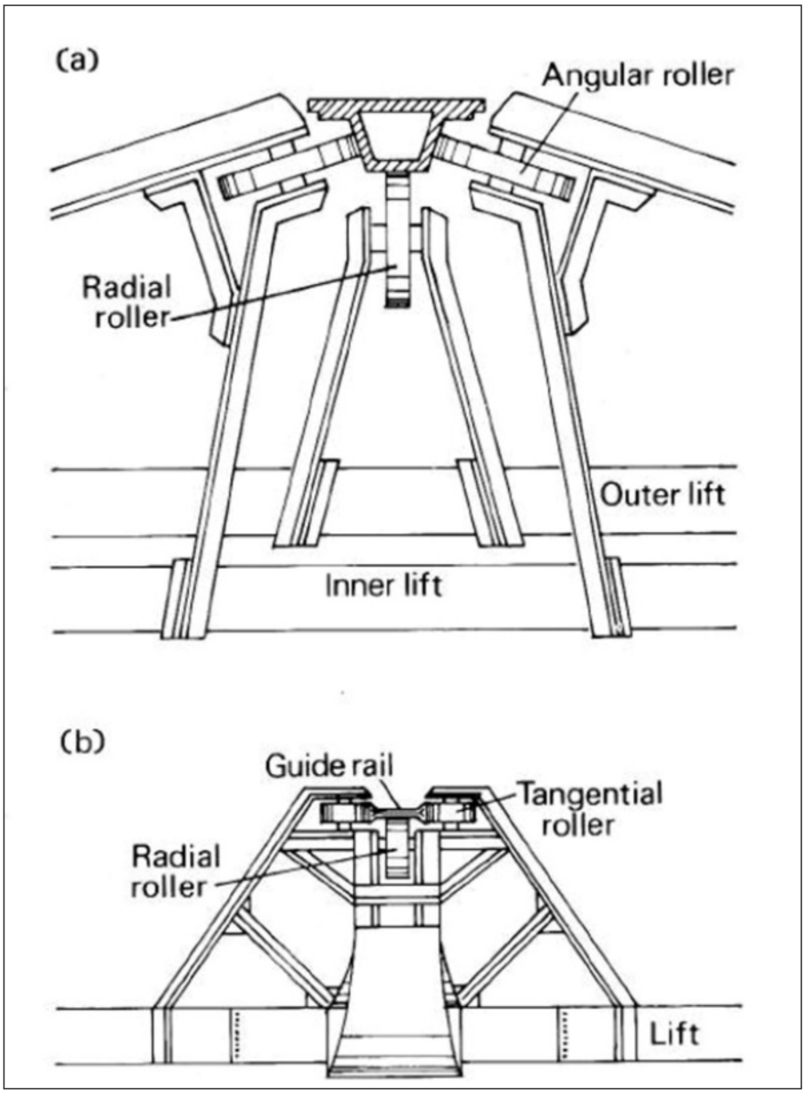


Figure 3.173 Holder Carriage Rollers. To enable carriages to pack together when the gasholder is deflated, rollers of different types are fitted to different lifts. (a) Combination of angular and radial rollers on gasholder at East Greenwich and (b) Combined tangential and radial rollers used on a gasholder in Manchester. Source Sturt 1981. Image courtesy of IGEM Archive.

Tripods were replaced by column guided gasholders, the first being developed by John Mallam which used a central column constructed from cast iron and rollers mounted on the top and bottom of the bell (Sturt 1981).

Multiple column gasholders (See figures 3.167 and 3.168) were developed, using cast iron columns, these were braced together at the top and sometime mid-sections with cast or wrought iron trellis cross girders and sometimes diagonal cross ties, replacing the earlier tripods. The cast iron columns of the 19th century gasholders were built to be static and designed to react as individual cantilevers to the forces acting on them. The rigidity of these columns was created through them having a superabundance of dead weight (Meade 1916).

A unique group of six gasholders, designed by Thomas Kirkham for the Imperial Gas Company in 1870-75 provide an excellent example of these types of gasholder, they are Grade II listed and are still present at the former gasworks at Bromley-by-Bow, London.

Some early gasholders used counterbalance weights (*see figures 3.162, 3.165, 3.167 and 3.168*). They were used on smaller gasholders often where there was no exhauster. They reduced the resistance to gas entering the gasholder, but likewise also reduced the pressure of gas leaving the gasholder. Hughes and Richards commented on their use on small gasholders in 1880, but Meade noted that it had been phased out by 1916. Gasholders which used counterbalances, were never entirely counterbalanced, as they always required sufficient weight to give the necessary pressure to force the gas through the mains.

Given the considerable weight of the cast-iron columns, there was a limit to the size of gasholder which could be constructed, and the piers required to support them were large and costly. The moulded design of cast Iron columns had allowed them to incorporate aesthetic features such as classical Greco-Roman columns. The cast iron column-guided gasholders proved the standard design, until advancements in the later 19th century. They were superseded in the 1880's by standards constructed of wrought iron and from the 1890's mild steel (Meade 1916, Sturt 1981, Tucker 2014).

Wrought iron standards (Figure 3.174) were spaced circumferentially around the top of the tank at distances ranging from 15 to 30 feet apart. These were braced together by horizontal girders and diagonal ties (*See Figures 3.168 and 3.175*). The girders for large holders were built up from steel sections, whilst the diagonal ties (which were in tension only) were made from plain round or flat steel bars (Meade 1916).

The first gas holder to have a frame guide wholly constructed from wrought iron standards, was designed by John Paddon and built by Samuel Cutlers and Sons for the Hove Gasworks of the Brighton and Hove General Gas Company in 1876 (Figure 3.175). The gasholder had a diameter of 100 feet and the guide framing was 75 feet tall and had three lifts. The site was very exposed, and the standards were tee section in plan to provide extra stability in both directions and tapered to the top. The standards were built from angles and plates and incorporated the use of St. Andrew's crosses.

Another of John Paddon's contributions to gasholder design was the Paddon wind tie. This was a trussing system of overlapping tie-bars or (later) steel cables, which connected the tops of alternate standards, at a height above the limit of which the gasholder bell or inner lift would travel. They were used to stiffen the top girders allowing the frame it to keep its shape and share the load between the different columns or standards. These were used on the surviving listed No.13 gasholder at Old Kent Road, London (Meade 1916, Tucker 2014 p56).

This stiffness could also be achieved using lattice box girders at the top of the columns or standards forming the guide frame into a rigid ring (Tucker 2014 p56).

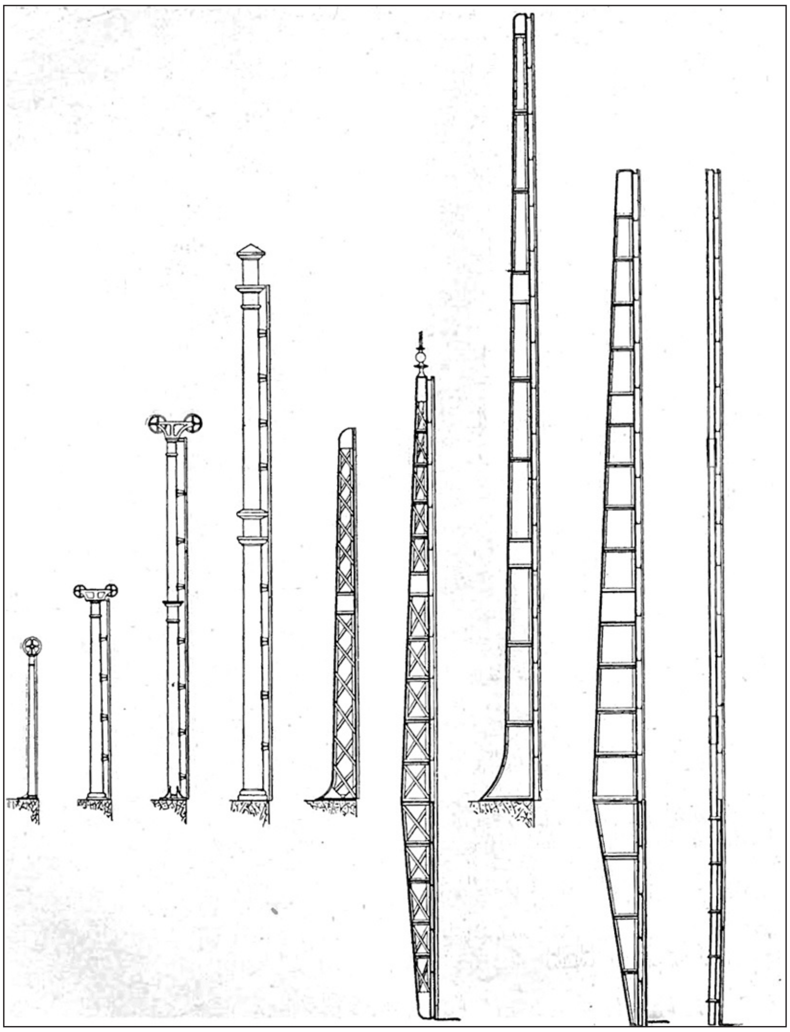


Figure 3.174 Various forms of gasholder standard, the three left most standards are cast iron columns fitted with pulleys, used for suspending counter balances. The fourth from the left is a cast iron column. The remaining standards are wrought iron or steel standards. Source Meade 1916.

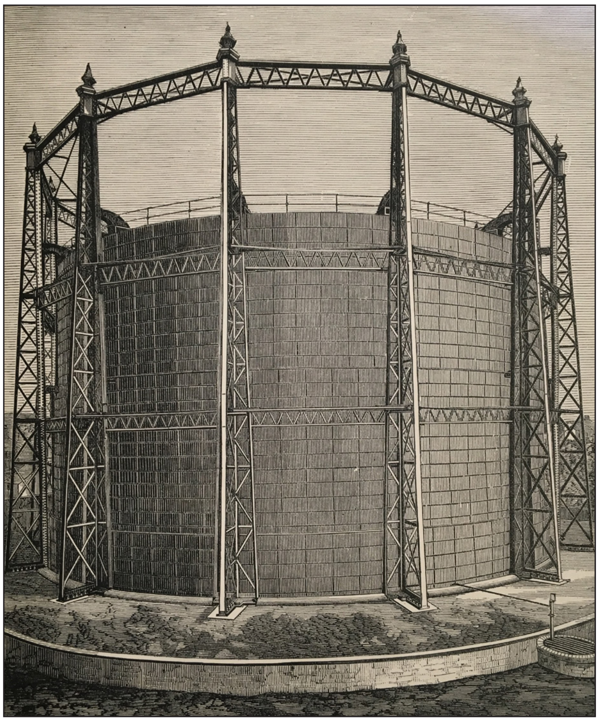


Figure 3.175 John Paddon's gasholder built at the Hove gasworks, which was the first frame guide wholly constructed from wrought iron standards. Source King's Treatise, Vol II (Fewtrell and Newbigging 1878).

Even with the adoption of wrought iron or steel lattice standards instead of cast iron column, the guide frame was still used in a similar way. The stiff standards being rigidly connected by girders into a frame, sometimes with the use of diagonal ties. A fundamental change in design occurred when Sir George Livesey developed the concept of the whole guide frame acting as a one cylindrical member cantilevered from the ground. This provided vertical tension on the windward side, vertical compression on the leeward, and considerable diagonal forces in the sides. The prototype gasholder built in 1878 was the now listed No.13 gasholder at Old Kent Road shown in Figure 3.176. This gasholder was 220 feet in diameter and 160 feet high. The standards used were slim by comparison to previous examples and were attached together as a cylinder using diagonal ties and horizontal struts instead of girders. This lightweight design saved a considerable sum of money for the South Metropolitan Gas Company (Cripps 1889 p iv p59-61, Tucker 2014, p57-58).

Figure 3.176 No.13 Gasholder built at the Old Kent Road gasworks of the South Metropolitan Gas Company. Image courtesy of National Grid Gas Archive.

Sir George Livesey along with his Brother Frank further developed this design when they designed the huge (250 foot deep by 198 foot high) No.1 gasholder built 1886-87 at the South Metropolitan Gas Company works at East Greenwich in 1886-7. and soon afterwards the even larger No.2 gasholder (see Figure 3.172 (Cripps 1889 p iv p59-61, Tucker 2014, p57-58).

This lattice shell concept was further adapted by Samuel Cutler and Sons, who developed Cutler’s patented guide framing (Figure 3.177) in 1888. This design consisted of networks of vertical standards braced by diagonal triangulated framing forming equilateral triangles. No horizontal girders were used except for the top of the frame. All the standards and diagonal bracing being of a web design (Tucker 2014, p59).

In general, the more modern the gasholder, the lighter the material used to construct the guide framing. Mild steel was introduced in to the construction of gasholders in the 1890's, George Trewby, the engineer of the Gas Light and Coke company used mild steel for the construction of the whole crown and the principal members of the guide frame at of No.9 gasholder at Beckton and No.6 gasholder at Kensal Green. The greater economy of steel led to it replacing wrought iron in the construction of gasholders.

Figure 3.177 A two-lift frame-guided gasholder with below- ground tank, using Cutler's patented system, Southern England. Image courtesy of IGEM Archive.

In the 20th century the guide framed gasholders faced stiffer competition from frameless gasholders, however some further developments occurred often with the gasholder frames becoming very utilitarian and form from H sections. Meade recommended for gasholders up to 750,000 cubic feet capacity, the "standards could be constructed from plain H joists at centres of from 15 to 18 feet, stayed up by a smaller size of the same section for the horizontal cross struts". (Meade 1916 p424).

3.5.6 Tucker Typology

The Tucker Typology was developed by Malcom Tucker to classify guide frames and their associated girders. Tucker (2014) describes this as "The typology is centred on the arrangement and construction of the columns or standards, these being the primary element in a guide frame. Within any type there were often several possibilities for the construction of the girders, and those seen by the author in literature or fieldwork, in both London and elsewhere, have been noted. There are bound to have been some other combinations, reflecting the individuality of engineers. To bring some order out of this, the most common girder types have been emphasised in bold typeface, and apparently single occurrences are bracketed. Trends with time are noticeable, including the proliferation of alternative designs in the last quarter of the nineteenth century. This tabulation cannot bring out the finer points, such as connection details, although these may have significance nevertheless.". The Tucker typology is not reproduced here but can be found in Recording Guidelines.

3.5.7 Flying Lifts

The 1880s were a time of great innovation within the design of gasholders, with many different concepts tried, one of these was the flying lift. The flying lift (Figure 3.176) was an additional inner lift; which instead of running within guide rails, the flying lift could extend above the columns or standards without its guide wheels being directly attached to them (Sturt 1981).

George Livesey engineer of the South Metropolitan Gas Company had considered the options for reducing the height of the guide frame required to support the gasholder, which led to the concept of the flying lift. George and Frank Livesey built the first flying lift at the Rotherhithe gasworks between 1887 and 1888. This gasholder had three lifts, with the inner lift extending beyond the guide framing (Anon 1888, Sturt 1981).

The South Metropolitan altered several their holders by adding flying lifts, the now listed No. 1 gasholder at Kennington being an example (Figure 3.178). This gasholder was built in 1878 to the design of Corbet Woodall for the Phoenix Gas Company. Frank Livesey had its capacity doubled to 6 million ft^3 in 1891 by the addition of two extra lifts, one of which was a flying lift (Anon 1888, Sturt 1981, Tucker 2014).

Figure 3.178 An aerial photograph of the Kennington Oval Gasholder Station showing No.1 gasholder with the flying lift in use. Image courtesy of National Grid Gas Archive.

The South Metropolitan Gas Company incorporated two flying lifts into the giant No. 2 gasholder built East Greenwich, these extended 60 feet above the 126 foot high standards when fully inflated (Sturt 1981).

The incorporation of flying lifts in a gasholder placed extra stress on the guide system, resulting in heavier wear. The engineering had to be very accurate to ensure that when the gasholder deflated again, the guide wheels would re-engage in the guide rails, this was a particular risk in high winds.

The engineer needed to be certain that the modified gasholder structure could withstand the additional weight and shear forces exerted by strong side winds on the flying lift. Southwell Cripps an eminent gas engineer, who had studied the engineering of gasholders in detail, authoring books and papers on the subject, investigated the stability of the flying lift. He identified that the weight of the lower lifts prevented the gasholder from overturning, but recommended that not more than a third of the holder should rise above the guide frame (Cripps 1889).

Despite these disadvantages flying lifts were added to existing holders and new holders were sometimes designed to have an extra lift as a later development. The use of the flying lift allows less expensive guide framing to be built which is also less obtrusive (Sturt 1981).

The flying lift could also take the form of an additional spiral guided or rope guided lift. The use of flying lifts was a common practice for many years to quickly increase the gas storage capacity on gasworks, but was later phased out. This method benefited from being relatively easy and cheap to retrofit without interfering with the existing guide frame or columns

3.5.8 Cable or Wire Rope Guided Gasholders

Another innovation of the 1880's which removed the requirement for a frame support to a gasholder was the cable or wire-rope guided gasholder. This used a complex arrangement of at least three separate cables for a single-lift gasholder which stretched via a series of pulleys from the top of the gasholder tank to the top of the gasholder vessel and back. This kept the cables taut and the floating vessel in position. They were invented in the 1880s by the Darlington based engineer, Edward Pease. Figures 3.179 shows a two-lift example of a cable-guided gasholder (Anon 1895c p1088-1089, Stevenson 1901 p62-63, Meade 1921 p625, Tucker 2014 p42).

A large three lift gasholder of this design was built for the Middlesbrough Corporation Gas Department by Messrs. Ashmore, Benson, Pease, and Co., Limited in 1895. Their use was relatively short-lived (*circa* 1890-1910) as alternative designs proved more effective and reliable. Meade described them as historical interest only in 1916. They were retrofitted on some column-guided tanks where ground instability had caused the columns and tanks to move, and the gasholder to jam (Anon 1895c p1088-1089, Meade 1916).

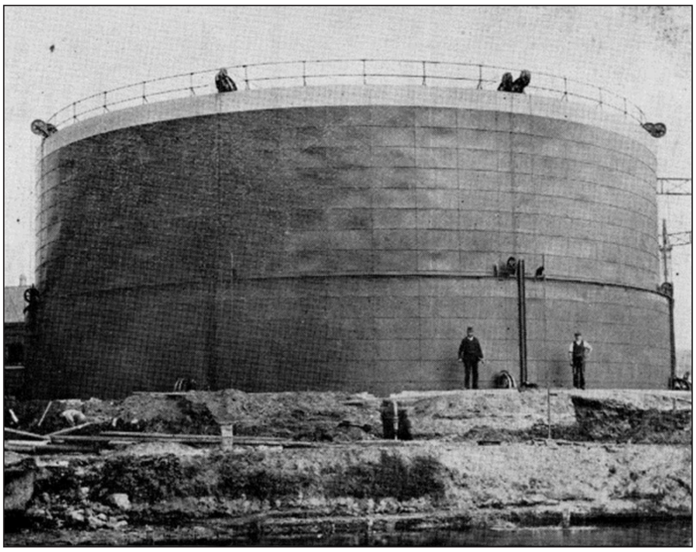


Figure 3.179 A cable-guided gasholder constructed at the Stafford gasworks in 1898, by Ashmore Benson and Pease. Source Gas Journal 1898.

3.5.9 Spiral Guided Gasholders

The spiral-guided gasholder concept was originally proposed by Mr W.H.Y. Webber in 1887. The design which succeeded was patented in 1887 by Mr W. Gadd and Mr W.F. Mason of Manchester. The spiral-guided gasholder dispensed with the external frame above the tank, with the lifts supported instead by spiral guiding rails fixed to the lifts and internal stiffeners (Meade 1916).

This design was radically different to any used previous, with guidance system which used rails in helical form, inclined at 45°, these were fixed to the side of the gasholder lifts as shown in Figures 3.180 and 3.181.

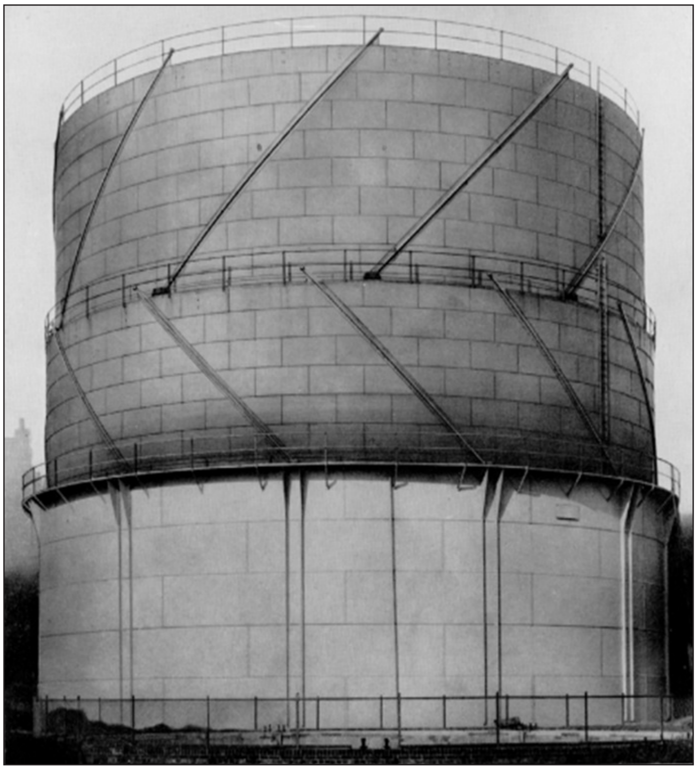


Figure 3.180 Spiral-guided gasholder with two lifts in a steel above-ground tank. Image courtesy of IGEM archive.

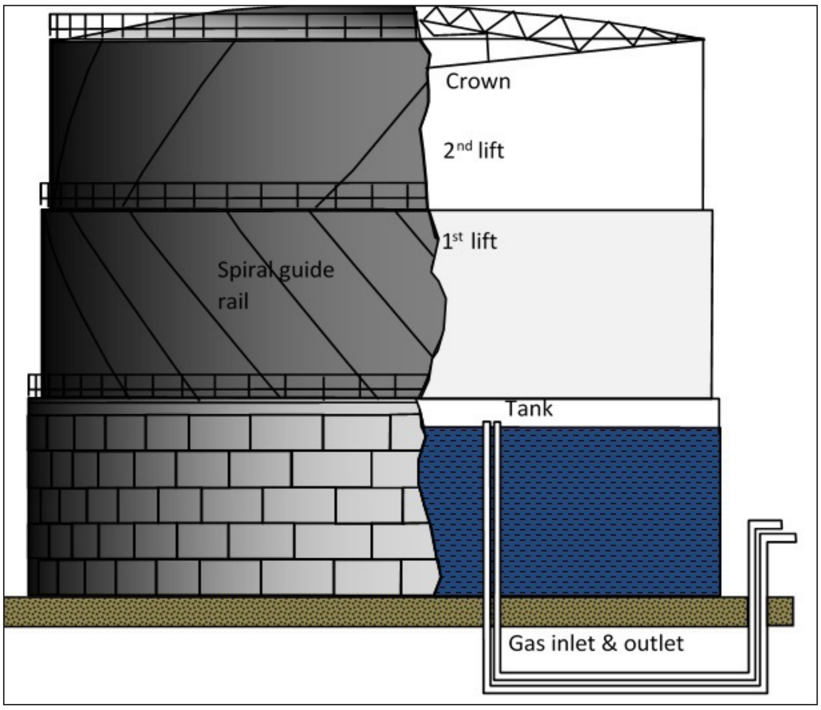


Figure 3.181 Schematic of a spiral-guided gasholder with an above-ground tank, showing the internal detail and water level. Source R. Thomas.

The spiral guide rails were gripped between pairs of rollers (two above and two below the rail) on the edge of the tank in such a manner that the bell moved up and down in a screw-like fashion (Figure 3.182).

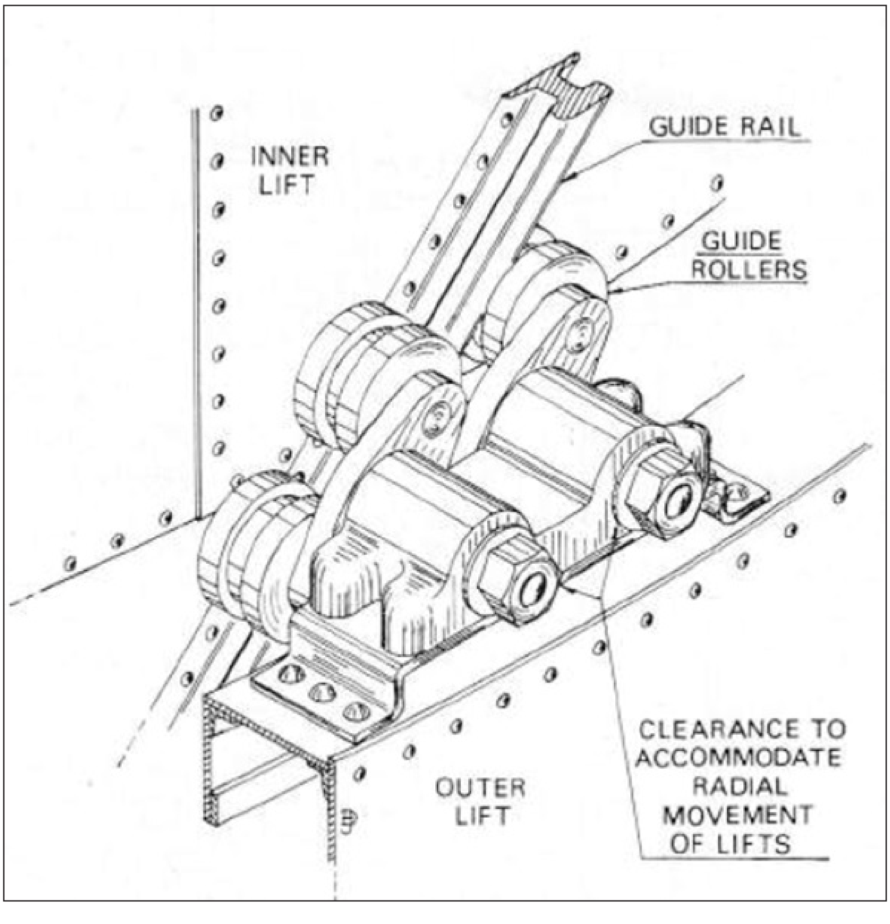


Figure 3.182 Multiple Roller Carriage which guides the upwards and downwards movement of the spiral gasholder. Sturt 1981. Image courtesy of IGEM Archive.

Originally the rails were hidden on the inside wall of the lift. But later designs placed them on the outer wall with the rollers positioned at the top of each lift and the tank. This made the guidance system more accessible for maintenance and gave significant operational advantage over column-guided holders. The guide rails could be all left-handed, all right-handed, or successive combinations of both (Meade 1921).

The first example was built in 1890 at the Northwich gasworks, Cheshire, by Clayton, Son and Co Ltd. of Leeds. This example was a two-lift gasholder (Meade 1921, Sturt 1981).

Originally the gasholders were relatively small but by 1937 a spiral guided gasholder with a capacity of 8,000,000 ft^3 was built at Meadowhall, Sheffield.

Spiral-guided gasholders required more precise engineering and maintenance, as a result, the rollers were at greater risk of jamming than the other types of gasholders. They were particularly at risk from the roller freezing or the water freezing in the cup, both of which could lead to serious consequences of the lifts (Meade 1921, Sturt 1981).

Due to their more economic construction and ease of operation they had largely replaced all other design by the late 1930s, with many spiral guided gasholders being built in the tanks of former frame-guided gasholders (Sturt 1981, Tucker 2014).

3.5.10 Features of the Gasholder Bell and Lifts

The early gasholder bells were constructed on heavy wooden frames (Accum 1815), however the benefits of cylindrical bells built from sheet metal had become apparent soon after (Accum 1819).

The top of the circular bell, or inner lift for telescopic gasholders, was referred to as the Crown. It was typically curved and was constructed from riveted (later welded) iron or steel plate of a nominal 1/8 inch (3.175mm) in thickness (Sturt 1981).

As the technology and understanding advanced and the thickness of the plate used was often described using units of Birmingham Wire Gauge (BWG), typically thicknesses of 8, 9, 10 and 11 BWG were used which equate to: 0.165; 0.148; 0.134; and 0.120 mm in thickness. Thicker plate was used in areas where great stiffness was required such as the centre plate or edge of the crown. The crown had to be designed such that it could withstand the pressure of gas and the strains that were caused when fully inflated but also able to support itself when the gasholder was empty of gas, for example whilst being repaired (Meade 1916, Sturt 1981).

Due to the relative weakness of the crown, support was required to prevent it from buckling when all the lifts were down and there was no gas pressure within the gasholder. In these cases, the crown required either: 1) its own internal frame (akin to the supports in an umbrella) to provide strength; or 2) an internal frame built within the tank which could support and maintain the shape of the crown when empty of gas, called a Crown Rest (Figure 3.183).

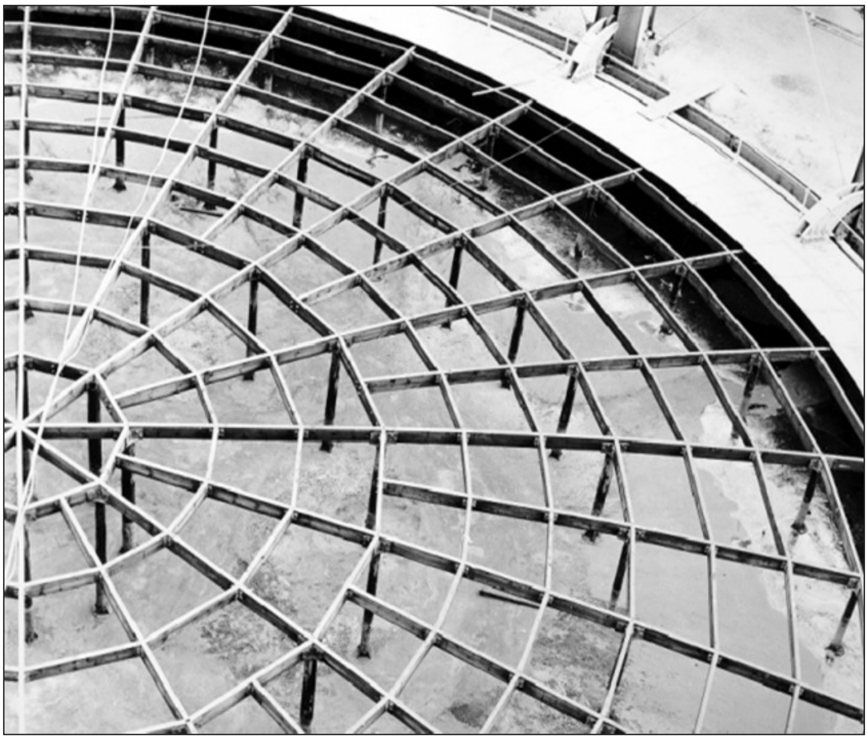


Figure 3.183 A column guided gasholder with the crown sheeting removed, exposing the wooden crown rest and water-filled tank below. Image courtesy of National Grid Gas Archive.

Where an internal frame was used, it comprised of a series of rafters radiating from the centre which attached to the crown curb around the edge of the crown. At the centre of the crown a strong centre column was constructed to which the radial rafters would attach. When the gasholder was grounded this central column, known as a "King Post" would rest on a bed-plate or pier in the centre of the tank, constructed of brick, concrete or steel construction. Trussing was generally limited to gasholders with a diameter of 170ft (52m) or less, due to the technical limitations of the method (Meade 1916 p446-447).

As gasholders were built larger and larger, later examples were untrussed and used a "Crown Rest", this was a wooden or sometime steel framework constructed on the dumpling to support the crown when deflated. An example is shown in Figure 3.183.

As telescopic gasholders were developed, the cup and grip were required to interconnect the lifts. These were described briefly in the introduction to this section. The cup and grip shown in Figure 3.184 were used to connect the lifts together and form a gas tight seal between them. The cup was a u-shaped channel rolled over the outer edge of the bottom of the inner lift and any other lift for which there was another lift outside it. The grip was a u-shaped channel rolled over the inner edge of the top of outer lift and any other lift for which there was another lift inside it (Sturt 1981).

When the holder was filled with gas the inner lift would rise until it reaches its maximum height, at which point the cup and grip engaged with each other and both lifts would then rise together. This then happened subsequently with additional lift (Sturt 1981).

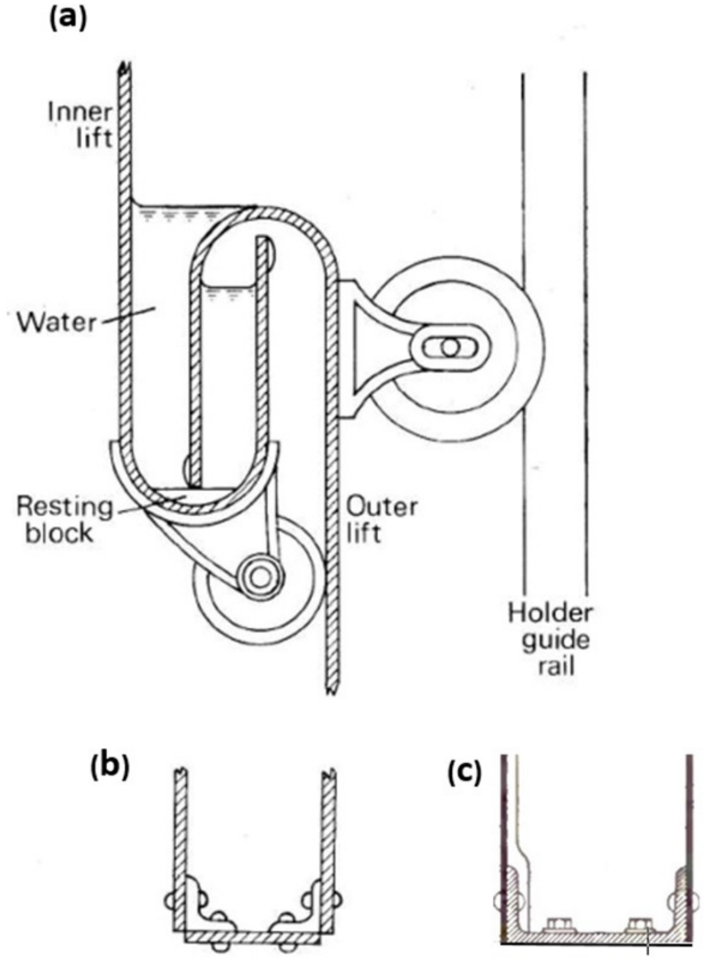


Figure 3.184 Gas-tight seal used in telescopic holders. (a) Cup and grip, with lift inflated, introduced by George Piggott, 1862. (b) Riveted cup used before this and (c) the cup formed from Rolled Channel Section, introduced about the same time as Piggott's design. Adapted from Sturt 1981.

As the cup emerged from the water filled tank, it was full of water, the water acting as a gas-tight seal (Figure 3.184). The cups and grips were nominally 8 inches wide and 16 inches deep. Larger gasholders could have cups and grips up to 12 inches wide and 24 inches deep (Meade 1916 p426).

The cups and dips were originally formed from riveted sections of angles and plates, which were problematic, prone to leak and difficult to repair. The smooth-curved U section was introduced by the contractor George Piggott, bent from a single plate. He first introduced this design in 1862 on a gasholder built at Old Kent Road. The use of square channel rolled channel sections had been introduced at a similar time and had become the preference by 1916 (Meade 1916, Sturt 1981).

The cup and grip could be problematic in cold weather, when the water in the cup could freeze causing serious damage to the gasholder. Electrical or steam anti-freeze systems were employed to prevent ice occurring (Sturt 1981).

3.5.11 Waterless or Dry Gasholders

The pressure seal for a gasholder provided by water, was simple and reliable, which was the key to its long durability. It did however provide some disadvantages, namely, the requirement for a very strong tank to hold the water, the water could add moisture to the gas and the low pressure at which the gasholder could operate, which was limited by the water seal.

The construction of durable dry gasholders had been attempted a number of times. The first attempt was made by Caslon in 1826 (Stewart 1958). A more notable attempts were made by William Knapton of York, who improved on Caslons's idea in 1849 and who had patented a dry gasholder in 1857. He used this design at the gasworks built at Cawood in Yorkshire and a few other small private gasworks (Anon, 1857). From the brief description of Knaptons design, it's form was similar to traditional gasholder using iron pillars above a brick tank, but the gas holding vessel was constructed of iron sheeting attached to Indian rubber, which provided the gas tight seal. Technical limitations of the time meant that the design was not more widely used.

This design allowed for a simplified system, where the major moving part was the piston, dispensing with the need for the water seal and associated water-filled tank. The piston was able to rise and fall via the guide rollers. The outer cylindrical shell was dissimilar in appearance to other gasholders. The outer shell remained static, had the same diameter throughout, and the roof of the structure was permanently fixed (Anon. 1857).

This design allowed the heavy water tanks used on water-sealed gasholders to be dispensed with, requiring less expenditure on the foundations and tank. Another benefit would be that the gas would remained dry.

The construction of an effective dry gasholder did not occur until 1915, the design had been patented in Germany 1913. This was developed by the German company Maschinenfabrik Augsburg-Nürnberg AG (MAN) and known in the UK after the initials of the Company, as a MAN gasholder. MAN did infact develop other gasholders, including the MAN Wölbbassin (German Patent DE 251368). This gasholder had a tank with a wall which curved outward, which better distributed the pressure of the water within the tank allowing a lighter construction to be used on larger gasholders (Strache 1913, p494).

The MAN dry gasholder (Figures 3.185 and 3.187) was fixed multi-sided polygonal steel tank built above ground in a vertical position. The gas was sealed within the tank by a flat polygonal shaped piston, which was stabilised with two set of rollers, one radial and one tangential, mounted around its edge.

The piston could move up or down dependent on the amount of gas stored. The MAN gasholder had a seal formed around the edge of the piston made from rubbing plates fitted to the sides of the piston by counterbalanced weights. Under the rubbing plates, folds of rubberised canvas were fitted forming a trough filled with tar (Figure 3.186). As the piston moved, the tar would run down the walls to the base where the tar was recirculated to the feed tank at the top of the gasholder (Sturt 1981, Stewart 1958, Tucker 2014).

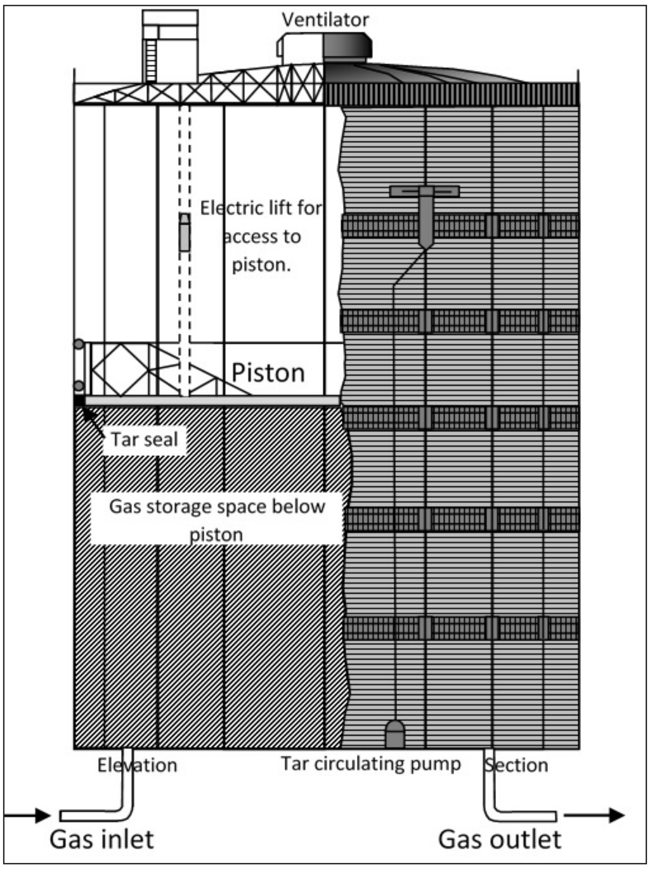


Figure 3.185 A schematic of a MAN waterless gasholder. Source R. Thomas..

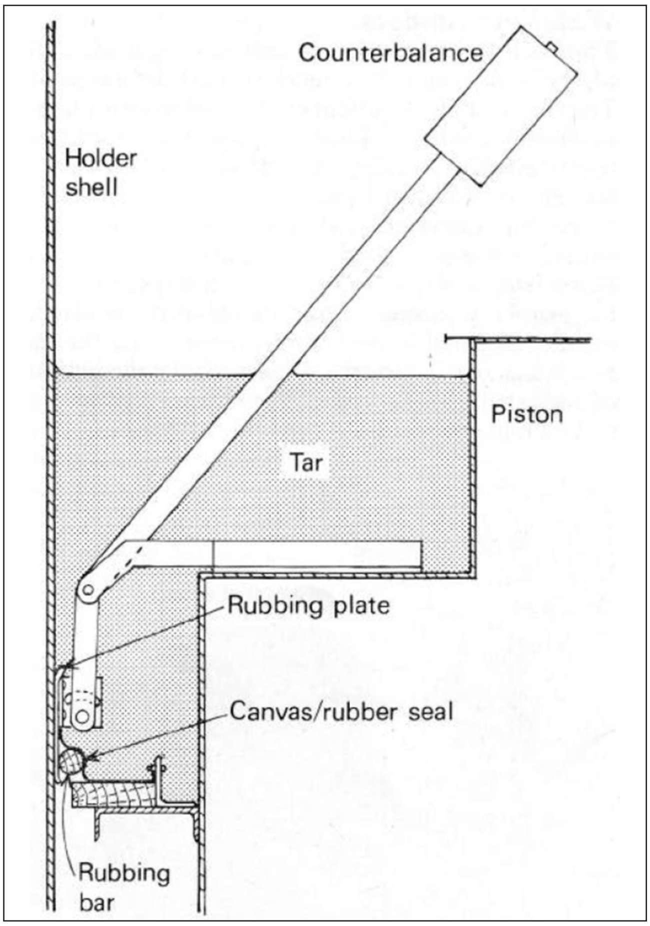


Figure 3.186 The tar seal of the MAN gasholder, showing the counterbalance which kept the rubbing plate under pressure against the shell. Source Sturt 1981. Image courtesy of IGEM Archive.

The first MAN gasholder built in England was built at Ipswich in 1927 (Sturt 1981). The Gas Light and Coke Company built seven MAN gasholders, the last of these was at Southall and has recently been removed (Everard 1949, p 335,). The best known example was built at the Battersea gasholder station and was a prominent landmark on the London Skyline, a photograph of this gasholder decorated to commemorate the coronation of Queen Elizabeth II is shown in Figure 3.187.

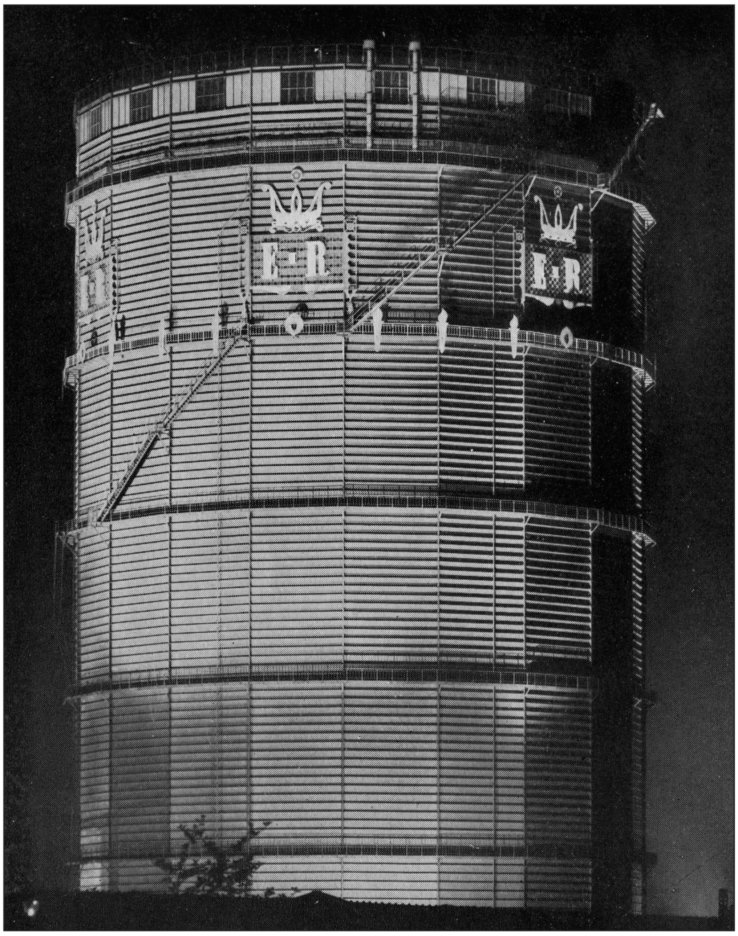


Figure 3.187 The Battersea MAN waterless gasholder, decorated to celebrate the coronation of Queen Elizabeth II. Image courtesy of National Gas Grid Archive.

The largest MAN gasholder ever built was constructed in Chicago (USA) in 1934, it had a capacity of 566,000 m^3 (20m ft^3) (Stewart, 1957).

Mssers Aug. Klönne of Dortmund, Germany, who developed a wide range of plant associated with gas manufacture. They first took out patents for their waterless gasholder in 1882. But the first example was not built until 1927, in Dortmund. The Klönne design was cylindrical rather than the MAN Polygonal shape (Sturt 1981).

The Klönne dry gasholders had a similar design with a moving piston and two sets of stabilising rollers (Both radial). The seal sealed around the edges by a ring grease or oil (Stewart 1958, Tucker 2014). The largest low pressure gasholders ever built was of the Klönne design, built in 1937 at the Nordstern coal mine near Gelsenkirchen in Germany. It was approximately 80m in diameter and 136m high and had a capacity of 600,000 m^3 (21m ft^3).

The third design of dry gasholder was the American Wiggins dry gasholder (Figure 3.188) which was introduced into England in the 1950's, with examples built at Millom, Oxted and Ashford.

Figure 3.188 Wiggins Type Dry Gasholder at Millom, England. Source Syd Bennett.

This American design is still popular and is used for gas storage for the steel, iron, and coke-making industries. This design also used cylindrical tank built from steel in a fixed, vertical position above ground. The gas was held within the tank by a piston, again stabilised by rollers, sealed around the edges by a flexible membrane (Figure 3.189).

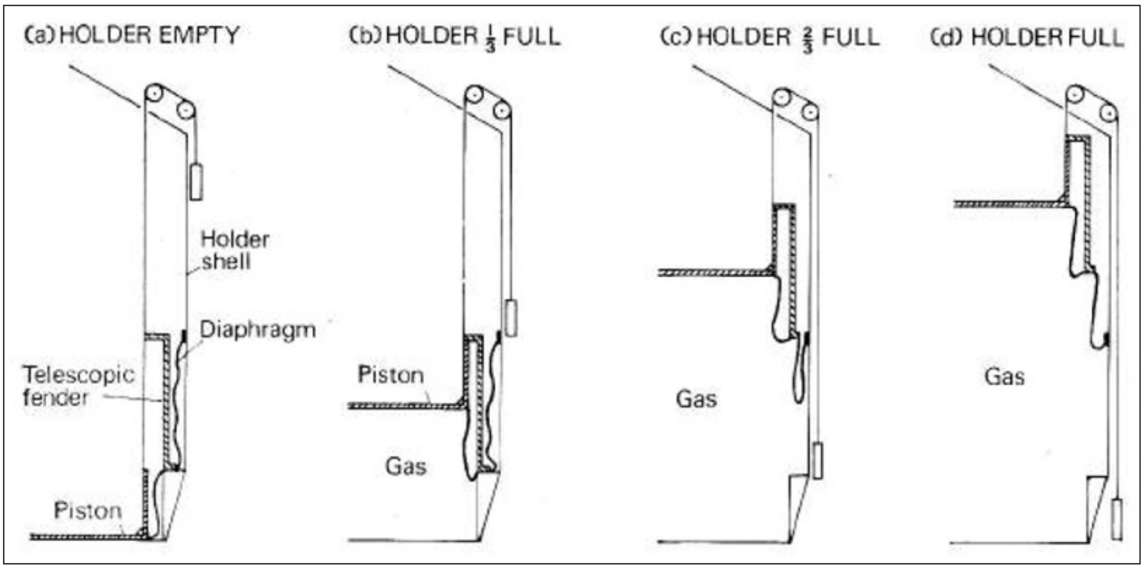


Figure 3.189 A diagrammatic representation of a Wiggins gasholder when empty (A), one thirds full (B), holder two thirds full (C) and full (D). Source Sturt 1981. Image courtesy of IGEM Archive.

3.5.12 High Pressure Gasholders

High pressure gasholders, known as receivers, started to be used in England around the 1930s. A high pressure receiver measuring 32 ft. in diameter by 102 ft. long was known to have been installed at Skipton Gasworks in 1932. This operated at 50 p.s.i.g. (Pounds per square inch gauge), a much lower pressure than later used (Clements 1968).

Early high pressure gasholders were constructed from surplus Lancashire boilers of rivetted construction, these were capable of operating at a pressure of 80 p.s.i.g. and had a releasable volume of approximately 8,000 ft^3, these evolved into specially designed bullet shaped vessels of riveted construction as can be seen in Figure 3.190 (Clements, 1968).

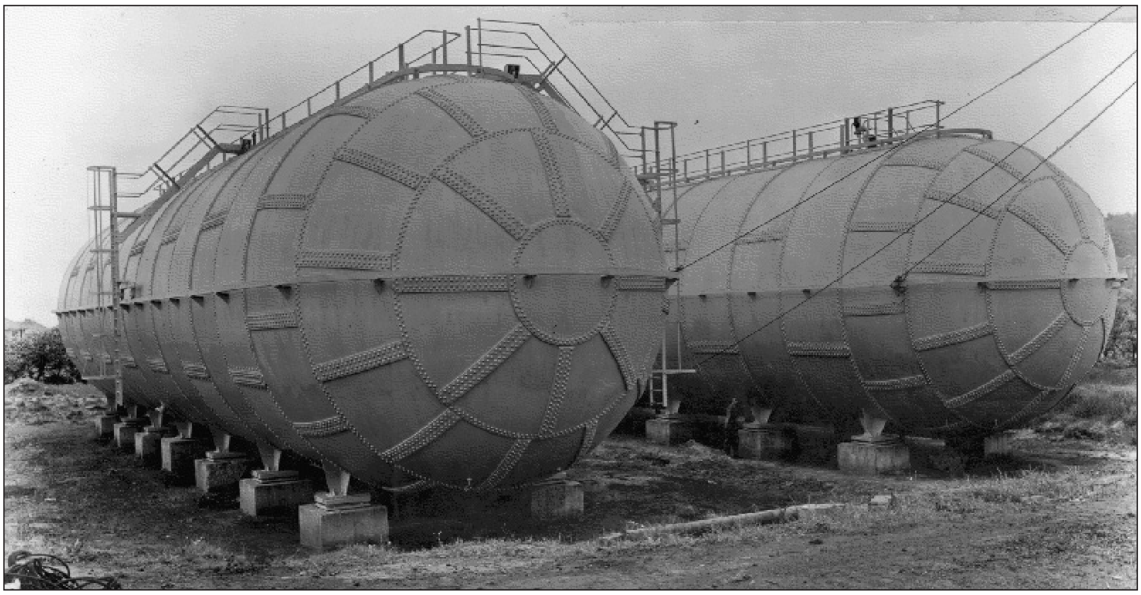


Figure 3.190 Early high pressure bullet gasholders at the former Oakengates gasholder station Shropshire. Image courtesy of National Grid Gas Archive.

In some circumstances clusters of connected high pressure pipeline were laid beneath fields to act as a temporary forms of high pressure gas storage (Briggs and Marchant 1969).

The later high pressure receivers of welded construction operated at a presure of 250-350 p.s.i.g. and were either fed with high pressure gas directly from the grid mains or via a compressing plant (Clements, 1968).

The long cylindrical vessels (Figure 3.191) were mounted on two plinths by saddles. One saddle was attached to the plinth, the second was not, this allowed for any movement in the cylinder due to contraction or expansion of the vessel due to changes in temperature or pressure. The thickness of the metal plate had to be designed to withstand the both the pressure and the fatigue caused by cycling between high and low pressures (Briggs and Marchant 1969).

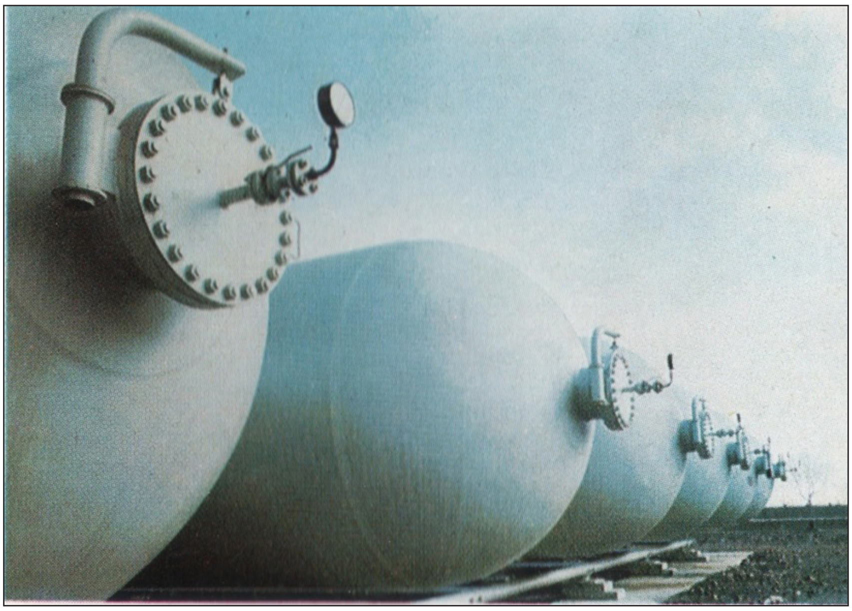


Figure 3.191 Welded high pressure gas storage bullet tanks. Image courtesy of National Grid Gas Archive.

Another type of pressure vessel was the Horton Sphere which was developed in the USA and was spherical. Their name is derived from Horace Horton, the founder of the Chicago Bridge & Iron Company which developed this type of high pressure storage vessel. An example of the Horton Sphere is shown in Figure 3.192, which was constructed at Canvey Island (Barash and Gooderham, 1971).

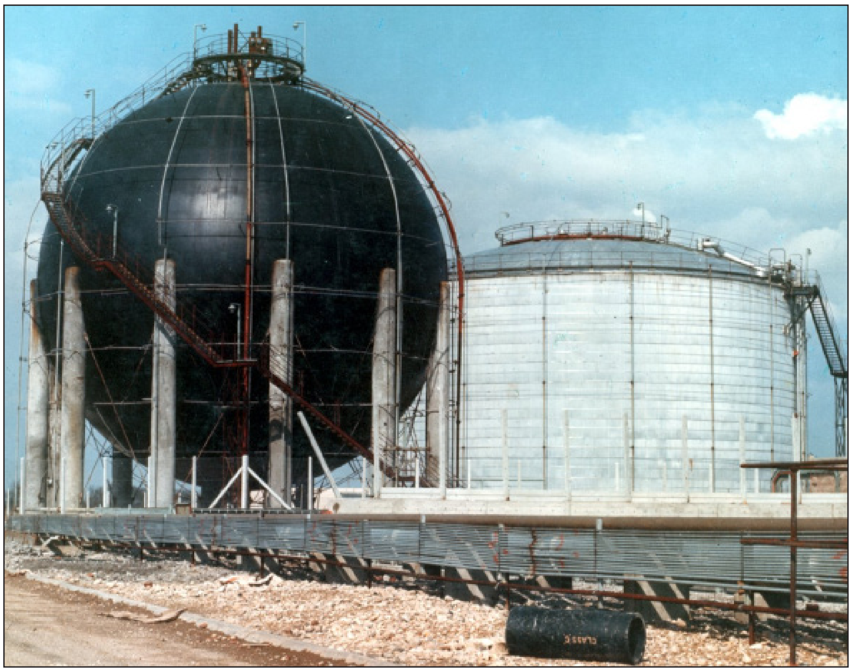


Figure 3.192 High Pressure Horton Sphere (left) and LNG storage tank (right), Canvey Island, Essex. Image courtesy of National Grid Gas Archive.

With the introduction of the high pressure grid systems, high pressure gas making plant and later on the advent of North Sea Gas, high pressure gas receivers became an economic proposition because of the advantage which could be made of the high gas pressures at the terminals, without the necessity of recompression (Barash and Gooderham, 1971).

3.5.13 Underground Gas Storage

Underground Gas Storage was first used in Canada in 1915 and a year later in the USA in 1916. In both cases depleted oil wells were used for the storage of gas (Barash and Gooderham, 1971).

Gas storage was also tried in the water bearing rock formations (aquifers) in the USA in 1946. This form of storage had become common place by 1960 in the USA. The Rough Gas Field (Yorkshire, off-shore) which became an operational gas field in 1975 was converted to an operational gas storage facility in 1985, after the gas reserves had been depleted. The site provided a major gas storage facility until its proposed closure in 2017 (Anon 2017). Similar smaller sites at Humbly Grove (Hampshire), Hatfield (Yorkshire) and Morecambe Bay (Lancashire off-shore) are still operational.

The storage of gas in salt caverns created by solution mining (a process which dissolved the salt in water) was developed in England in 1959. This eventually led to the development of several gas storage facilities in salt caverns, with operation storage facilities at Teesside, Hole House and Holford in Cheshire and Hornsea in Yorkshire.

3.6 Chemical Works Processes

Large gasworks also incorporated chemical works to process the by-products from gas making process. The main chemical processes operated on a gasworks are described below.

3.6.1 Tar Distillation

Coal tar a viscous liquid which is obtained from the carbonisation of coal, was a by-product of the manufacture of coal gas at gasworks. Tar had been previously obtained from wood and distilled to produce useful products for purposes of such as wood preservation. Henry Haskins was awarded a patent in 1746 for a “New method of extracting a spirit or oil out of tar, and by the same process produce the finest of pitch.” His patent included boiling the tar and subjecting it to a still. Haskins patent may have been intended for wood tar, although it would have been equally as applicable for coal tar (Lunge 1909 p307).

The German chemist Accum, in 1815, was the first to boil down coal-tar in closed vessels (stills), to obtain a volatile oil which could be employed as a cheap substitute for turpentine, although only at a laboratory scale (Lunge 1909 p307).

John Bethel discovered that valuable products could be obtained from coal tar through the process of distillation, a process he patented in 1838 (No. 7731). Bethel discovered that oil extracted from coal tar could be used to preserve timber, replacing the Kyan (Mercury Chloride) and Margary (Copper Sulphate) used previously (Holland 2002). The use of middle and heavy oils as timber preservatives was one of the earliest applications of coal tar and led to the gradual realisation that it could be a valuable product rather than a nuisance to dispose of. (Lunge 1909 p9, Young 1922 p361).

Longstaffe and Dalston are believed to have erected the first coal tar distillery in Leith, Edinburgh in 1822. Their distillery extracted by distillation an oil used for dissolving rubber. This oil was then used to dissolve rubber for the manufacture of waterproofs by Mackintosh. The Residue was used to manufacture lampblack. Another tar distillery was also established in Manchester in 1834 for manufacturing a naphtha oil to be used to dissolve residual pitch, producing a black varnish. This was an unsuccessful attempt to replace a similar product produced from wood which was used in hat manufacture (Lunge 1909 p307, Young 1922 p361).

For early tar distilleries, such as the Crews Hole distillery in Bristol, creosote and pitch were the only saleable products. All the other oils would have been burnt in a restricted airflow to make lampblack (Holland 2002).

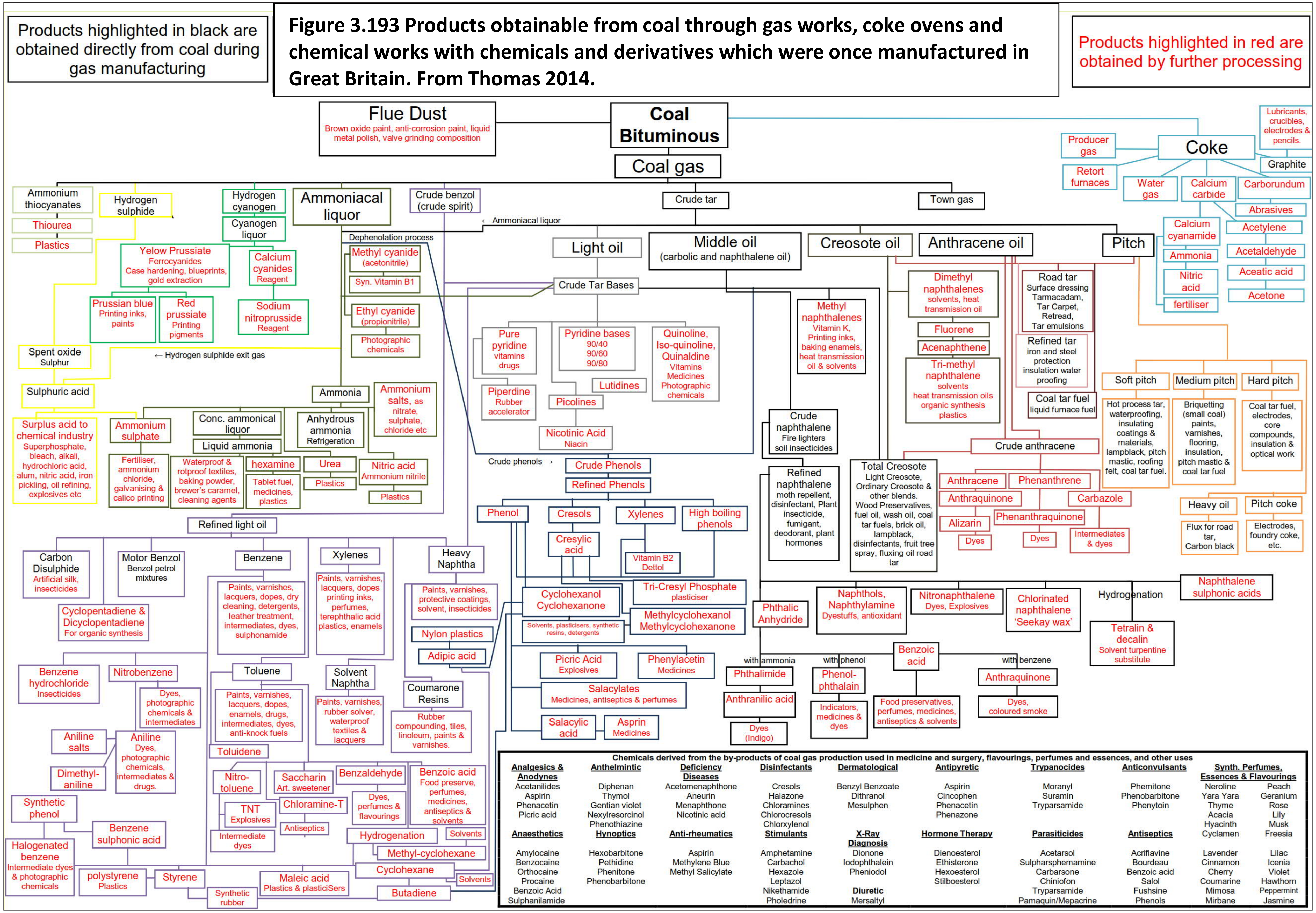
The importance of the light oils present in coal tar were identified by Hofmann, who described the presence of benzene within the oils, but later Mansfield investigated the composition of the oils in more detail. The ability to produce or extract oils from these distilled fractions of light oils helped to establish the organic chemistry industry, with small scale uses, such as nitrobenzene being produced as an alternative of essence of almonds. It was not however until the discovery of aniline colours in 1856, and the discovery of the red dye alizarin in anthracene oils that major demand for coal tar by products was created (Lunge 1909, p10).

The organic chemical industry which developed from the distillation of coal tar, created products directly or indirectly used as wood preservatives, fuels, disinfectants, flavourings, colours, medicines and various pitches for roads, roofing tar, and as a binder for electrodes and insulation as shown in Figure 3.193 (Gas Council 1953, Holland 2002).

The distillation of coal tars was more common at larger gasworks although a few small and medium-sized gasworks would also distil tar. The best examples of tar distillation plants on gasworks would be the by-products plants at the former gasworks at Beckton, East Greenwich and Southall (Norman 1922).

Gas companies would generally work together to form cooperative tar distilleries. The cooperatives would take tars from all the gasworks in a specific region which did not have their own tar-distilling capacity or found it more economical for the tar distillery to distil the tar. Private tar distillers would also buy tar from the gas companies. By-product coking works often operated their own tar distilleries, given the high volume of tar they produced (Nabb, 1986).

Fractional distillation was used to separate fractions of the coal tar into oils and compounds of similar boiling points. The fractions generally referred to are light oils, middle or carbolic oils, heavy or creosote oils, and anthracene oils and pitch, the residue which remained (Lunge 1909).



Products highlighted in black are obtained directly from coal during gas manufacturing

Figure 3.193 Products obtainable from coal through gas works, coke ovens and chemical works with chemicals and derivatives which were once manufactured in Great Britain. From Thomas 2014.

Products highlighted in red are obtained by further processing

Chemicals derived from the by-products of coal gas production used in medicine and surgery, flavourings, perfumes and essences, and other uses

Analgesics & Anodynes	**Anthelmintic**	**Deficiency Diseases**	**Disinfectants**	**Dermatological**	**Antipyretic**	**Trypanocides**	**Anticonvulsants**	**Synth. Perfumes, Essences & Flavourings**	
Acetanilides	Diphenan	Acetomenaphthone	Cresols	Benzyl Benzoate	Aspirin	Moranyl	Phemitone	Neroline	Peach
Aspirin	Thymol	Aneurin	Halazone	Dithranol	Cincophen	Suramin	Phenobarbitone	Yara Yara	Geranium
Phenacetin	Gentian violet	Menaphthone	Chloramines	Mesulphen	Phenacetin	Tryparsamide	Phenytoin	Thyme	Rose
Picric acid	Nexylresorcinol	Nicotinic acid	Chlorocresols		Phenazone			Acacia	Lily
	Phenothiazine		Chlorxylenol					Hyacinth	Musk
Anaesthetics	**Hynoptics**	**Anti-rheumatics**	**Stimulants**	**X-Ray Diagnosis**	**Hormone Therapy**	**Parasiticides**	**Antiseptics**	Cyclamen	Freesia
Amylocaine	Hexobarbitone	Aspirin	Amphetamine	Dionone	Dienoesterol	Acetarsol	Acriflavine	Lavender	Lilac
Benzocaine	Pethidine	Methylene Blue	Carbachol	Iodophthalein	Ethisterone	Sulpharsphemamine	Bourdeau	Cinnamon	Icenia
Orthocaine	Phenitone	Methyl Salicylate	Hexazole	Pheniodol	Hexoesterol	Carbarsone	Benzoic acid	Cherry	Violet
Procaine	Phenobarbitone		Leptazol		Stilboesterol	Chiniofon	Salol	Coumarine	Hawthorn
Benzoic Acid			Nikethamide	**Diuretic**		Tryparsamide	Fushsine	Mimosa	Peppermint
Sulphanilamide			Pholedrine	Mersaltyl		Pamaquin/Mepacrine	Phenols	Mirbane	Jasmine

Figure 3.193 Products obtainable from coal through gas works, coke ovens and chemical works with chemicals and derivatives which were once manufactured in Great Britain. Source R. Thomas 2014.

3.6.2 Tar By-products.

For each ton of coal carbonised about 10 gallons of coal tar was produced. In 1953 1.5 million tons of crude tar were produced at gasworks in in Great Britain. The pitch was the greater portion of the tar (about 50%) and the hot pitch was allowed to run into large open pits, called pitch beds, where it would cool and harden (Gas Council, 1953).

Once solid the pitch would then be broken up before being broken into lumps for use elsewhere for purposes such laying tarmac roads and in varnishes (see Figure 3.194) (Gas Council, 1953).

Figure 3.194 Breaking up pitch in pitch beds at the former East Greenwich gasworks. Image courtesy of National Grid Gas Archive.

About 30% was used as road tar in 1950 (Figure 3.195), but it also found other uses in the manufacture of Asphalt pipes and asphalt paper, lamp black, varnishes, pitch binders (Lunge, 1916). About 15 million gallons of Creosote were produced annually circa 1950, another significant proportion of the total crude coal tar. Creosote was used as a wood preservative, disinfectants, sheep dips and printing inks (Gas Council, 1953). Coal tar fuels were used extensively during World War Two, as alternatively to petroleum products. (Gas Council, 1953).

Coal tar was also responsible for the manufacture of very harmful insecticides such as DDT and Grammexane as well as some weed killers (Gas Council, 1953).

Sulphonamide drugs were derived from coal tar, this included the drug M&B 693 short for 2-(para-aminobenzenesulphonamido) pyridine which was the first effective treatment for Pneumonia and used to treat wounds. Mepacrine derived from coal tar was used as an antimalarial drug during World War Two (Gas Council, 1953). The painkillers aspirin (Salicylic acid) and Morphine and the disinfectants Salol and Lysol were also manufactured from by-products derived from coal tar as was the artificial sweetener Saccharin and synthetic forms of Vitamin B1, B2 and K (Gas Council, 1953).

Figure 3.195 Laying coal tar pitch as tar Macadam. Image courtesy of National Grid Gas Archive.

Aniline dyes which were discovered by William Perkin in 1856, were derived from coal tar. They became a major economic driver for the coal tar industry, their discovery is described in the history section of this report (Gas Council, 1953).

Nylon was original manufactured in the UK from by-products derived from coal tar. One of the first plastics, Bakelite, was developed by Dr Leo Henricus Arthur Baekeland and patented in the USA in 1909. It was manufactured from phenol and formaldehyde which could also be derived from coal tar (Lunge 1909, Gas Council, 1953).

3.6.3 Sulphuric Acid Plant

Sulphuric acid was one of the most important industrial acids and its production was always in high demand. A useful source of sulphur to produce sulphuric acid was the gasworks purifier waste, spent oxide which would typically consist of about 50% sulphur. Spent oxide was produced when granular iron ore usually in the form of bog iron ore, was used to remove hydrogen sulphide and other sulphur compounds in addition to cyanide from manufactured gas. It was introduced in London in 1851 by the Imperial Gas Company and other gas companies soon followed (Townsend 2003).

Gasworks became an important source of sulphur for sulphuric acid production, and it is known that it was being bought by chemical companies in London to produce Sulphuric acid as early as 1861. Several large gasworks such as Beckton and East Greenwich (Figure 3.196) manufactured sulphuric acid. Gasworks were required to purchase sulphuric acid for use in the manufacture of ammonium sulphate, a fertilizer produced by many gasworks.

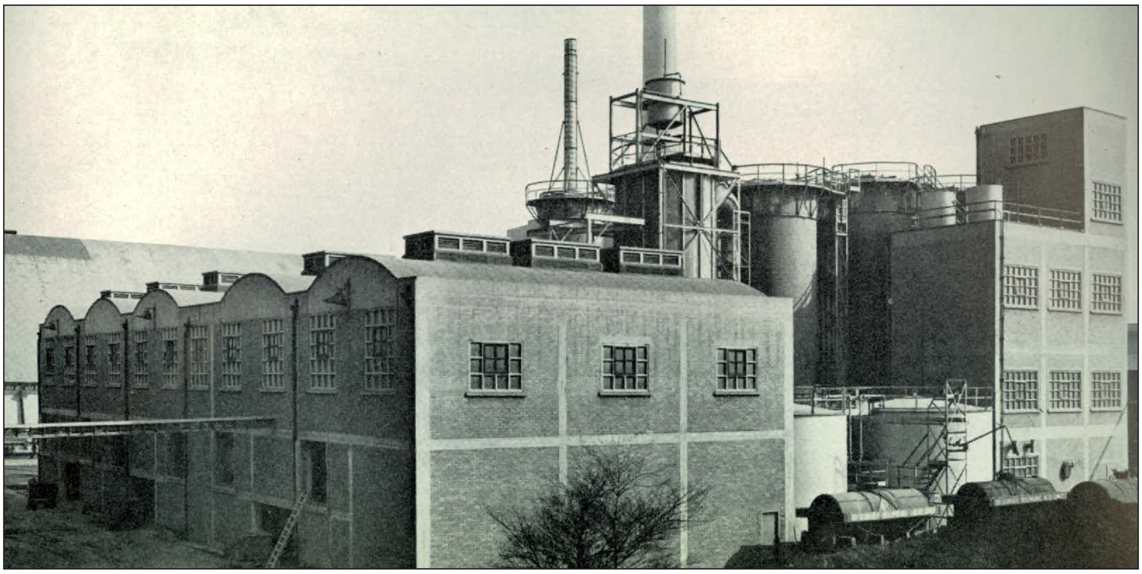


Figure 3.196 The sulphuric acid plant at the East Greenwich gasworks. Image courtesy of National Grid Gas Archive.

The two processes primarily used in sulphuric acid manufacture were: 1) the lead Chamber process; and 2) Contact process. The lead chamber process was developed in Birmingham in 1746 by John Roebuck. It was improved in 1827 when Guy-Lussac introduced a lead lined tower for the recovery of nitrogen oxides and in 1859 when John Glover introduced a tower for the denitration and concentration of sulphuric acid.

The Contact Process was first developed and patented in 1831 by Peregrine Phillips, a British vinegar merchant. The process passed sulphur dioxide produced by burning sulphur or pyrites over a platinum catalyst with additional air to form Sulphur trioxide. The first sulphuric acid plant was built using this process was constructed in Freiburg, Germany in 1875 (Ashar and Golwalker 2013 p1-2). The process was not effectively introduced until the beginning of the 20th century, when Knietsch of Badische Anilin und Soda Fabrik disclosed the operating parameter in his patent. This process was generally used on larger chemical works and not typically on a gasworks, so is not described further (Ashar and Golwalker 2013 p1-2, Louie 2005 p1-3 & p3-3).

The original lead chamber process burnt sulphur and potassium nitrate (Saltpeter) in a room lined with lead foil. The Saltpeter acted as an oxidising agent which converted the sulphur to sulphur trioxide, which then reacted with the water to form sulphuric acid of about 35-40% concentration. This reaction was very slow and required the presence of nitric acid or oxides of nitrogen to proceed efficiently. (Ashar and Golwalker 2013 p1-2, Louie 2005 p1-3 & p3-3).

The spent oxide would be collected from the purification plant and delivered to the chemical works where it was unloaded (Figure 3.197). The process started with the spent oxide and any other sulphur rich material being burnt within a furnace, resulting in the formation of sulphur dioxide. The hot sulphur dioxide gas entered the bottom of the Glover tower where it is washed with sulphuric acid, which had nitric oxide and nitrogen dioxide gases dissolved within it. The gas from the furnace was pulled through the system into the base of the Glover tower, either from a draught produced by a chimney or by mechanical means (Lloyd 2011 p23-29, Ashar and Golwalker 2013 p1-2).

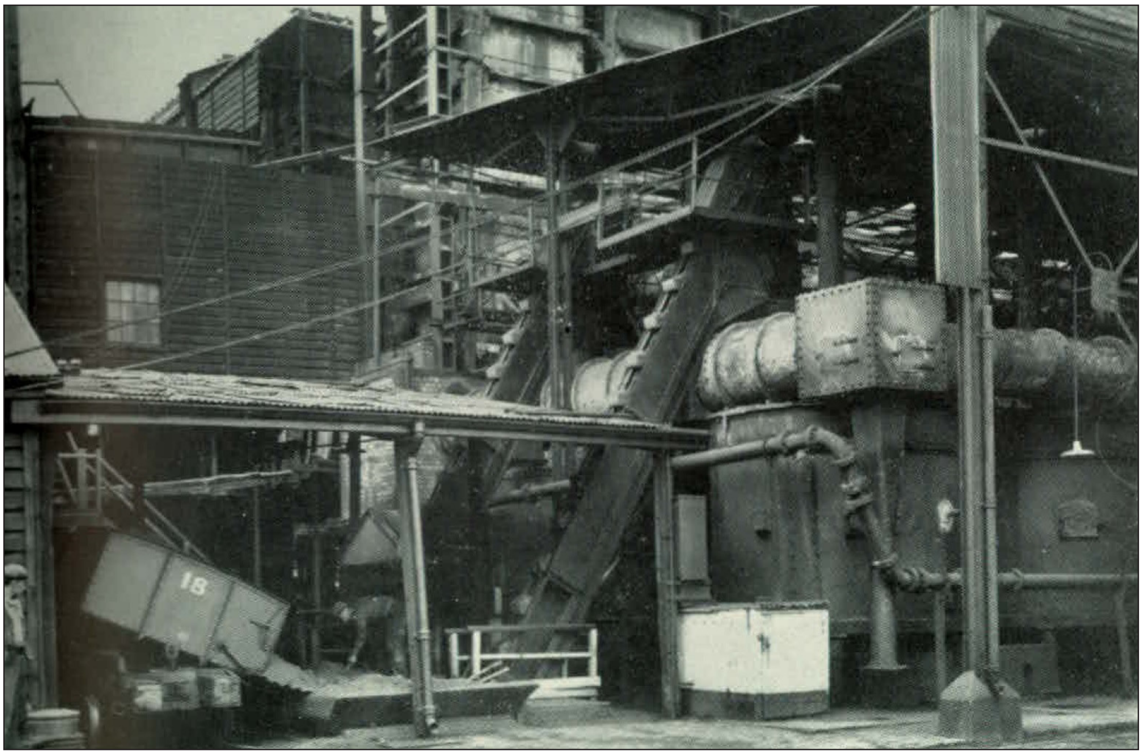


Figure 3.197 Spent oxide being unloaded from rail wagons into buckets en-route to burning in the furnaces of the Becton sulphuric acid plant. Image courtesy of National Grid Gas Archive.

The Glover tower served two functions: it concentrated the acid by evaporating water using the hot gases; and it stripped nitrogen oxides from the liquid to the gas phase (denitration). Some of the sulphur dioxide was oxidized to sulphur trioxide and dissolved in the acid wash forming what was known as tower acid or Glover acid (Lloyd 2011 p23-29, Ashar and Golwalker 2013 p1-2).

From the Glover tower, the mixture of sulphur dioxide, sulphur trioxide, nitrogen oxides, nitrogen, oxygen and steam entered the large lead-lined chambers where it reacted with more water. Sulphuric acid was then formed by a complex series of reactions, it condensed on the walls, and then collected on the floor of the chamber. The acid produced in the chambers contained between 62% and 68% Sulphuric acid (Lloyd 2011 p23-29, Ashar and Golwalker 2013 p1-2).

The lead chambers were often supported on a wooden or iron frame above ground to allow leaks to be more readily detected.

From the chambers, the gases passed into a reactor called the Gay-Lussac tower where they were washed with cooled concentrated acid (from the Glover tower). This was another lead-lined tower, filled with coke. Any vapours of nitrogen oxides or sulphur dioxide were dissolved in the acid. The waste gases exiting the Guy-Lussac tower were usually discharged into the atmosphere via a chimney (Lloyd 2011 p23-29, Ashar and Golwalker 2013 p1-2).

Sulphuric acid was removed from the system at a concentration of about 78%. Nitrogen losses were made up with nitric acid which was added to the Glover tower. The sulphuric acid was then stored on site and sold to merchants or direct to companies requiring this reagent. It was also used on-site for the manufacture of ammonium sulphate (Lloyd 2011 p23-29, Ashar and Golwalker 2013 p1-2).

The overall chemistry of the process, including the chemical reactions with nitrogenous intermediates, was much more complex.

The overall reaction for the process was:

$$SO_2 + ½\ O_2 + H_2O = H_2S0_4$$

The lead chamber process was used on the Beckton Chemical works (part of the Beckton gasworks) up until 1970, when the works closed (Townsend 2003).

The Phoenix wharf on Greenwich peninsula originally was from 1869 home to Hills chemical works, which supplied sulphuric acid to the South Metropolitan Gas Company for Ammonium Sulphate production. This company was purchased by the South Metropolitan Gas Company prior to the end of the 19th century as they were expanding their East Greenwich gasworks. These works produced sulphuric acid by the Chamber process but later the South Eastern Gas Board installed a Kachkaroff process of sulphuric acid manufacture, with similarities to the Chamber process in that towers were used for the manufacture of the acid. The plant was designed to produced 65 tons per day of 77% sulphuric acid, with each furnace (Figure 3.198) burning 10 tons of spent oxide per day.

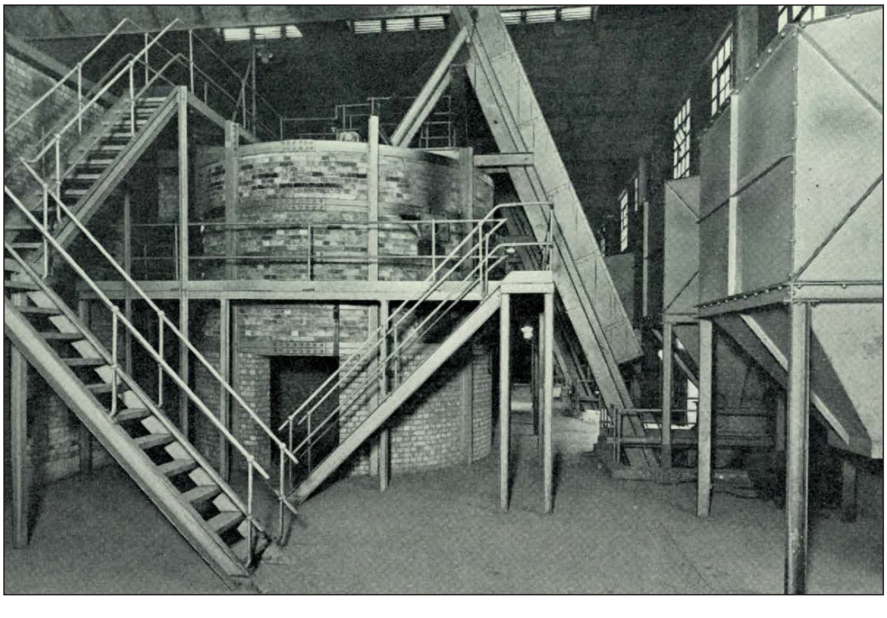


Figure 3.198 The Spent Oxide burners at the Kachkaroff plant of the East Greenwich gasworks, circa 1950. Image courtesy of National Grid Gas Archive.

Towards the end of the 19th century processes were developed which could extract sulphocyanide compounds from spent oxide through dissolving the compounds in water and then evaporating the water. The sulphocyanide compounds were used in dyeing and calico printing (Arnold 1890 p39-53).

3.6.4 Ammonium Sulphate Plant

Two of the by-product generated from a gasworks, the ammoniacal liquor and spent oxide could be used to produce another useful by-product Ammonium Sulphate, which was used as a fertiliser.

The process was quite simple and involved driving off the gaseous ammonia (NH_3) and reacting it with sulphuric acid (H_2SO_4) in line with the following reaction:

$$2NH_3 + H_2SO_4 = (NH_4)2SO_4$$

A small gasworks that did not have access to steam would use an under-fired still or boiler to drive the ammonia from the liquor. This process was not ideal and was not used in large works. When the liquor reached near-boiling point, a great number of odorous gases such as hydrogen sulphide would be suddenly released. Dealing effectively with these gases without causing a great deal of nuisance was extremely difficult. Larger gasworks had continuously operated stills into which liquor would continuously run. These continuous plants would operate using steam produced for various purposes in the gasworks' boilers (Arnold 1890 p39-53). A schematic of the Sulphate of Ammonia plant operated at the East Greenwich Gasworks circa 1950 can be seen in Figure 3.199.

For each ton of coal carbonised about 25lbs of ammonium sulphate was produced (Gas council, 1953). For a typical plant encountered on most gasworks the process would operate as described. The ammoniacal liquor would be pumped into an overhead tank and flow through into a superheater; there, the liquor would be heated to boiling point by gases from the saturator (Figure 3.200). From the superheater, the liquor passed into the top of the still ((Figure 3.200); the latter contained a series of perforated trays which would contain the liquor to a depth of 2½ inches (6.3 cm). The liquor flowed down through these trays, being continuously vibrated. Steam was admitted through the base of the still; as it ascended, it boiled the liquor and released the ammonia (Arnold 1890 p39-53).

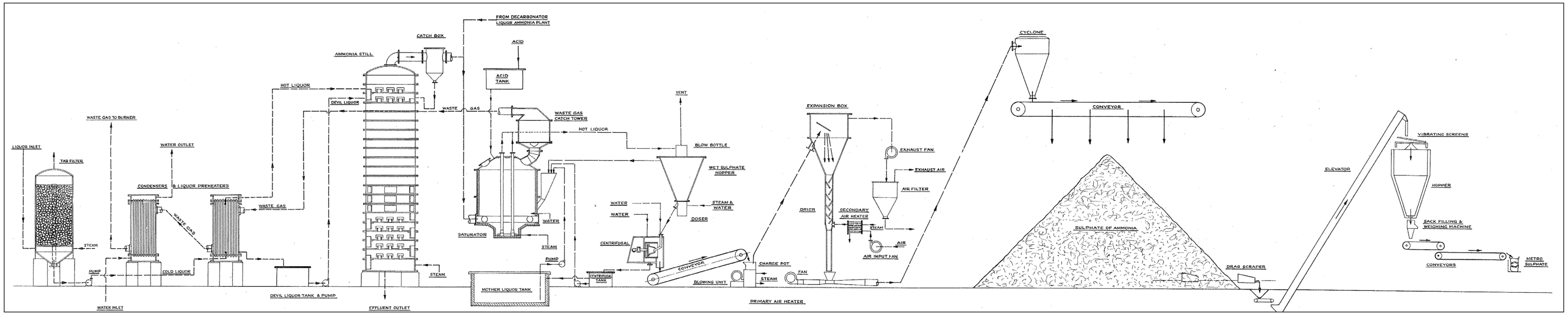


Figure 3.199 Schematic of the Sulphate of Ammonia plant located at the East Greenwich Gasworks circa 1950. Image courtesy of National Grid Gas Archive.

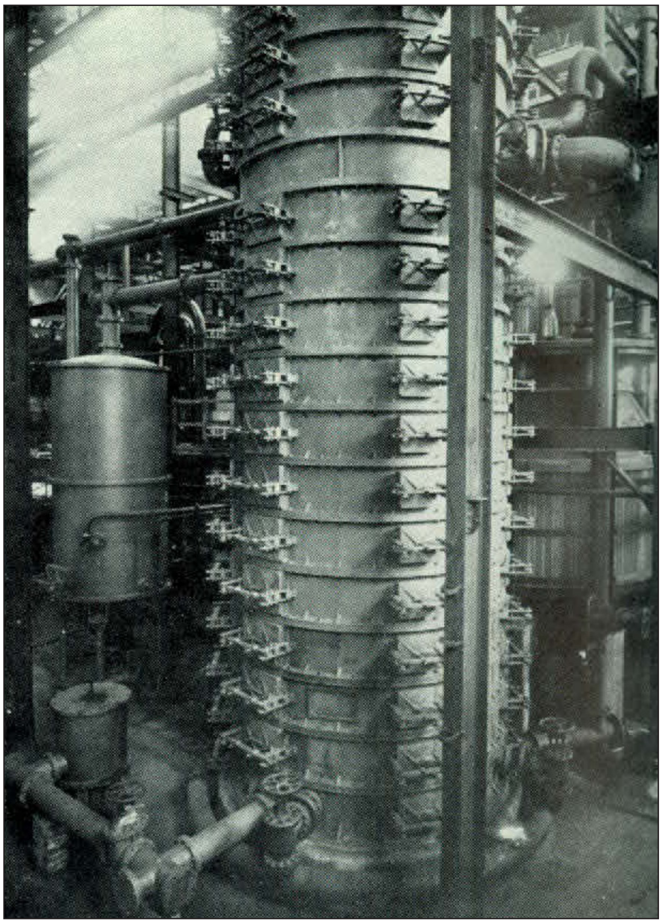


Figure 3.200 Sulphate of ammonia plant, showing liquor tower or still (centre), liming unit left and saturator (right) at Beckton Chemical Works. Image courtesy of National Grid Gas Archive.

Cream of lime (a suspension of calcium hydroxide ($Ca(OH)_2$) in water) was pumped into the bottom compartment of the still. Once thoroughly mixed with the liquor, it flowed through a secondary still where the same process was repeated, releasing all the ammonia. Ammonia gas coming off the stills was mixed with sulphuric acid in the saturator to form ammonium sulphate (Arnold 1890 p39-53). The ammonium sulphate was removed using a ladle and left to dry. Once dry, it was placed in the sulphate store where it was put in sacks for sale and distribution. The more modern (Arnold 1890 p39-53).

3.7 Ancillary, Welfare and Administrative Buildings

A range of other buildings and structures were present on or associated with gasworks. These included ancillary, welfare and administrative buildings. Some of these are described below in this section.

3.7.1 Water Softening/Water Treatment plant

Where the gasworks was supplied with hard water (from the town water supply, rivers or wells) the gasworks would normally install a water softening plant also referred to as a water treatment plant, which would be housed within a building on the works. Various chemical processes (e.g. lime treatment) and/or ion exchange resins were used which could soften the water by the removal of calcium, magnesium, and certain other metal cations in hard water.

3.7.2 Workshops

The workshops were an important feature of gasworks, they would be well equipped with machine tools. They would be used for repairs, fitting, plating, riveting, welding, blacksmithing, electrical engineering, carpentry, painting, plumbing and other associated activities.

An important use was the servicing and repair of lamps, meters and appliances as can be seen in the examples shown in Figures 3.201 and 3.202. As a lot of repair and servicing works were carried out in-house by the gas companies, such workshops could be a considerable size. Defective customers meters or appliances would be recovered, repaired and returned. They would include painting and enamelling facilities.

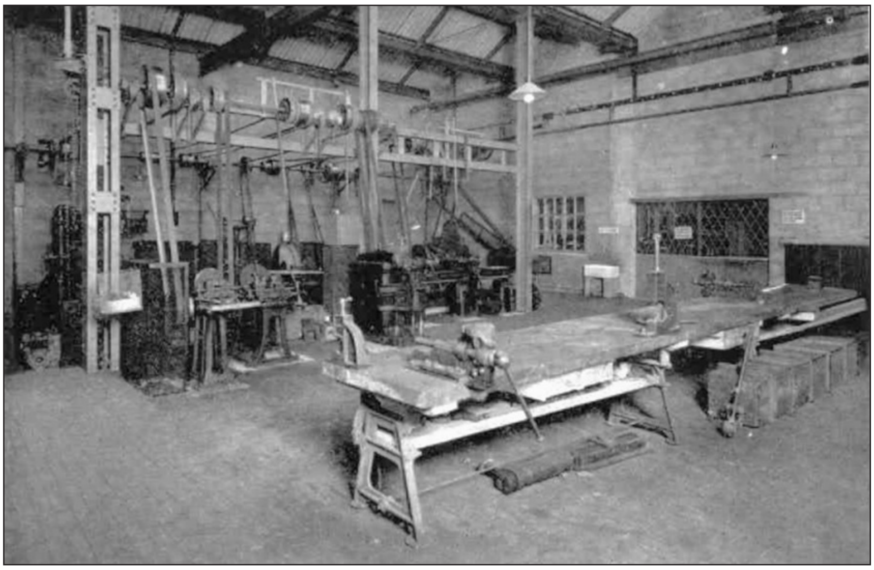


Figure 3.201 The Repair Workshops at the Oswald Street Gasworks, Burnley, 1928. Image courtesy of National Grid Gas Archive.

Figure 3.202 A gas lamp being repaired in a gasworks workshop. Image courtesy of National Grid Gas Archive.

The Sydenham gasworks included facilities for sand blasting (Figure 3.203), caustic and solvent baths, metal finishing baths, welding facilities and burning off ovens.

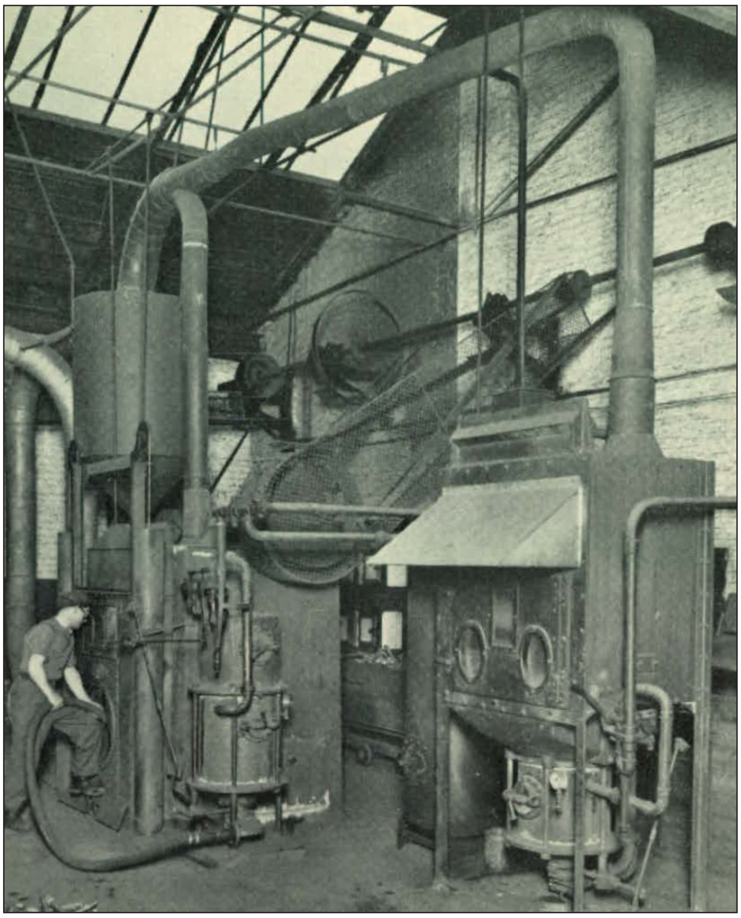


Figure 3.203 The sand blasting plant at Sydenham gasworks. Image courtesy of National Grid Gas Archive.

The workshops often contained appliance and meter storage and repair facilities. It would provide a base for the crews and their equipment which worked on the replacement, repair and extension of the gas distribution network. These buildings could be simple or quite grandiose such as those shown in Figure 3.204, which survive and now house the Weston Super Mere Museum.

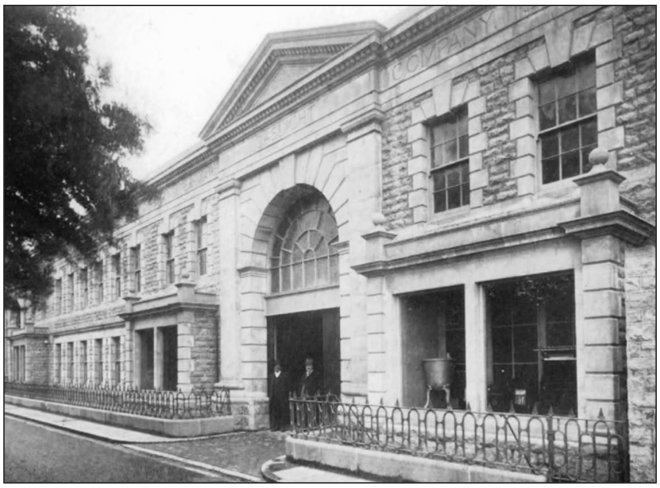


Figure 3.204 The former workshops and Stores at the Weston Super Mere Gaslight Company, Burlington Street, Weston Super Mere, Somerset. Image courtesy of National Grid Gas Archive.

3.7.3 Smithy

Most gasworks would operate a smithy, for the manufacture and repair of items for the gas company. The Smithy or Blacksmiths contained the forge, which was used by the smith to heat metal to a temperature where it became easier to shape by forging. The forge would have used coal or coke as a fuel to heat the metal to malleable state or undertake other metallurgical processes such as hardening or annealing.

Figure 3.205 The Smithy at the East Greenwich gasworks during World War I. Image courtesy of National Grid Gas Archive.

3.7.4 Stables

Stables were an integral part of the gasworks up until the early 20th century. The stable housed horses, which were used for the collection of coal and delivery of coke and other by-products to the local area. Such a horse drawn wagon can be seen in Figure 3.206.

Figure 3.206 Horse drawn wagon of the Bow Common Gasworks. Image courtesy of National Grid Gas Archive.

The horses were also used for the transport of coal (if it was not shipped directly to the gasworks by train, canal or collier). A complete stable would consist of stalls, loose-boxes, one or more sick or isolation boxes, a washing-box or shed, coach-house, harness-room, denning and saddle rooms, a provender-room, tool-house and lofts for hay and corn. Typically, a site would be chosen that is dry and well-drained, light and ventilated without a draught. An Example of a former stables at Fulham gasworks is shown in Figure 3.206.

Figure 3.207 Former Stables Fulham gasworks 1938. Image courtesy of National Grid Gas Archive.

3.7.5 Garage

During the 20th Century there was a gradual switch from horse power, to steam powered vehicles such as traction engines and tractors and then to diesel powered vehicles such as shown figure 3.208.

Figure 3.208 A wagon delivering coke for the Sunderland Gas Company. Image courtesy of National Grid Gas Archive.

These vehicles were used for the transport of coal (if it was not shipped directly to the gasworks by train, canal or collier). They would also cater for vehicles used for: mains laying and repair; delivery, repair and return of meters and appliances; fitters, collectors and inspector's vehicles. The garage of the Sydenham gasworks of SEGAS housed 130 vehicles in the 1950's.

3.7.6 Stores

Various stores were found on former gasworks, these would include stores for raw materials used in the gas making process, such as coal or lime, hardware such as retorts or firebricks and consumer items such as meters or appliances. Figure 3.209 shows appliances being dispatched from the gasworks stores.

Figure 3.209 Dispatching appliances from the stores. Image courtesy of National Grid Gas Archive.

3.7.7 Laboratory

The Laboratory as shown in Figure 3.210 was an integral part of the medium to large gasworks, where it would be used to undertake tests on the gas and by-products produced on the gasworks. The laboratory sometime formed part of the office building as it did at Bow Common. At large gasworks, the laboratory would include rooms for the station chemist, stores, samples, instruments, washing facilities and changing rooms. Associated with the laboratory would sometimes be a Test House, which would contain calorimeters for testing the gas.

Figure 3.210 Laboratories of the South Metropolitan Gas Company. Image courtesy of National Grid Gas Archive.

3.7.8 Welfare Facilities

Larger gasworks would provide a "First Aid and Dressing Station", with a doctor, nurse and equipment for the treatment of minor injuries (Figure 3.211). On large gasworks such as Southall a welfare officer would visit the gasworks daily to assist employees to resolve work or personal problems. The would also look after the welfare of the sick, injured or bereaved.

A mess rooms fitted with a kitchen and canteen would also be provided for staff, these were sometime divided or split across the site depending on staff function (e.g. stokers) in the larger gasworks.

Figure 3.211 First Aid and Dressing Station East Greenwich Gasworks. Image courtesy of National Grid Gas Archive.

Some larger gasworks would provide an Institute at an accessible point in the works, often by the entrance gate. A Sports and Social Club recreational facilities such as a sports ground (Figure 3.212) were also provided to employees, this often-included competitive sports such as football and athletics against gasworks of the same company or nearby gas companies.

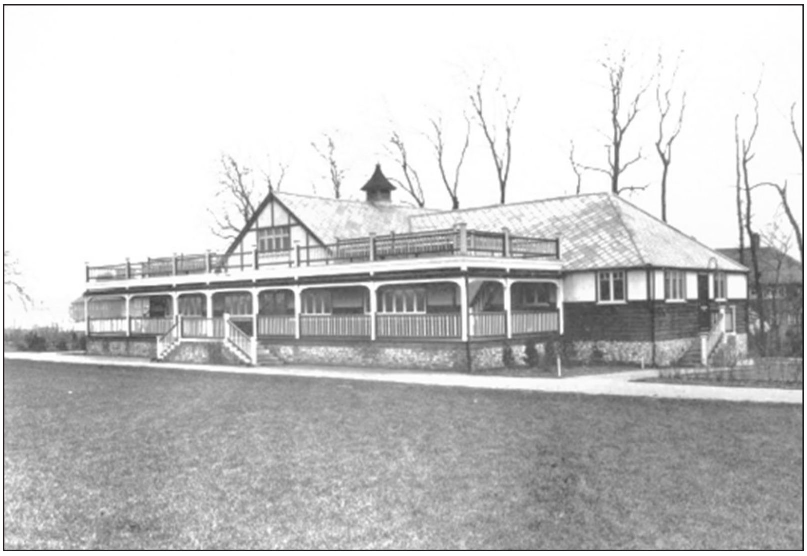


Figure 3.212 The Birmingham Corporation Gas Departments “Hollyfield Recreation Ground”, Holly Lane, Erdington, 1928. Image courtesy of National Grid Gas Archive.

3.7.9 Railway

Many gasworks operated their own private locomotives, on smaller gasworks these operated on a railway connected to a siding into which coal would be delivered. On larger gasworks such as Beckton a more extensive railway network was established with numerous locomotives transporting coal, coke and by-products around the works. An example of the railway at York gasworks is shown in Figure 3.213.

Figure 3.213 Coke wagons being loaded on the overhead railway, York, 1924. Image courtesy of National Grid Gas Archive.

The gas undertakings would often own their own fleet of wagons used to transport the coal. The Birmingham Corporation Gas Department operated its own railway wagon repair facility to service its fleet if 1,560 wagons in 1928 (Birmingham City Gas Department 1928).

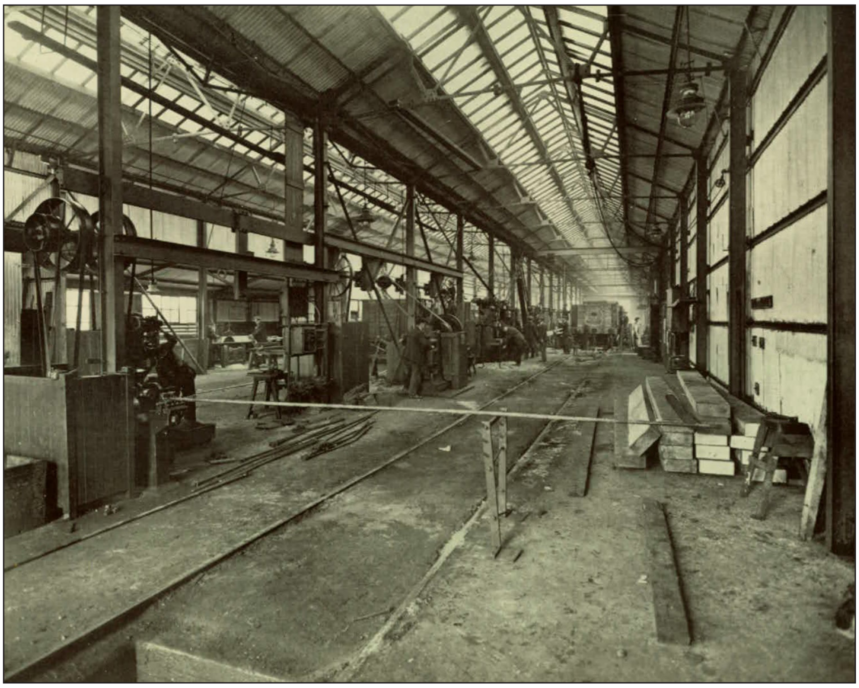


Figure 3.214 The Birmingham Corporation Gas Department Wagon Repair Shop, Washwood Heath, Birmingham. Image courtesy of National Grid Gas Archive.

3.7.10 Boundary Wall

Gasworks were usually secured around their perimeter by a brick or stone wall, as shown in Figure 3.215. The purpose of the wall was to provide a secure perimeter. The boundary walls were sometimes formed by the perimeter buildings and in some cases, could be quite ornate. The wall, or fragments of it are often the only remaining element of the original gasworks.

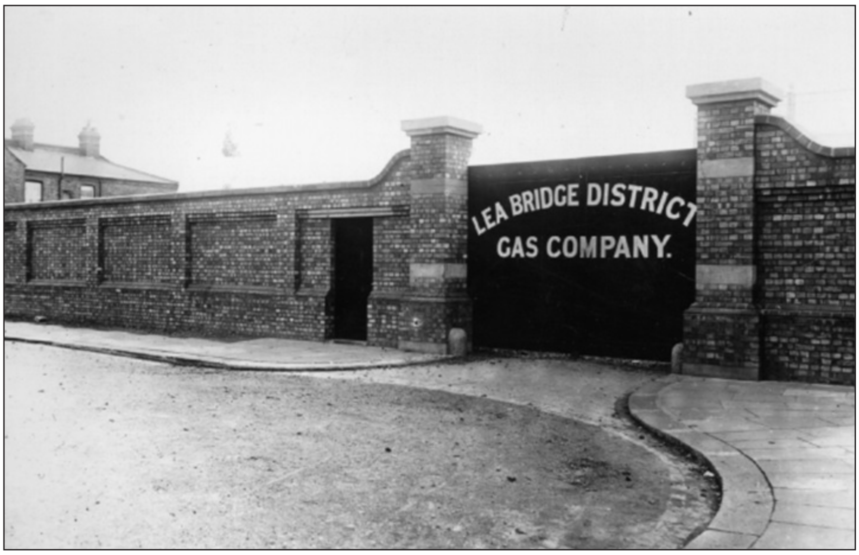


Figure 3.215 The former entrance gates into the Lea Bridge Gasworks, London. Image courtesy of National Grid Gas Archive.

3.7.11 Gateway into the Works

The entrance to a gasworks could vary considerably from an ornate arch to a couple of basic pillars. The gateway would often be fitted with wooden or sometime iron gates, to the same height as the perimeter wall. They were sometime painted with the name of the gas undertaking (Figure 3.215) and guarded (Figure 3.216).

Figure 3.216 The former entrance gates into the Fulham Gasworks, London. Image courtesy of IGEM Archive.

3.7.12 Offices and Administration Building

The administration of the gas company would be handled from the company offices and associated administration buildings. These would provide accommodation for the management of the undertaking, office clerks and secretarial staff and a boardroom for the directors or gas committee to meet. Accounts functions, and the payment of bills may also have been handled from these buildings. On small gasworks, the office may be constrained to a few rooms on the gasworks frontage.

The large gasworks would have a control room to ensure gas production and transmission/distribution were co-ordinated. A shift engineer would be on duty on such large sites 24 hour a day.

Some municipal gas undertakings, for examples the Birmingham Corporation Gas Department had its offices and main showroom in the Council House, Figure 3.217, (Birmingham City Gas Department 1928).

Figure 3.217 The interior of the former offices of the City of Birmingham Gas Department at the Council House. Image courtesy of National Grid Gas Archive.

Others occupied specially commissioned buildings within the centre of the town or city, such as the surviving example on Bloom Street in Salford, a building of High Gothic, built by local architect Thomas Worthington. At certain periods, for example the 1920's, renowned architects were employed to design the offices built on the gasworks, for example, the offices at the Bow Common (Figure 3.218) and the laboratory at Fulham gasworks were designed by Sir Walter Tapper RA, FRIBA.

Figure 3.218 The New Administration building built for the Gas light and Coke Company at the Bow Common Gasworks. Image courtesy of National Grid Gas Archive.

A few examples of gas offices have been listed including those at Ramsgate (Figure 3.219), Fulham, Derby and Salford and are included in the Gazetteer. Other prominent examples of their type such as Radiant House in Liverpool survive, but at the time of writing were not listed.

Figure 3.219 The surviving gas offices, Ramsgate, Kent. © Historic England.

An example of the frontage and interior of the combined former gas offices and showrooms of the York Gas Company are shown in Figure 3.220. These building no longer survive.

Offices would also be provided on the gasworks for specific functions, for example the weighbridge office, foremans office and gate keepers office.

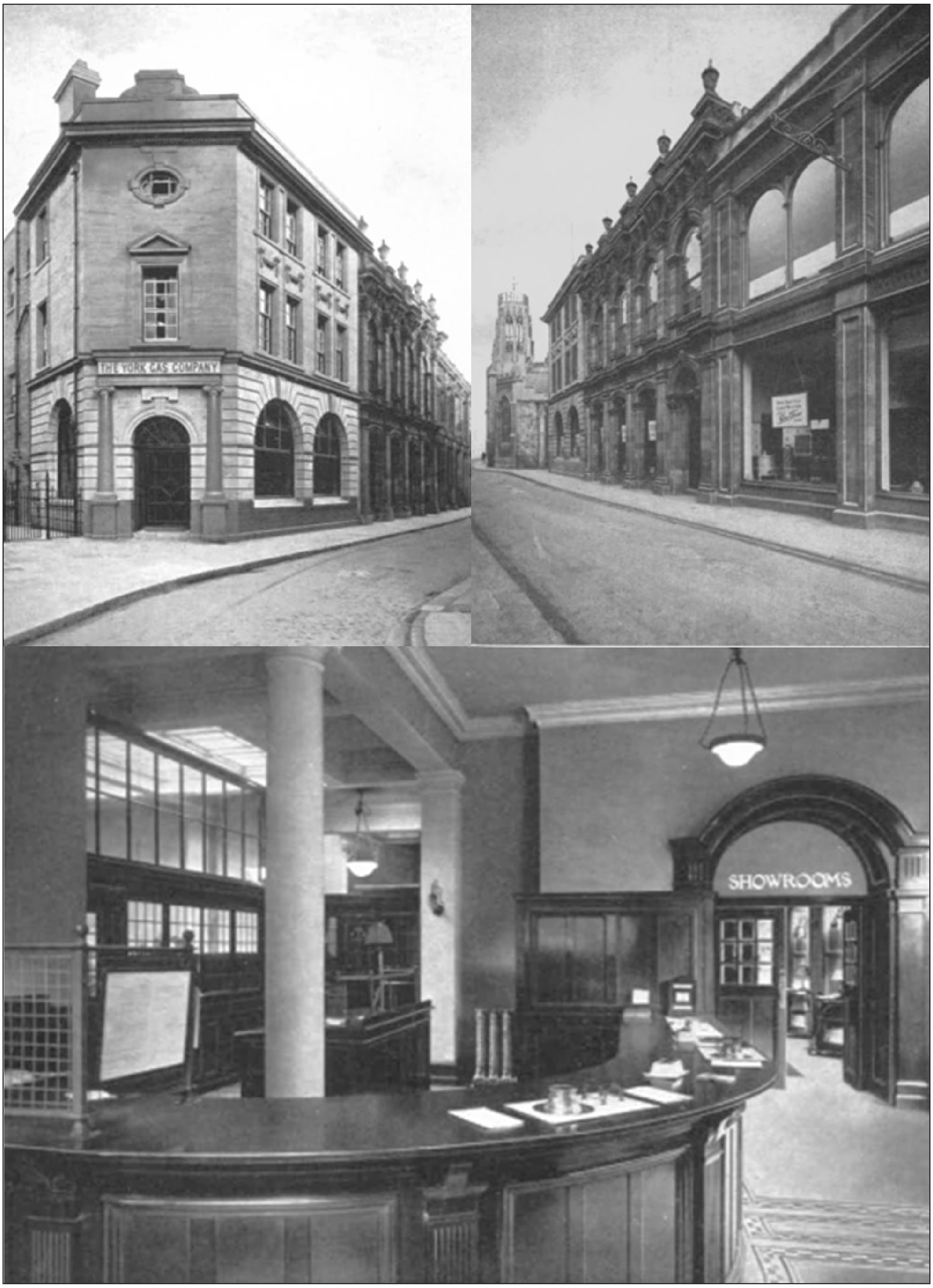


Figure 3.220 The frontage and interior of the accounts office of the York Gas Company located on St. Helen's Square and Davygate, 1924. Image courtesy of National Grid Gas Archive.

2.7.13 Gas showrooms

On many of the smaller gasworks the gas showroom was one of buildings which formed part of the frontage of the gasworks. The gas company's offices were often located above or adjacent to the showroom. As the gas undertakings grew these were often replaced by a showroom more conveniently located in the town centre.

For larger gas undertakings the showrooms were often a separate building. Typically, the main showrooms would be centrally situated in the town or city to allow easy access to customers as can be seen in Figure 3.221. The showroom would try to provide an attractive, modern, and spacious area to display of all types of gas appliances.

Figure 3.221 Therm House Oxford, the former offices, showrooms, demonstration theatre and homecraft centre of the Oxford Gas Company c1948. Source R. Thomas.

Typically, a Demonstration Theatre would be located in the same building which housed the showroom. It would provide interesting cookery demonstrations regularly throughout the year. A further service which was often based from the Showroom was the Home Craft Department whose aim was to provided training on how to run a home efficiently and economically, but at the same time it also provided the opportunity of seeing and using the latest gas appliances. Sometimes the gas undertaking would operate smaller local gas showrooms in the suburbs such as that shown in Figure 3.222, which was the small showroom in Acocks Green, Birmingham or Figure 2.223 a small gas showroom in Coventry. After privatisation the gas showrooms passed to British Gas, and were gradually closed down, a rare example the Leeds Gas Showroom still operates in Eastgate, Leeds.

Figure 3.222 Former Acocks Green Gas Showroom of the City of Birmingham Gas Department, c1928. Image courtesy of National Grid Gas Archive.

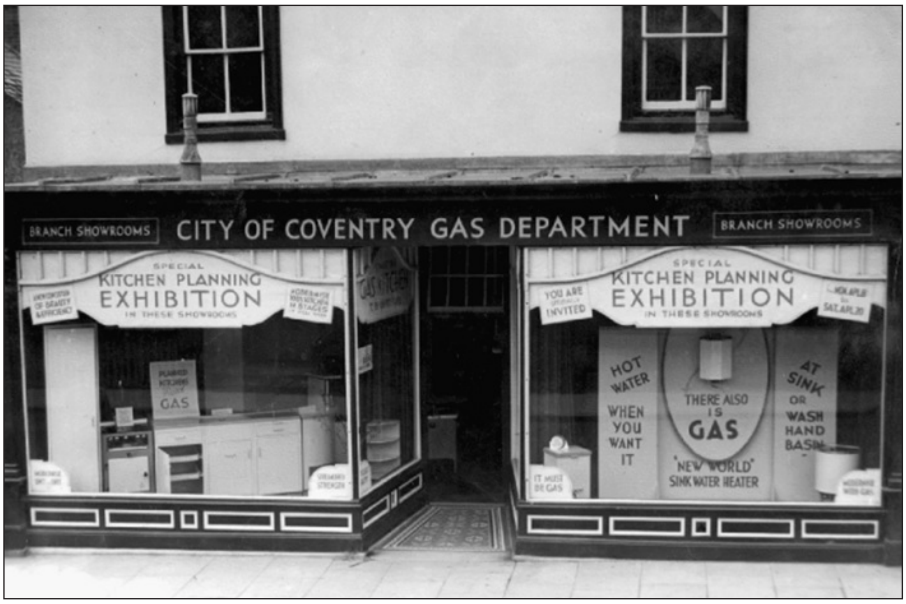


Figure 3.223 Former Gas Showroom Coventry, c1930's. Image courtesy of National Grid Gas Archive.

2.7.14 Employees Houses

The gas industry had historically provided accommodation for many of its workers. Typically even small town gasworks, would have a managers house, built on the same site as the gasworks. Additional workers flats, cottages or houses were often provided on or near to the gasworks, as can be seen in figure 3.224. These buildings are often one of the few surviving buildings, with many examples listed in the Gazetteer.

Figure 3.224 SEGAS employee's houses, Rotherhithe, London. Image courtesy of National Grid Gas Archive.

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