Gasworks Profile A:
The History and Operation of Gasworks (Manufactured Gas Plants) in Britain

A profile of the gas manufacturing process, its design, development, application and the types of waste and by-products which may be associated with the processes used.

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Contents

1. Introduction

Gas was manufactured in Britain between 1792 – when William Murdock first used coal gas to light his house and office in Redruth – and 1981, when the last gasworks closed in Britain. Britain now uses natural gas, having started to convert from manufactured gas in 1967, an operation taking 10 years to complete. This profile describes the historical development of the manufactured gas industry in Britain, outlining the processes used to manufacture gas from coal and giving a brief description of other processes. It is aimed at those who have a professional or personal interest in the manufactured gas industry.

2. A Brief History of the Development of the Gas Industry

Ancient Times and the Early Awareness of Gas

People were aware of the existence of flammable gas in ancient times, when 'Eternal Flames' formed the centrepiece of religious shrines. The external flames were seepages of combustible gases from sources of gas in the ground below. The Chinese were known to have captured natural gas seepages and transported them through bamboo pipes to be burnt to heat salt pans, evaporating water to produce salt. They had also worked out how to capture the gas in animal skins so it could be stored and transported.

It is, however, not until much later that the great potential of gas was realised, and a practical process to manufacture it developed. Many people from across Europe experimented with the distillation of coal, splitting it into its constituent parts of inflammable gas, ammonia rich water, tar and coke.

Photograph 1. Former gasworks clockwise from top, Coatbridge (Lanarkshire, Scotland), Falmouth (Cornwall, England) and Pembroke Dock (Pembrokeshire, Wales).

Jean Tardin documented in 'Histoire naturelle de la fontaine qui brusle pres de Grenoble' (1618), that he had heated crushed coal in a closed vessel producing coal gas, after identifying that the source of the fire well in Grenoble was gas escaping from burning coal beds.

Thomas Shirley made an early observation (1659) of 'carburetted hydrogen' emanating from a natural spring; when he put a candle to the surface of the water, it ignited. Shirley believed the source of the gas was coal below the ground.

Dr John Clayton, the Dean of Kildare, continued Shirley's work and, years later (1684), excavated the base of the spring to find coal 18 inches below. The gas escaping from the coal measures was inflammable and Clayton assumed that the coal was the source of the gas. Clayton's work continued with the distillation of coal in an open retort. He noted: 'At first there came over only Flegm, afterwards a black Oyle and then a spirit arose which I could no ways condense'. Clayton collected the gas in bladders which, if pricked with a pin and squeezed, emitted gas which could be ignited. Much of this work was unknown until Clayton published the work *circa* 1739.

In 1760, George Dixon (Photograph 2) of Durham undertook experiments heating coal in a kettle and igniting the gas which escaped from its spout. He established the first works for extracting tar from coal in Cockfield, Co. Durham, in 1779, the gas from which lit his house.

Carlisle Spedding, the manager at Lord Lonsdale's Saltom mine in Whitehaven (1765), lit his office with mine gas otherwise known as 'fire damp' which was vented from the mine. He had offered to supply the town with gas for street lighting, an offer they refused. This had followed earlier work (1733) by Sir James Lowther in burning fire damp at the surface of a mine from which it was being vented.

Photograph 2. A diorama of George Dixon demonstrating burning coal gas.

Archibald Cochrane, otherwise known as Lord Dundonald, had spotted a market for coal tar with the Royal Navy. By tarring the wooden hulls of the Navy fleet, he proved in tests that it would prevent them from rotting and fouling. Tar distillation ovens were built at the family home, Culross Abbey in Fife, but the Royal Navy did not purchase the tar. The gas produced from the distillation of the coal was reputed to have been lit, producing a bright flame visible from many miles away.

Abroad, others were active in experimenting with coal gas. Jean Pierre Minckelers, a professor at Louvain, lit his lecture room in 1785. In 1786, Professor Pickel lit his chemistry laboratory in Wurzburg, Bavaria. In France, Philippe Lebon obtained gas from heating sawdust in a retort and also lit a room by gas in 1791. Lebon is recognised as the father of the gas industry in France. The son of a court official of Louis XV, he was an engineer and scientist of considerable reputation and devoted great efforts to gas lighting, being awarded a patent in 1799 for this purpose. His worked spurred on the development of gas lighting across mainland Europe.

Most credit for the discovery of a commercial process for coal gas manufacture goes to William Murdoch, an engineer born in 1754 at Bello Mill, near the town of Lugar in Ayrshire, Scotland. Murdoch is believed to have experimented with producing gas from coal in a kettle when he was a child. After walking to the Boulton and Watt factory at Smethwick, Birmingham, from Lugar in 1777, Murdoch found employment. Mathew Boulton was particularly taken aback by an oval-shaped wooden hat that Murdoch was wearing. He had made it himself on a lathe of his own design.

Murdoch performed well and within a few years (1779) he was given the difficult task of selling and installing steam powered water pumping equipment to the Cornish mine owners. This was, at the time, the most prosperous industry in Britain, and Boulton and Watt's most valuable market. Murdoch was so well liked in Cornwall that he married Ann Paynter, the daughter of a local mine owner.

A Strong and Beautiful Light

Murdoch was based in Redruth, where he experimented with the production of gas from coal in a small iron retort in his back yard. The gas was piped into the house allowing him to light his house and office in 1792 (Photograph 3). Murdoch was an engineering genius, much

overlooked when compared to some of his peers. He also built the first working model steam carriage at the same house in Redruth in 1784.

Photograph 3. A diorama of William Murdoch demonstrating gas lighting at his home in Redruth, Cornwall.

Between 1795 and 1796, at the Neath Abbey Iron Works, Murdoch conducted further experiments into the design of retorts. He lit the counting houses of the works, describing the light produced by the gas as 'a Strong and Beautiful Light'. At the same time, Murdoch lit a factory in Old Cumnock, Ayrshire. He did this by filling small bladders with gas from a retort outside the factory and then attaching them to light fittings within the factory and burning the gas.

Recalled to Birmingham in 1798, Murdoch continued to experiment with gas lighting, without much support from his employers – until Gregory Watt visited Paris and discovered the rival work being undertaken by Philippe Lebon.

With more encouragement, Murdoch went on to light the Soho works of Boulton and Watt in 1802. To celebrate the Peace of Amiens, the exterior of the Soho works was illuminated, the first public gas lighting exhibition. Murdoch had experimented with a vertical retort design with the coal held in baskets, but this proved impractical and he developed horizontal retorts by 1802. Murdoch operated the retorts in a way that required him to light the furnace shortly before the gas was required, an inefficient form of operation. A colleague, John Southern, pointed out that if the gas could be collected within a storage device (gasholder), then fewer retorts would be required and they could be operated continuously. Murdoch examined the process of coal gas manufacture in great detail, costing his employers an estimated £5,000. In 1805, the Boulton and Watt factory was the only supplier of gas-making plant in the world. In the same year, Murdoch also developed the world's first circular gasholder (Photograph 4).

Following on from the success at the Soho works, Murdoch looked for opportunities to install gas plants at other sites. In 1804 George Lee of Phillips and Lee in Salford was the first industrialist to employ Murdoch to build a gas plant and install gas lighting in a mill, initially George Lee's house was lit by gas. Once its safety had been proved, Murdoch lit their Salford Twist Mill, one of the biggest factories in Britain at this time. The mill was fully lit by gas in 1805; in 1806, Chapel Street in Salford was the world's first street to be lit by gas.

Photograph 4. Murdoch's original circular gasholder at the Soho works.

Murdoch was not alone in his interest in gas lighting, a former colleague, Samuel Clegg, had set up as a rival and was busy installing a gas plant at Henry Lodge's Mill at Sowerby Bridge in Yorkshire. Clegg is believed to have beaten Murdoch by two weeks on the installation of gas at Sowerby Bridge.

Despite this success, the ambitions of Boulton and Watt, Murdoch's employers, in the field of gas lighting, were limited. It was a small part of a large business empire focussed on manufacturing steam engines. It was this lack of interest which caused Clegg to depart and for other employees to set up as gas engineering contractors to rival their former employer. Other engineers in the Birmingham area had also seen the potential for gas lighting and engineers such as Josiah Pemberton started designing their own plant for smaller works. Boulton and Watt focussed on the owners of large factories who could afford their plant and they went on to light some of the larger establishments in Britain such as Strutt's calico

mill in Derby, Gott's woollen mill in Leeds and two flax mills in Shrewsbury.

By 1815, the Boulton and Watt Company, and Murdoch, had started to withdraw from the manufacture of gasworks plants. Other specialist gas engineers had taken the lead. Gas was adopted in many large mills and factories across Britain most notably the mills across the north of England.

Mills had predominantly been lit by tallow candles or oil lamps, using up to 1,500 candles per night in the winter. Candles and oil lamps could easily be knocked over, and were responsible for many mills burning down with considerable loss of life. George Lee was offered a greatly reduced insurance cost (one third of the previous cost) for having the Salford twist mill converted to gas lighting, a great incentive.

In 1808, Murdock presented a paper to the Royal Society entitled 'An account of the application of coal gas to economical purposes', for which he received the Rumford Gold Medal.

The Development of the Public Gas Supply

The philosophy of William Murdoch was to build small gasworks to provide gas to a single establishment. Other proponents, however, had greater plans. A key figure was Friedrich Albrect Winzer (Figure 1), an impresario who had seen Lebon's early experiments in Paris. Hailing from Braunschweig (Brunswick) in Germany, to succeed in Britain he changed his name to Fredrick Albert Winsor.

Winsor proposed the concept of centralised gasworks providing gas to multiple establishments through gas mains under the street. It should be noted that Lebon had been murdered in mysterious circumstances crossing the Champs-Elysées in 1804, after which the development of gas in Paris almost ceased until renewed interest in the 1820s. If Lebon had not been murdered then gas may have been adopted in France much sooner.

Figure 1. Sketch portrait of Frederick Winsor.

Lebon's work on the thermolamp cannot be underestimated. It was highly influential in continental Europe and led to significant developments in gas manufacture outside of Britain. Following Lebon's death, Germany became the main centre for interest in the thermolamp, and a number of books and articles were written on the subject between 1802 and 1812. The most important thermolamps were built by Zachaus Winzler, including a large thermolamp in Bruno. Winzler was a chemist from Unlingen, Germany, who moved to Blnsko to run a saltpetre factory for the aristocratic Zu Salm family.

Winsor thought London a suitable place to develop a gas industry. He gained a reputation in the field, undertaking evening lectures and demonstrations at the Lyceum Theatre in London, going on to demonstrate gas lighting on Pall Mall in 1807. In the same year, Josiah Pemberton built a gasworks to light the Golden Lane Brewery and also the street outside the brewery.

Winsor had a very commercial outlook, much more so than Murdoch, and had unsuccessfully challenged Murdoch for a patent for lighting by coal gas. Winsor was intent on setting up a company to produce gas from a centralised gasworks. He first proposed the National Light and Heat Company in 1807 with the grand aim of supplying the whole country with gas. Making applications to Parliament for a charter, he found strong opposition from Murdoch and his friends. He persisted and, eventually, on 30 April 1812, the Gas Light and Coke Company (GL&C Co) received its Royal Charter. Its first gasworks was built on Cannon Row, Westminster, but the plant failed technically and the site was too small to meet future needs. What could be salvaged from Cannon Row was removed to a new site at Great Peter Street, Westminster, which was a success.

Winsor's success with the GL&C Co was short-lived. He was ousted by the ruling court and in 1813 was given an annuity of £600. This was suspended in 1815 and Winsor had to flee the country to avoid his creditors. He returned to France and floated a short-lived gas company. He died in 1830 a disappointed man, but his influence on the gas industry was significant.

The First Gas Engineer

Born in Manchester, England, Samuel Clegg was the son of a wealthy businessman, Wheatley Clegg. Samuel Clegg was educated at New College Manchester between 1794 and 1797; in 1798 he became an apprentice engineer at the Soho foundry of Boulton and Watt. Completing his apprenticeship, he worked on steam engines. His introduction to gas came when he assisted William Murdoch in lighting the Soho works for the 'Peace of Amiens' in 1802. Clegg soon realised the potential of gas and the limitations of working at Boulton and Watt, where gas was just one of many departments. He split from the company in 1805 and established himself as a rival gas engineer, based in Manchester.

A great innovator, Clegg experimented with the purification of gas using lime, incorporating such a plant at the gasworks he installed at Stonyhurst College (Preston, England) in 1811. Clegg also invented the gas meter and self-acting governor and adapted the Argand burner for burning gas.

In 1812, Clegg went to London to establish a small gasworks for the famous publisher Rudolph Ackerman. This proved an excellent advert for Clegg's skills as an engineer. On 25 December 1812, Clegg began work for the GL&C Co. This proved vital for the company's survival as its existing technical experts (Winsor, Accum and Hargreaves) were not engineers. He maintained the GL&C Co gasworks almost singlehanded for the first few years.

Clegg even took to lighting the gas lights on Westminster Bridge, as the lamplighters originally refused to light them for fear of explosion. He left the GL&C Co in 1817, installed gas at the Royal Mint, then went on to establish gas in various towns and cities including Birmingham, Bristol and Chester.

Having developed the large circular gasholders at the GL&C Co, Clegg spent much time persuading others that they would not suddenly explode. This included instructing a gas worker to put a pick axe into the side of a holder and then lighting the resulting gas leaking from the vessel. This burnt with a strong flame but no explosion.

These fears over gasholder safety required many of the very early gasholders to be housed within a building. These buildings were later dispensed with in Britain.

Clegg left the GL&C Co in 1817. Prior to this, he had been undertaking consultancy work and was important in the construction of many gasworks across Britain. He left the industry in 1824, returning at various times as his fortunes fluctuated. With his son, Samuel Clegg Junior, he produced an important book 'A Treatise on Gas Works and the Practice of Manufacturing and Distributing Coal Gas', from which Figure 2 is taken.

The Development of Gas Lighting

Lighting was the primary use for gas in the 19th century. The first gas burners were very simple, with names such as rat tail and cockscomb. They comprised iron caps with one or more pinprick holes through which the gas escaped and was burnt. Gradual improvements saw these simplistic burners replaced by more efficient models. Samuel Clegg converted the Argand burner for use with gas in 1809; Stone devised the batswing burner (Figure 3) in 1816; and the latter was further improved upon by Milne in 1820 to produce the union jet or fishtail.
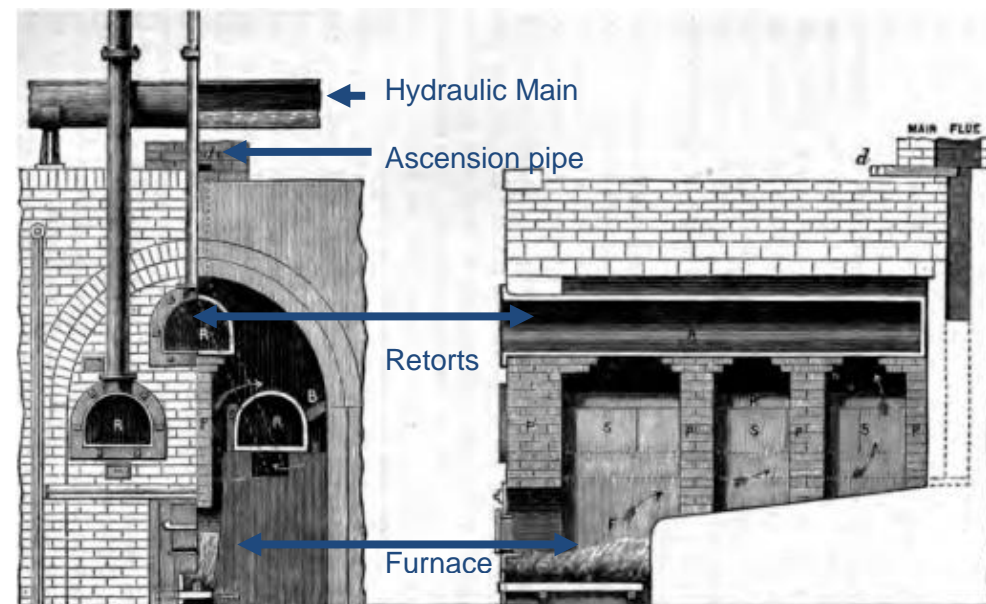

Figure 2. A schematic of a simple bench of three directly fired retorts which would be found in a small gasworks, attributed to Samuel Clegg Jnr. Source: Russell Thomas.
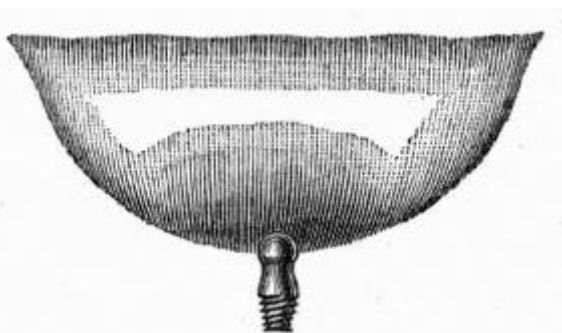
Figure 3. A batswing burner.

In addition to the town and city councils that required street lighting, the early customers were mostly public houses, hotels, theatres, shops and public halls and institutions.

The Great Expansion into the Provinces

Following on the heels of the GL&C Co, many other gas companies were established in London. By 1850 these numbered 13, the most notable rival being The South Metropolitan Gas Company, formed in 1834.

Outside London, Preston became the first provincial town to have a public gas supply, securing an Act of Parliament in 1815 to 'light, watch, pave, repair, cleanse and improve the towns streets'. The Preston Gas Light Company was formed and Samuel Clegg provided his assistant John Grafton to act as engineer. On 20 February 1816, Preston became the first town outside London to be lit by gas. Exeter and Liverpool soon followed, with Acts of Parliament in 1816. In Scotland, the Glasgow Gas Light Company received an Act of Parliament giving it statutory powers in 1817, with gas lighting commencing a year later. In Wales, a public gas supply was first provided to Swansea in 1821.

Gas spread rapidly throughout the country, often through the passing of 'lighting and watching' Acts of Parliament.

Conditions for the workers in early gasworks were very harsh. This was especially true for the stokers, whose role it was to load coal and unload coke from the retorts, and tend the furnaces in hot, dirty and dangerous conditions. An example of the conditions within the Brick Lane gasworks retort house can be seen in Figure 4.

Figure 4. An early painting depicting conditions within Brick Lane gasworks.

Expansion Abroad

In order to export Britain's new-found experience in gas manufacturing, the Imperial Continental Gas Association (ICGA, emblem Figure 5) was formed in 1824 by Major-General Sir William Congreve. By this time, gas was already starting to be manufactured in some European towns. This was in part promoted by success in Britain, but also followed on from the work of Lebon and Winzler with the similar gas-producing thermolamp.

In 1825, Congreve toured Europe to establish business ventures. Success was mixed, as some places already had established local gas-lighting rivals. His first venture was a small oil gasworks in Ghent, purchased from a local company; this was later converted to use coal.

The ICGA went on to operate in the Netherlands, Belgium, Germany, Austria, Hungary and France. Given the nature of their short- to medium-term contracts, and political changes and war in Europe, the business changed considerably. Despite these changes the company continued to operate until 1987.

Figure 5. The emblem of the Imperial Continental Gas Company.

The ICGA was not unique and other British companies were established to target Europe, including the European Gas Company and the Continental Gas and Water Company.

British engineers also looked abroad to seek their fortune independently. Aaron Manby established Manby, Wilson and Co. otherwise known as the 'Compagnie Anglaise', to light some of the streets of Paris. George Bower exported entire gasworks as kits to be built abroad in countries from Russia to Argentina. French and German companies

were also later created to export expertise in gas manufacture.

The British Empire was also targeted by British companies such as the Colonial Gas Company, and by independent gas engineers who set up their own companies. With British support and independently, gasworks were built across the globe on all continents except Antarctica.

Municipal Undertakings

Gas undertakings were all privately owned until the Manchester Police commissioners took an interest in gas lighting. Their first involvement came in 1807 when a gas light was installed over the door of the King Street police station. The Manchester Police commissioners were the government authority in the town and were responsible for lighting (and watching) the streets with oil lamps. They passed a resolution in 1817 to build a gasworks at Water Street to light the police stations and principal streets, and to sell any surplus to private customers. This was the first example of a municipally owned gas undertaking.

The Manchester Police commissioners built another gasworks at Rochdale Road in 1824. Manchester was incorporated in 1838 by the Municipal Corporations Act of 1835 and the gas undertaking passed to the Manchester Corporation in 1843, making it the first municipal gas undertaking.

Many other gas undertakings came under municipal ownership, in particular in the Midlands and North of England. The Birmingham Corporation purchased the two private gas undertakings operating in the Birmingham area in 1875, operating them as the Birmingham Corporation Gas Department.

The gas departments were an important source of revenue for the towns and cities which owned them, and the profits funded many important civic projects. Between 1844 and 1921, the Manchester Corporation gas department earned the council a profit of £3.4m, a considerable sum of money at the time.

The Continued Development and Growth of Gas

By the 1840s, gas lighting had been adopted in the private homes of the wealthy, although it was often confined to certain rooms and not the entire house. A boost was given to the industry when the new House of Commons adopted gas lighting in 1852, and continued to use gas until 1900.

The increased demand for gas storage on a gasworks led to a major innovation in gasholders. The telescopic gasholder was developed by Tate in 1824, and the first example was built in Leeds. This had the added benefit of increasing gas storage without increasing the footprint required by the gasholders. Telescopic gasholders consisted of vessels (lifts) situated one inside the other; when the inner lift was fully extended the next outer lift would also start to rise

People started to look for alternative uses for gas, for example cooking (Figure 6). In 1826, James Sharp, the assistant manager of the Northampton Gas Company, experimented with the possibility of cooking with gas. He installed an experimental gas cooker in his home, and its relative success won him the patronage of Earl Spencer in 1834, after which he began to produce cookers commercially.

There was a great surge of interest in the late 1840s, probably due in part to Alexis Soyers, the celebrity chef of his day. Soyers used gas cooking extensively in the London Reform Club where he worked. The engineers Croll, Ricketts,

King, Goddard and Sharp all manufactured new cookers, but they did not become popular until the 1870s.

The first gas-heated bath was developed in 1850, although such new developments were not without their inherent safety risks.

Figure 6. An early gas cooker of Arden Hill and Company. Source: Russell Thomas.

Regulation and Competition

The gas industry remained largely unregulated in its early years. No restrictions were placed on the prices charged or profits made by the gas undertakings; generally their only obligation was to provide parish gas lighting at a cheaper rate.

In 1847, the Gasworks Clauses Act was introduced to regulate the construction of

gasworks and the supply of gas to towns. The Act regulated all aspects of the industry including pipe laying, profits, annual accounts, penalties, waste produced and by-products. It was just one of a number of important acts which would regulate the gas industry in the coming century.

Parliament relied upon competition in the gas market to keep prices low. In London, almost all areas had the choice of two potential gas companies to supply them. This system was regarded as uneconomic and very inconvenient, as it led to excessive digging up of the roads. In 1853, the area south of the Thames adopted 'districting', with specific companies responsible for supplying specified districts. This concept was later adopted throughout London via the Metropolis Gas Act of 1860.

New Markets Ahead

In 1856, William Perkin was an assistant of August Wilhelm von Hofmann at The Royal College of Chemistry. One summer, whilst Von Hoffman was abroad, Perkin discovered the dye known as Mauveine. Perkin had been working on a way to synthesise quinine in the fight against malaria, but instead discovered Mauvine. Perkin patented the dye and as a result founded the aniline dye industry (Figure 7). Coal tar from the gas industry was the substance from which Mauvine was extracted.

This early discovery by Perkin helped to demonstrate the important and diverse chemicals which were present within coal tar. The coal tar by-product became valuable and could be sold to the new emerging coal-tar-based chemical and dye industry. It became an important industry in its own right, particularly in Germany.
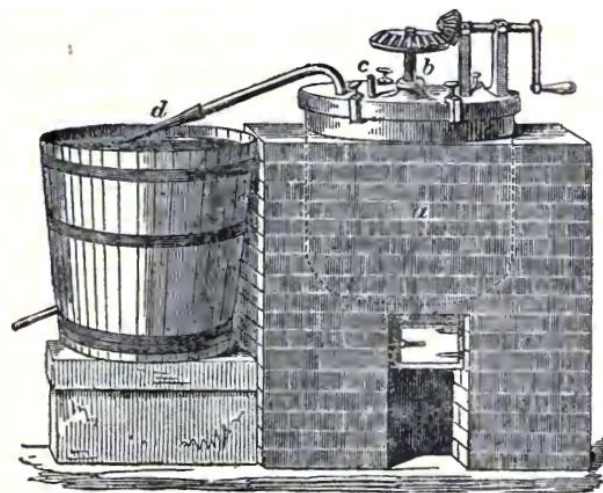
Figure 7. An early apparatus for the production of aniline dyes, from the 'British Coal Tar Industry' by William Gardner.

In 1855, Robert Bunsen, a famous German chemist, invented the atmospheric gas burner known to many as the 'Bunsen burner' (Figure 8). This mixed the air and gas prior to the flame allowing it to burn much hotter. It made more efficient use of the gas burnt and allowed a greater range of uses, especially in commercial and domestic heating applications. This development ultimately saved the gas industry, as heating applications became ever more important as the industry evolved.

Another significant development occurred in 1856, when Frederick Siemens developed the regenerative furnace. This furnace could operate at a high temperature by using the regenerative preheating of air. In a traditional furnace, a large part of the heat derived from combustion was lost, carried off in the hot gases which escaped up the chimney. In the regenerative furnace, the hot gases passed through a chamber (a regenerator) filled with loose bricks which absorbed the heat. Once the chamber was well

heated, the hot gases were diverted to another similar chamber. The incoming air for combustion was then heated by passing through the hot regenerator chamber, absorbing the heat which has been stored in the bricks. After a suitable interval, the air flows were again reversed through the second regenerator. The regenerator ensured that heat was recovered as efficiently as possible.
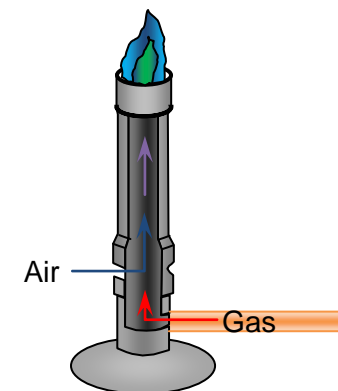
Figure 8. A schematic of a Bunsen burner. Source: Russell Thomas.

Other notable regenerators were developed in Germany and imported to Britain, including the continuous regenerators developed by both Schilling and Klonne, the latter being introduced in 1885. These systems did not require multiple chambers, but were arranged so hot exit gases could continually heat incoming air.

The effective use of the regenerator was dependent on another furnace developed by Siemens. This was a furnace which could produce a crude gas from the incomplete combustion of coal, known as the Siemens gas-producer (described later in the section on horizontal retorts).

Gaseous fuel passed via a flue from the producer to the regenerative furnace heating it. The combined regenerator and producer were used together at Chance's glassworks in Birmingham in 1861, and were described by Michael Faraday in his farewell lecture to the Royal Institution. This system was gradually improved and introduced to the UK through Frederick's brother, William Siemens, gaining widespread use in many industries, including the gas industry.

Producer gas plants provided the great benefit of allowing the production of heat at high and uniform temperatures. They later became used for heating all forms of gas retort. This allowed the gas-making process to proceed at higher and more efficient temperatures than previously.

Dowson developed a complete suction gas producer plant in 1878 which could be used both for industrial and domestic purposes. He demonstrated the effectiveness of gas engines in 1881 when he combined a producer gas plant with a gas engine.

Gas producers became regularly used in industry, producing a low-quality gas unsuitable for lighting but able to power gas engines and heating furnaces.

The only producer-based gas production process to use gas for distribution was the Mond Gas process. An entire gas network was built in South Staffordshire to produce Mond gas from a gasworks in Tipton. This supplied local industry with a gas for heating and powering engines. The process also produced large amounts of the chemical ammonium sulphate.

Mond gas was rich in hydrogen and carbon dioxide. It was of little use for lighting, although it could be used for industrial purposes. This is covered by *Gasworks Profile D - Producer Gas Plants*.

In 1863, the British Association of Gas Managers was formed, the forerunner to the current Institute of Gas Engineers and Managers, which celebrated its 50th anniversary in 2013.

Thomas Fletcher trained as a dentist but had an interest in engineering. He originally developed dental equipment, but by the early 1880s was manufacturing gas appliances. under the name of Fletcher Russell and Co Gas Engineers, Fletcher took Bunsen's invention and developed many different applications for it, including furnaces, fires, cookers and water heaters as well as laboratory equipment. Appliances were developed by many other gas engineers, including John Wright (featured in Figure 9).

A Bright Future?

Baron Carl Auer von Welsbach was an Austrian chemist who made a major contribution to the gas industry with his invention of the gas mantle in 1887. He discovered that the oxides of certain rare metals had the ability to emit light when in a state of incandescence. After many years of research, the final mantle was produced by soaking a textile in a mixture of 99% thorium dioxide and 1% cerium (IV) oxide. When the mantle was heated by the Bunsen burner it produced a brilliant light.

It should be noted that, in 1826, Drummond used incandescence in the commercial application of lime-light through the oxy-hydrogen heating of calcium oxide. Platinum mantles had also been used to light the town of Narbonne, France, in 1848. They were also used by Hogg, who used an aerated flame burner with a platinum mantle.

Figure 9. Advert *circa* 1898 for gas fires by John Wright and Co from the Gas Engineer's Textbook and Gas Companies Register 1898.

None of these developments had anything like the impact of Welsbach's invention once it had been perfected (Figure 10).

Welbach's invention was timely, with the gas industry facing a new rival: the electric light bulb. Humphrey Davy demonstrated the first electric arc lamp in 1806, but it was impractical and went no further. The more robust light bulb for everyday use was developed by Joseph Swan (UK) in 1878 and Thomas Edison (USA) in 1879. They later collaborated to form the Edison Swan Electric Company Limited otherwise known as Ediswan.

Figure 10. An advert for a gas mantle from the Gas Engineer's Textbook and Gas Companies Register 1898.

Electricity did not become a practical reality until metal filament lamps were perfected in 1911 and the Electricity (Supply) Act had been passed in 1926, leading to the establishment of the National Grid. The gas mantle had allowed the gas industry to compete with its new rival electricity for much longer than would have otherwise occurred; gas lighting was still preferred in some towns in the 1950s. Gas lighting has not completely disappeared in the UK: there are still approximately 2,000 public gas lights in the greater London area.

The Sugg family has always been associated with the gas industry. Thomas Sugg made and fitted the original gas pipes for Frederick Winsor in Pall Mall, London, in 1807 and the Sugg brand is still producing gas lighting equipment today. William Sugg & Co was a famous company specialising in gas lighting, and it made many notable developments in this field, but also in the fields of heating and cooking.

The development of new products and the gas mantle gave the gas industry greater flexibility to target new markets and produce a different type of gas, no longer dependent upon a high illuminating power.

In November 1869, work commenced on the construction of the Beckton Gasworks of the GL&C Co. Beckton (Photograph 5) was the largest gasworks ever built.

Photograph 5. This painting of the original Beckton gasworks used to hang in the station engineer's office.

Prepayment gas meters were invented in 1870 by T.S. Lacey. This was a major development, making gas available to those who could not have previously purchased it and could not have afforded its installation costs. Gas was opened up as a viable alternative fuel to a whole new group of people and led to a great expansion in the gas industry in Britain. British gas companies also started to hire out cookers and other appliances to customers.

New Technology Drives the Industry Forward

One major issue with making gas from coal was the time taken to get the gas plant operational and producing gas. This led to a heavy reliance on storage in gasholders. If sufficient storage was not possible then the continuous heating of coal gas plant was required to more readily accommodate rapid increases in gas production. This was both inefficient and uneconomic for the gas manufacturer.

Water gas provided an alternative method to meet peak demand for gas. Although discovered earlier, it was not until *circa* 1873 that a commercially viable system was developed by Lowe. Lowe devised an intermittent system which produced gas on a cyclical basis, first heating the system and then injecting steam to produce a gas comprised of hydrogen and carbon dioxide. This gas lacked illuminating power, but could be enriched by the injection of oil, a process called Carburetted Water Gas (CWG). The first major installation of a CWG plant in Britain was at the Beckton gasworks near London. This subject is covered in *Gasworks Profile C on Water Gas Plants*.

During the period from 1885 to 1905, gas engineers undertook a considerable amount of development work, producing inclined and vertical retort systems. After early work by the likes of Rowan, Coze, Rice, Schilling, Bueb, Settle and Padfield, two companies established themselves as the market leaders in vertical retorts. These companies were Woodhall

Duckham and Glover West (Photograph 6), and they constructed many of the vertical retort plants in the UK.
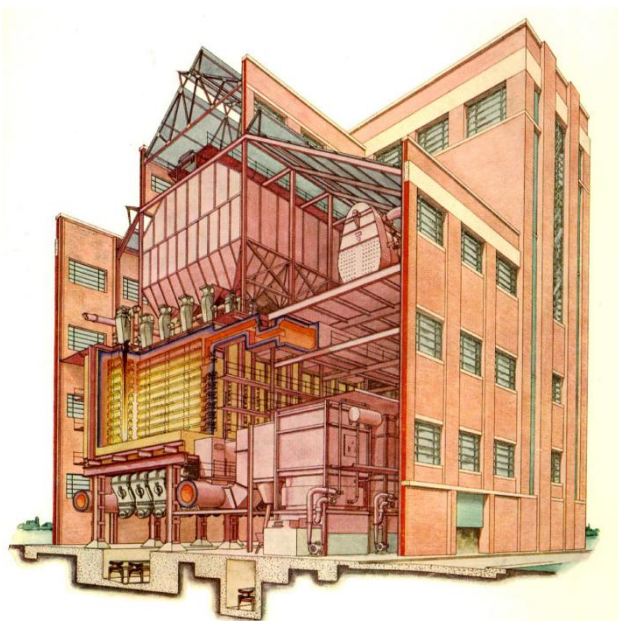
Photograph 6. An artist's impression of West's vertical retort plant.

Vertical retort plants operated with the coal being fed vertically through the retort rather than horizontally, allowing continuous operation. These are described in detail in section 4.3.

The Inter-War Years

The First World War had a major effect on all aspects of British life, and the gas industry was equally affected. The war had diverted funds away from the gas industry whilst driving up the price of raw materials. Price controls were enforced, and the war effort meant chemicals were required for fuels, textiles and munitions manufacture.

The war also took away skilled staff and diverted engineering materials from the gas industry, leading the industry into stagnation and decline. Many small gas companies struggled during this time; some went bankrupt and others had to amalgamate to survive. This led to many of the smaller works closing, and supplies coming from larger, more economic gasworks.

The Gas Regulation Act was introduced in 1920, and changed the basis of charging for gas. It also introduced a national basis for the testing and reporting of gas quality. From the middle of the 19th century, the quality of gas had been based on its illuminating power; the act changed the basis to the calorific value of the gas. With the invention of the gas mantle, and the move away from lighting markets, the illuminating power of gas was now largely irrelevant.

A development in the 1930s was the increasing number of holding companies formed, including the Devon Gas Association and the Severn Valley Gas Corporation. These holding companies bought up control of predominantly small gas undertakings. They allowed the undertakings to trade as the original company, but provided central control and assistance in a financial, managerial and technical capacity. Many of these small undertakings would have collapsed without the holding company's intervention.

In 1932, Eric Fraser created 'Mr Therm' (Photograph 7) as an advertising symbol for the GL&C Co. He was later adopted by the British Commercial Gas association on behalf of the wider British gas industry.

Photograph 7. Mr Therm, the gas industry mascot, exploring the treasures of coal tar.

As the end of the 1930s loomed, so did the prospect of another world war. The Second World War had a greater toll on gas infrastructure than the first. The industry had seen gas demand increase, with gas and its by-products (from explosives to motor fuel) essential to the war effort. The gas industry was instrumental in producing hydrogen gas for the barrage balloons which formed an important part of the British air defences.

As gas workers went off to war, many women were brought in to work in the gasworks providing a vital service in the war effort (Photograph 8).

The aerial bombing of gasworks and gas mains was hugely damaging; skilled staff were lost from the industry to the war effort and funds for new plant were hard to obtain. The damage incurred by the gas industry would require major reconstruction investment.
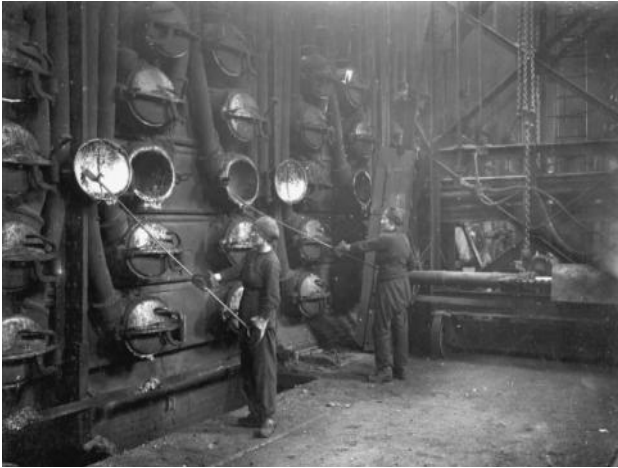
Photograph 8. Women stokers during the war.

In 1944, the minister of fuel and power appointed Geoffrey Heyworth as chairman of a review into the gas industry. The aim of the review was to consider how the industry could develop while reducing the cost of gas for all types of consumers. The Heyworth review highlighted many issues, including the need to improve the gas transmission network by amalgamating to form larger companies.

On the basis of the Heyworth review, the incoming Labour government decided that nationalisation was the best course of action for the gas industry. Nationalisation occurred through the Gas Act of 1948. The 1,064 local gas undertakings were vested in twelve area gas boards (Photograph 9). Each gas board was an autonomous body with its own chairman and board structure.

To ensure communication between the area gas boards and the Ministry of Fuel and Power, the Gas Council was established. Each area board divided its region into geographical groups or divisions.

Photograph 9. A map showing the area boards in England and Wales in 1949; the 12th board covered all of Scotland.

The Search for Alternative Sources of Gas

With the ever increasing cost of coal, the industry began to look for alternative gas feedstocks or gas supplies.

One such alternative supply was mines gas, which was rich in methane. The Point of Ayr colliery in North Wales proved to be a valuable source of this gas. The 95% pure methane gas could not be used directly, but was reformed first. Put simply, this process used steam to split the methane into a town gas of hydrogen, carbon monoxide and carbon dioxide. It produced a lean gas which was then enriched with methane to the required British thermal unit standard. Although a useful source, mines gas could only supply a small portion of Britain's requirements.

The Gas Council had joined forces with the German Lurgi company to develop new approaches to gasifying lower grade coal. This is discussed in section 4.6 on the Lurgi Gas Process.

Early on-shore exploration for gas in Britain had found small gas fields in Heathfield (Sussex), Whitby (Yorkshire) and Cousland (Scotland), but nothing significant on a national scale.

As an alternative to coal, the gas industry started to use oil more as a feedstock for gas manufacture, which led to the construction of oil gas plants such as SEGAS plants (Photograph 10). Later, as by-products of the petroleum industry became available at economic prices, new reforming plants were built across Britain; these used butane, naphtha and Primary Flash Distillate (PFD) as feedstocks.

Photograph 10. The Isle of Grain SEGAS plant.

The Demise of Gas Manufacture

The economic advantages of town gas from the reforming of petroleum feedstocks marked the beginning of the end for the production of gas from coal in Britain. The USA had already switched to natural gas after large supplies had been discovered, and pipelines were constructed to transport the gas across the country.

Without a plentiful local supply of natural gas, the British gas industry was already looking elsewhere for new sources of gas. In the 1950s, the North Thames Gas Board had been looking at the potential of importing Liquefied Natural Gas (LNG) to a special facility built at Canvey Island; this was achieved in 1959 with the first import of LNG from the Gulf of Mexico. This was the first successful LNG transportation by an ocean-going ship, the Methane Pioneer (Photograph 11).

Photograph 11. The Methane Pioneer, one of the first LNG importation ships docked at the LNG importation facility at Canvey Island.

From 1964, regular trips started between Algeria and Canvey Island, importing up to 700,000 tonnes of LNG per year. The Canvey Island project would have developed further if it had not been for the discovery of gas in the North and Irish Seas. Grimsby was the location of the first offshore discovery of gas in Britain.

The need for better cross-country gas transmission became apparent, and Feeder 1 was constructed in 1966. It was built to transport gas from London to Leeds, signalling the creation of the National Transmission System (NTS, Photograph 12). The NTS has since expanded significantly and is an essential part of delivering and storing gas in Britain.

Photograph 12. Building the National Transmission System.

Also in 1966, the Chairman of the Gas Council, Sir Henry Jones, formally announced that Britain was switching to natural gas. The first North Sea and offshore gas field was the West Sole gas field discovered in August 1965; by 1967, North Sea gas was being brought ashore at the Easington terminal. The Bacton terminal (Norfolk) opened in 1968; Theddlethorpe (Lincolnshire) followed in 1972, and St. Fergus (Aberdeenshire) opened in 1977.

Before Britain could switch from manufactured town gas to natural gas, all of the fittings used to burn town gas had to be replaced. This required the largest engineering feat undertaken in Britain since the end of the Second World War. Known as the 'conversion programme', it required the physical conversion of every gas appliance in the country (Photograph 13).

Photograph 13. The Conversion Programme. Flaring off town gas from the gas mains.

Halfway through the conversion programme, the Gas Act of 1972 abolished the Gas Council and the British Gas Corporation was formed. This centralised the gas industry into a single

business, although the regional structure was retained.

On completion, the 10-year conversion programme signalled an end to the manufacture of gas in England and Wales. Gas production at Romford Gasworks was switched off on 26 August 1976. The last gasworks making gas from coal were to be found in the remote areas of Scotland. The last gasworks to close in Britain was the small hand-charged horizontal retort gasworks in Millport on the Isle of Cumbrae, which closed in 1981. Whilst the gas industry has continued to thrive and meet new challenges, the story of gas manufacture in Britain ends here.

3.   Different Scales of Gasworks

Gasworks were built at different scales to supply everything from large houses up to cities. As the scale increased, the type of plant used and its efficiency changed. Below is a brief description of the differences in plant at gasworks of different scales.

3.1   Country House Gasworks

Country house gasworks were often the smallest-scale gasworks plant that could be purchased. Often supplied in kit form, they could be easily erected at the purchaser's home. This simple kit generally consisted of a retort house, coal store, condensers, washer, purifier and gasholder. Famous gas engineers such as Bower, Holmes, Edmundson and Porter supplied gasworks kits worldwide, at scales ranging from country houses up to towns. They would be shipped as kits and erected by local engineers. An example of a gasworks designed by the gas engineers H. Skoines and Co. is shown in Figure 11.
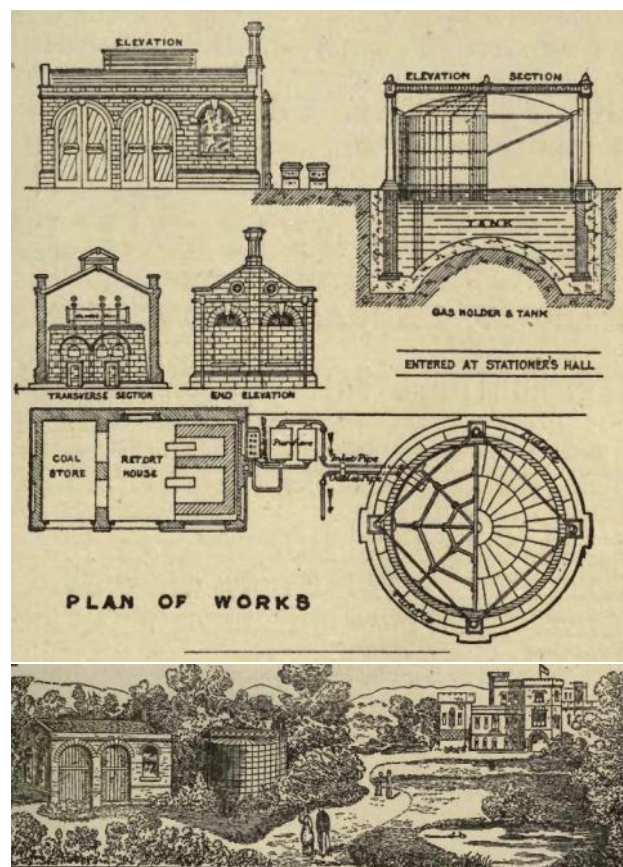
Figure 11. A simple design of a country house gasworks by H. Skoines and Co.

The gasworks could be housed in their own separate building (Photograph 14) or within the outbuildings of a farm or stables. The gasholder is often the only indication of the gasworks, being marked on the map as a 'gasometer'. Country house gasworks were popular from the early 19th century up until the start of the 20th century when they started to be phased out by alternative lighting methods such as acetylene gas, petrol air gas or electricity. Acetylene gas and petrol air gas could be produced using relatively small plants which were less costly to purchase and operate

than a coal-gas-based gasworks. The gas plants were very popular and could be easily bought and installed by the owners of smaller houses. Electricity only became a major competitor post-1910, with the development of more durable light bulbs. Electricity plants were often built to replace gas plants.

Photograph 14. The remains of a country house gasworks retort house in Gloucestershire.

Many hundreds of country house gasworks were built in Great Britain and Ireland. These country house gasworks also supplied outbuildings such as stables and saw mills, providing light and power. In addition, estate villages were often provided with a supply from the gasworks, although generally at a cost, subsidising the estate owner's own use. The gasworks were usually built approximately one mile away from the country house to keep the air and water pollution away from the house.

Gasworks buildings were sometimes built in an ornate design to blend in with other estate buildings, often taking the design of a small country brewery with the distinctive louvred roof.

Ancillary purification plant would be hidden so as not to be visible from the roads or bridleways.

Similar sized gasworks were also built at schools, hospitals, asylums, mills and some industrial buildings and factories. Those built at mills were the original early examples of such small gasworks. Some mill gasworks could be closer in scale to village and small town gasworks, as they were supplying large mills that required a considerable amount of lighting. Many mill gasworks did later evolve into village or town gasworks.

3.2   Small Town and Village Gasworks

In the mid 19th century, every town in Britain with a population of over 10,000 was lit by gas. In addition, many villages (including estate villages as mentioned above) had their own gasworks. This would provide some limited street lighting, supply municipal buildings such as churches, and supply those lucky residents wealthy enough to afford it. Such small gasworks (see Photograph 15) were often private businesses established by wealthy local businessmen.

Photograph 15. A typical village gasworks in Somerton, Somerset. The main building is the retort house, the gasholder can be seen behind.

3.3   Large Town and City Gasworks

Most large towns and cities developed large gasworks (Photograph 16) outside urban areas where there was room to accommodate the plant and it would not create too much pollution for neighbouring residents. The most famous such example being Beckton – developed into the world's largest gasworks - built by the GL&C Co in East Ham, a long way from London. The largest gasworks were also the most efficient, and could process large amounts of coal and supply gas more cheaply than the smaller works. These large gasworks could often enable their owners to purchase smaller nearby gas undertakings and close their less efficient gasworks. The gas supply would then be provided by a new gas main linking their large gasworks to the gas network of the small gas company, often retaining the gasholders of the latter.

Photograph 16. A typical large gasworks in Blackburn, Lancashire, UK.

4.   Gas Manufactured from Coal

4.1   Overview

This section explains how a gasworks operated, listing the plant used and the way in which they operated. A general overview is shown in Figure 12 and explained briefly below.

Coal was placed within a sealed vessel called a retort and heated externally by a furnace. Without air, 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 compounds, some of which were further broken down into even smaller compounds. This process released molecules such as hydrogen, 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 gas leaving the retort was cooled, removing most of the tar and oil compounds trapped in the gas as coal tar. The gas would be washed to remove soluble compounds such as ammonia and phenol which formed ammoniacal liquor, and then the gas would be purified to remove sulphur and cyanide compounds. The treated gas, now called town gas, was stored in a gasholder, ready for distribution through gas mains beneath the streets to customers. Coke remained in the retort, which was removed and cooled by dousing with water. A more detailed view of a complex gasworks is shown in Figure 13.

Figure 12. The production of town gas from coal. The black arrows show the progress of the gas through the plant and the grey arrows show the processing of the by-products. Source: Russell Thomas.

Coal storage and transfer to ships at a docks

Transport of coal by coastal collier.

Coal import, handling and storage

Coal extracted at coal mine

Coal transported by train (coal was also transported by canal

Guide-framed water gas relief holder

Water gas plant

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.

Waterless gas holder

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.

Coke from retort house

Benzol recovery plant

Naphthalene washer

Station meter

Electrostatic detarrer.

Secondary condenser

Primary condenser

Dry gas plant

Purifiers

Washer-scrubber

Livesey washer

Exhauster

Vertical retort house carbonising coal.

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.

Liquor main

Tar and liquor tank

Tar main

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

Coke to grading, storage and sales.

Tar distillation plant

Spiral-guided gas holder with above-ground tank

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

Coal tar pitch in pitch bed.

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

Concentrated ammoniacal Liquor (CAL) plant

Liquor tank

Sulphate of ammonia plant. Ammoniacal liquor processed to become ammonium sulphate fertiliser.

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.

Gas Light and Coke Co.

Gas governor house.

Rail wagons loaded with CAL

Gas street light.

Commercial consumers

Petrol station – benzol motor fuel

Private gas supply to house

Coke grading plant – Coke sales to domestic and industrial users.

Figure 13. The production of gas from coal and the manufacture of by-products on a large gasworks, showing the process from the mining of the coal to the distribution in the gas mains. Source: Russell Thomas.

4.2   Types of Coal Used for Gas Making

Coal is a highly variable substance. Its incredibly complex chemistry is still not fully understood, partly because of the difficulty in analysing it. It is primarily composed of a mixture of very large complex aromatic compounds. As natural organic matter proceeds through the coalification process, the carbon content increases and the oxygen content drops. The coal becomes more ordered, forming large collections of aromatic ring structures, and eventually forming anthracite and graphite. For more information on the coalification process see reference 1 in the bibliography.

Not all coals were suitable for gas making. The preferred types 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 coal types available.

The types of coal used are slightly confused by the different methods used to classify it. Using (Marie) Stopes classification by Maceral, the types of coal suitable for gas production included:

- 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.

In Britain, coal used for gas making would be high volatile coals 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. The ASTM method used in the USA suggested that 'Bituminous-Common Banded Coal' was the most suitable for gas making.

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 (Figu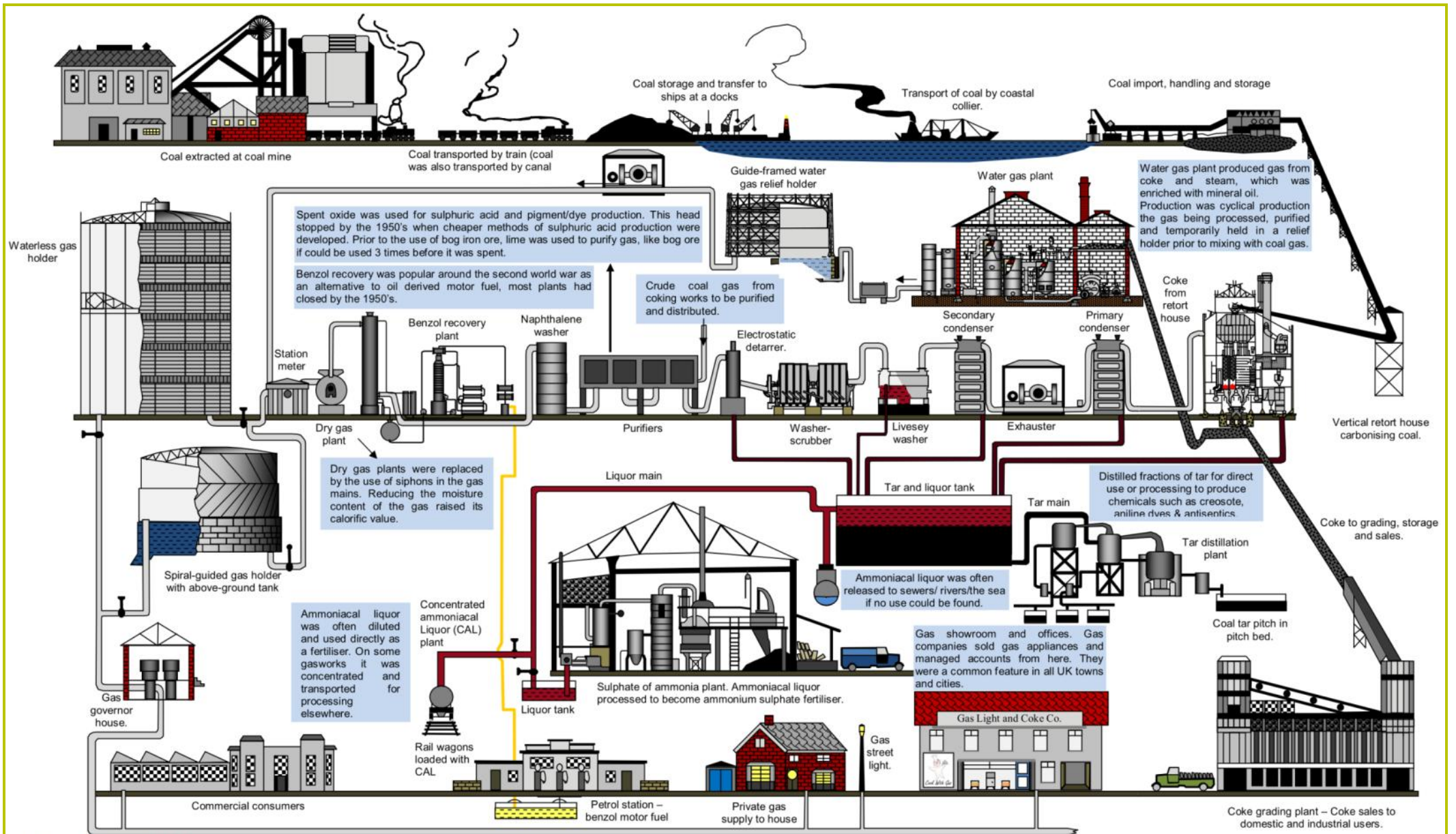re 14). Cannel coal was however, only available in limited in supply and was therefore expensive; however, it was often mixed with other coals to improve the illuminating properties of the gas. It was also the coal of preference for many country house and estate gasworks, especially in Scotland, where this type of coal was more abundant. It left little ash and made the management of a small gasworks very simple.
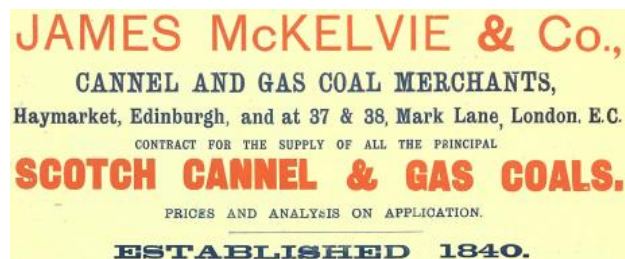
Figure 14. An advert for Scottish cannel coal.

The gas industry's dependence on cannel coal for enriching the illuminating properties of gas would have started to diminish as the gas mantle took over from older aerated burner design 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.

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 along the eastern and southern coasts of England in ships called colliers (Photographs 17 and 18), and influenced gas production there. Further inland, Midland and Yorkshire coal were more easily available by rail transport and there was a preference to carbonise these in vertical retorts (when they later became available).

Photograph 17. A coastal collier taking its cargo of gas coal down the Thames to the gasworks, on its journey from the northeast.

The coals in Scotland were preferentially carbonised in vertical retort plants (when available). 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 (e.g. North Somerset).
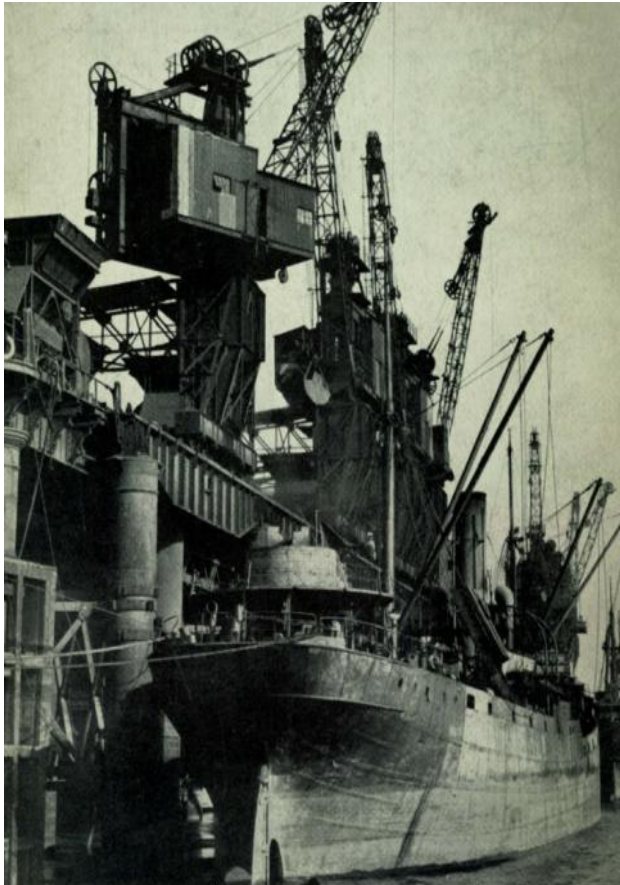
Photograph 18. Unloading coal from a coastal collier by steam cranes at the wharf at Beckton.

Coal was transported from the coal mines to the gasworks by collier, by canal barge, or by 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. Both methods were expensive and inefficient.

As the available quantities of suitable gas coals diminished, the gas industry eventually looked towards the gasification of low-grade coal through complete gasification (see section 4.5 on Complete Gasification) and the Lurgi process, before the later switch to oil and then natural gas.

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.

4.3 The Retort House

The retort house was where the gas was manufactured. It housed the retorts which were grouped together into benches. Within the retorts, coal was heated in an oxygen-free environment where, instead of combusting, the volatile components were driven off, leaving a relatively pure form of carbon called coke as residue.

Retort technology changed over the years, becoming gradually more advanced. Although William Murdoch experimented with a variety of different designs, the one favoured in the early years of the industry was a horizontal retort.

Horizontal Retorts

A horizontal retort was primarily a D-shaped vessel, around 6.7 m (22 ft) long, 0.55 m (22 in) wide and 0.45 m (18 in) high. Originally, retorts were circular and made from cast iron, but they were not very durable and so were further improved through the use of fireclay and later silica. The retorts would suffer from wear and tear so had to be replaced on a regular basis; the settings were designed to be taken apart and rebuilt.

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.

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 (largely pure carbon).

The horizontal retorts could be heated by various methods, the earliest being the direct-fired setting (Figure 5). The more advanced semi-gaseous setting and gaseous-fired settings (Figure 15) appeared as a result of Siemens' work in 1857 to design an effective gas producer, but was not effectively introduced to the gas industry until 1881, when it was introduced in Glasgow and led to a great improvement in the efficiency of gas manufacture.

Early retorts were heated directly by a shallow fuel bed – 0.3 m (1 ft) deep – of coke lit beneath in the furnace (Figure 2). 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 later in small gasworks.
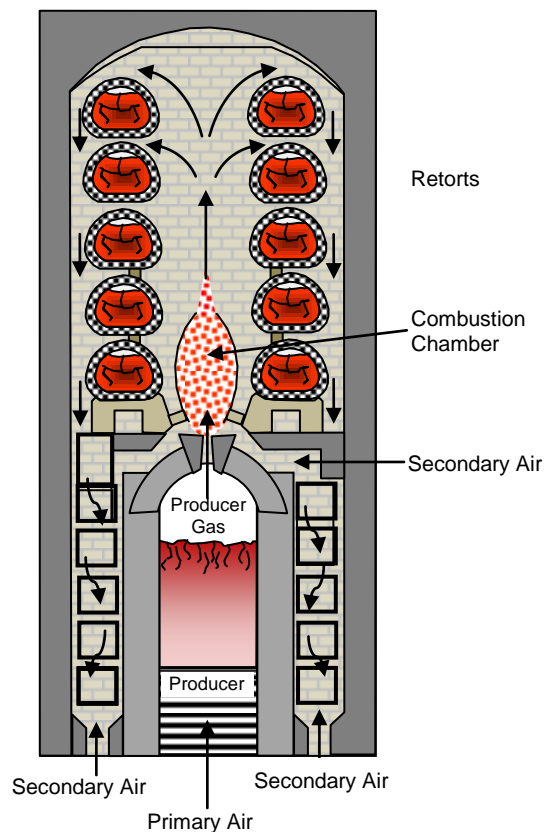
Figure 15. Cross section of a gaseous-fired horizontal retort, showing the gas producer. Source: Russell Thomas.

The semi-gaseous setting had a deeper fuel bed, 0.6 m (2 ft) deep, and provided some control over air supply, allowing some carbon monoxide gas to escape and burn adjacent to the retorts. It allowed greater carbonisation temperatures to be achieved with lower fuel consumption.

A later development was the gaseous-fired setting which used a gas producer to heat the retorts (Figure 15). After success in Glasgow in 1881, this system was then adopted on all future modern retort designs. The fuel bed in a producer would be *circa* 1.5 m to 1.8 m (5 to 6 ft) deep and the primary air supply was very carefully controlled to enable the correct composition of the producer gas.

The gas producers channelled gas to a combustion chamber directly around 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. Another important factor was whether the waste gas from the producer was used to heat incoming air, thus enabling great efficiency and higher carbonisation temperatures to be achieved. This was called a 'recuperative' or 'regenerative' gaseous-fired setting.

Loading and unloading a stop-ended retort was hot, arduous and dangerous work (Photograph 19), but it was often the only practical option in small gasworks. The increasing size of gasworks and retort houses in towns and cities allowed for further innovation. The development of the through-ended retort by Lowe (1831) made it much easier to mechanise the process by which a retort could be loaded and emptied (Photograph 20).

The most notable examples of charging machines were built by West (1886), Arrol-Foulis and Fiddes-Aldridge. The later of these used a method devised by Belgian engineer M. De Brower, which projected coal into the retort using the energy derived from the centrifugal force of spinning the coal in a large wheel.
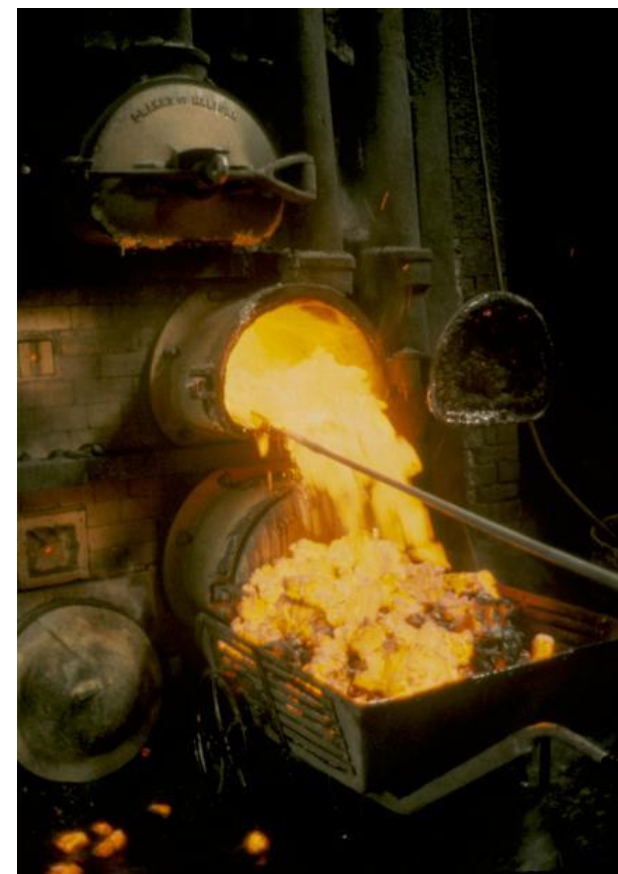
Photograph 19. Manually emptying hot coke from a stop-ended horizontal retort.

At the front of the retort (above and behind the door) was the ascension pipe. Some through retorts had a second ascension pipe on the rear door. The role of the ascension pipe was to allow the gas and vapours to escape from the retort and rise up 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.

Photograph 20. Unloading a through-ended retort mechanically.

Photograph 21. Loading a retort with a mechanical charger.

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 and very high temperatures, and so the roof was louvred to allow heat to escape.

Initially, horizontal retorts were used on all sizes of gasworks. Later gasworks used ever larger horizontal retort houses with mechanical charging and emptying of the retorts employed, such as those shown in Photographs 20 and 21. In the early 20th century, new types of retort became commercially available, such as inclined and vertical retorts and chamber ovens, some of which could enable continuous operation.

The Inclined Retort

In the late 19th century, inclined retorts were developed based on work undertaken by Coze at Rheims in France (Figure 16). Inclined retorts were designed to make loading and unloading operations easier, but unfortunately this was often not the case. The retort was placed at 32° to the horizontal, the theoretical angle of repose for coal. In theory, the system benefitted from less wear and tear and could be used without the charging 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 method. 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.

The inclined retorts were never very popular in Britain, although they were used in some gasworks, such as the original public gasworks in Coventry. With the development of the vertical retort they were soon superseded, although the design was still popular in some small gasworks.

Figure 16. Advert for an inclined retort.

The inclined retorts were about 3.60 m (12 ft) in length and tapered from 0.60 m (24 in) by 0.38 m (15 in) at the bottom to 0.55 m (22 in) by 0.38 m (15 in) at the top. The carbonisation process within the inclined retort would take about eight hours.

The Vertical Retort

A later development was the vertical retort; as the name suggests, the retort was rotated by 90° so that it was in the vertical plane.

Vertical retorts came in different designs. The original system – the Intermittent Vertical System – was patented in England by Bueb in 1904, after being trialled at the Dessau Gasworks in Germany. It had considerable advantages over the horizontal system. It reduced labour, as to a great extent the coal could be moved by 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 counterparts.

A further development was the introduction of the continuous vertical retort, which could, as the name suggests, operate continuously. The first
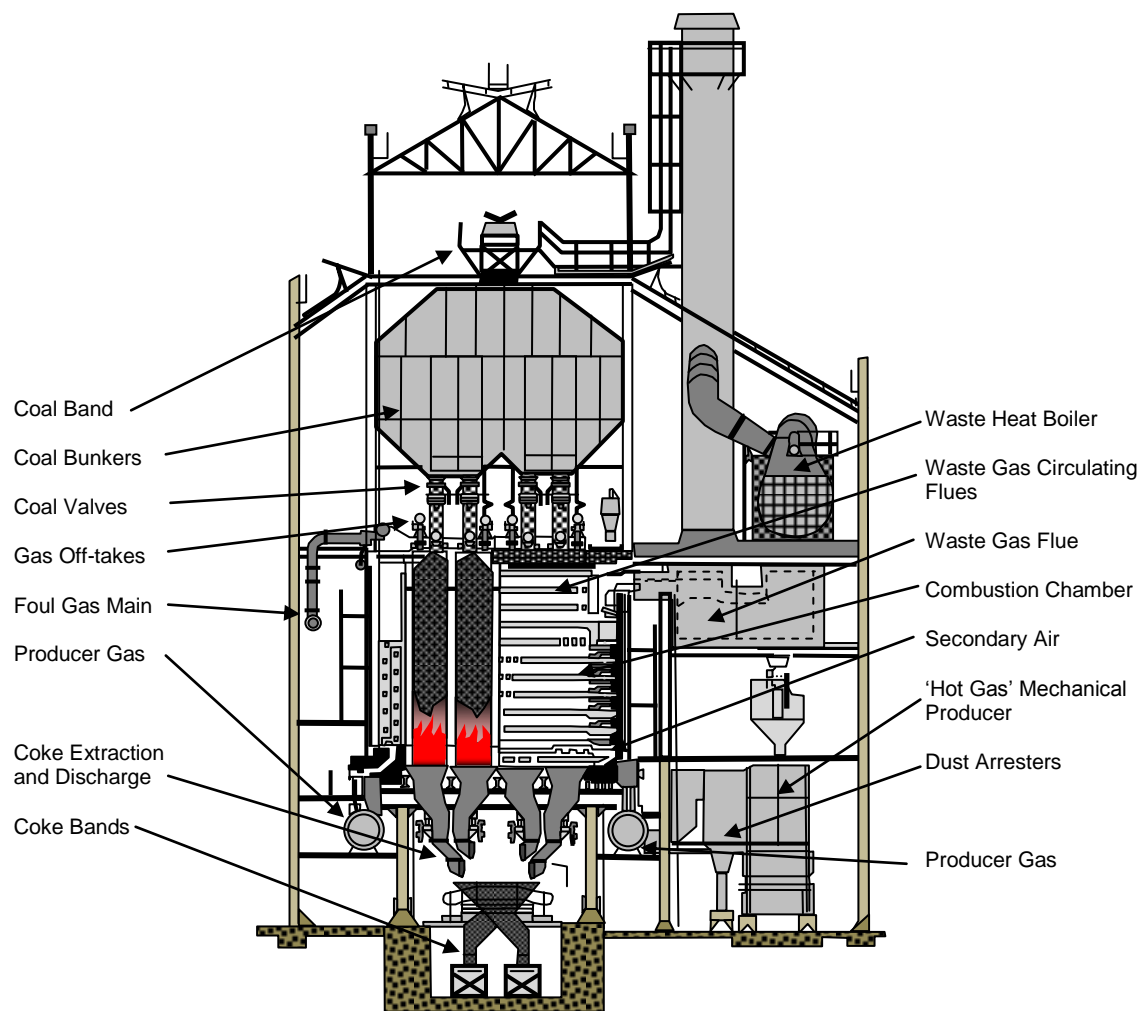
Figure 17. Cross section of Glover West vertical retort. Source: Russell Thomas.

The following labels appear on the figure:

Coal Band
Coal Bunkers
Coal Valves
Gas Off-takes
Foul Gas Main
Producer Gas
Coke Extraction and Discharge
Coke Bands

Waste Heat Boiler
Waste Gas Circulating Flues
Waste Gas Flue
Combustion Chamber
Secondary Air
'Hot Gas' Mechanical Producer
Dust Arresters
Producer Gas

continuous vertical retorts were built at Bournemouth gasworks by the gas engineering company Woodhall Duckham. The plant entered commercial operation in 1906. The rival Glover West Company built a continuous vertical retort plant at St. Helens in 1907. An example of the Glover West vertical retort can be seen in Figure 17, which shows the customary vertical retort stack with coal being fed vertically down the retort from the hopper. Further vertical retort plants were built at many of the medium-sized and larger gasworks across the UK, and other manufacturers also entered this market.

The process operated as follows. Coal of a suitable size was carried by conveyer to the top of the retort house where it was fed into a hopper. 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.

The coal passed down through the producer-gas-heated retort vessel by gravity. 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, (effectively an Archimedes screw). 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.

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, as described earlier.

The yield of gas in the vertical retorts could be increased by a process called 'steaming', where 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 discovered) and the Second World War. In some gasworks, steaming was used all year and continued until production ceased.

Vertical retorts were used at many medium and large gasworks, although some large works such as Beckton chose to keep horizontal retorts because of the more saleable tars they produced. Many small gasworks continued to operate horizontal retorts until closure, often because they could not justify the expense or did not have the demand for gas to build a vertical retort plant.

Intermittent Vertical Chamber Ovens

There was also another type of plant similar to an intermittent vertical retort, called an Intermittent Vertical Chamber Oven (IVCO). These were less popular than the continuous vertical retort in the UK, but included the White Lund gasworks in Morecambe, the last traditional coal gasworks to be built in England.

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.

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.

4.4   Coke Ovens

Coke ovens were not common on British gasworks, only three were built: at the gasworks at Saltley in Birmingham; and at Beckton (Photograph 22) and East Greenwich in London. Because of their large size, coke ovens could produce large amounts of gas on a continuous basis.

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 – with the exception of Carburetted Water Gas (CWG) which was only produced at times of peak demand.

Coke ovens were not originally designed to produce either gas or by-products such as tar. It was not until the value of these by-products was realised that by-product coke ovens were constructed. Coke ovens where there was no attempt to recover the by-products were generally referred to as 'beehive coke ovens'. As the name suggests, these were in the shape of a beehive and built from brick. Any by-products formed were burnt or released into the air escaping from the top of the ovens.
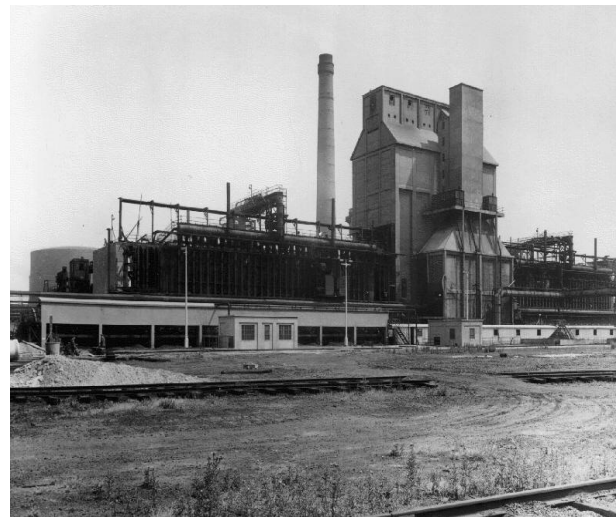
Photograph 22. Beckton coke ovens.

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.

Coke ovens are the only remaining operational coal carbonising plant in Britain. The coke oven was effectively a long rectangular box constructed of refractory (heat resistant) material, roughly 12 m (40 ft) long and 4.5 m (15 ft) high, but only 0.3 m (12 in) to 0.5 m (20 in) wide, with large iron doors at both end. 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 combustion of gas takes place with the preheated 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 is 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, the refractory material would be damaged, requiring a costly replacement.

Coke ovens can be heated by one of two forms of gas. Current practice uses coke oven gas to heat the ovens; historically, it was common practice to heat the ovens with gas manufactured in a separate gas producer. Coke oven gas is now used, as its value is limited and it cannot be supplied in the gas mains as it once was. In addition, the value of the coke that would be used in producers has risen, making it uneconomical to operate gas producers now.

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 different 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.

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 similar to that of a gasworks. The main plant involved is described in section 4.7 (and onwards).

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 composition of the by-products formed was different due to the lower carbonisation temperatures used; most notably, the coal tars were less thermally degraded.

4.5   Complete Gasification

Complete gasification was a concept whereby the carbonisation and the water gas process (described in section 5.1) could be operated simultaneously; it was also referred to as a double gas plant. Coal usually graded to the size of closely graded nuts or cobbles was used. The complete gasification plant aimed to try to combine the prior carbonisation of the coal in a retort followed by the cyclical water gas process. The coal was carbonised in a vertical retort and the resulting coke or char would move by gravity down into the water gas plant below.

These plants produced a gas which was different to a normal town gas. If the whole baseload was supplied by this plant, the gas was denser and had a higher carbon monoxide content.

The water gas phase could be operated with or without oil enrichment. The best known example in Britain was the Tully Gas Plant, of which many were built.

4.6   Lurgi Gas Process

The Lurgi process was developed in 1927 in Germany to look at the complete gasification of the brown coal deposits in the East Elbe. The Lurgi process used the mixture of oxygen, steam and high pressure to achieve the effective complete gasification. 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. Plants have also been built in Australia, South Africa, the USA and more recently China.

Unlike conventional gasification, which would have produced carbon monoxide and hydrogen from the steam and oxygen, the Lurgi process formed methane, as a result of continuous high-pressure operation. The Lurgi gas generator had similarities to a conventional producer gas 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. As a pressure vessel, the coal was added and ash was removed via a system of locks, with the ash removed in a solid state.

A Lurgi gasification plant was built for the Scottish Gas Board at Westfield, completed in 1963. It used a locally sourced low-grade coal from an adjacent Westfield open-cast coal mine. It produced gas at high pressure (20.6 bar or 300 psi) and supplied a low-toxicity gas to a high-pressure grid system in the Fife and central areas of Scotland.

A similar gas plant was built for the West Midland Gas Board at the Coleshill gasworks, near Coventry. Designed to take coal from the nearby Kingsbury Colliery, it was the first gas plant in the West Midlands to produce high-pressure gas at 24 bar (355 psi). It too entered operation in 1963.

Both plants were conventional dry-ash Lurgi gasification plants, and they were in operation for approximately 10 years. The process may have gone on to provide a greater part of Britain's gas supply, but decisions had been made to switch to natural gas, reinforced by the discovery of the North Sea gas fields.

The story did not end there. From 1974 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, however gasifiers based on the BGL design are now being built and operated in China.

4.7 Ancillary Plant for Processing Coal Gas

The Condensers

Once the gas left the retorts via the ascension pipe, hydraulic main and foul main, it entered the condensers. The hydraulic and foul mains both acted as primary condensers, helping to remove much of the tar and some of the ammonia from the gas.

Photograph 23. A set of two atmospheric condensers, Gunnislake gasworks, Cornwall.

The role of the condenser was to cool the gas and remove coal tar from the gas, draining it to a below-ground tar tank or well. Many different designs were employed. On small gasworks, gas would generally be cooled using an atmospheric condenser (Photographs 23 and 24).

This relied on the temperature differential between the ambient air temperature and the hot gas to cool the gas; this process was more successful in the winter, when the outside air temperature was low.

Photograph 24. A horizontal atmospheric condenser.

The annular condenser was a slightly more advanced design formed from two concentric cylinders. Both internal and external faces of the condenser were open to the atmosphere. The 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.

Another more advanced design was the water tube condenser (Photographs 25 and 26). 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 orientation.
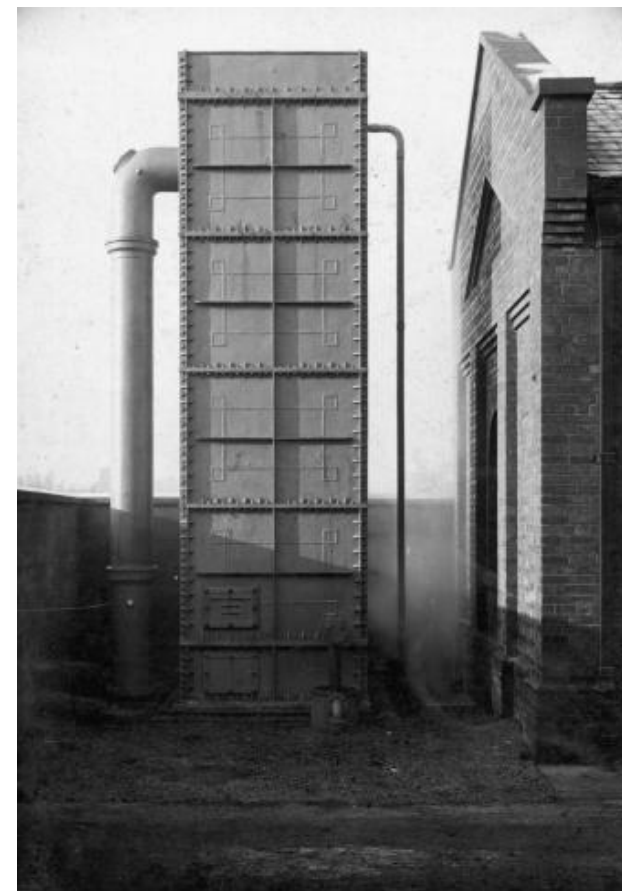
Photograph 25. A vertical water tube condenser.

The very early gasworks built by the Neath Abbey Iron Company had a very simple design. This consisted of a long water-filled trough through which water passed and in which the gas pipes were placed. A more advanced version of this design was used at the Old Kent Road Gasworks of the South Metropolitan Gas Company.

Another form of condenser was the Pelouse and Audoin condenser, which originated from France. The purpose of this condenser was to break up the suspended tarry particles and remove them from the gas. This apparatus consisted of an outer cylindrical cast iron chamber through which the gas would enter and leave, and an outlet for the tar to drain away.
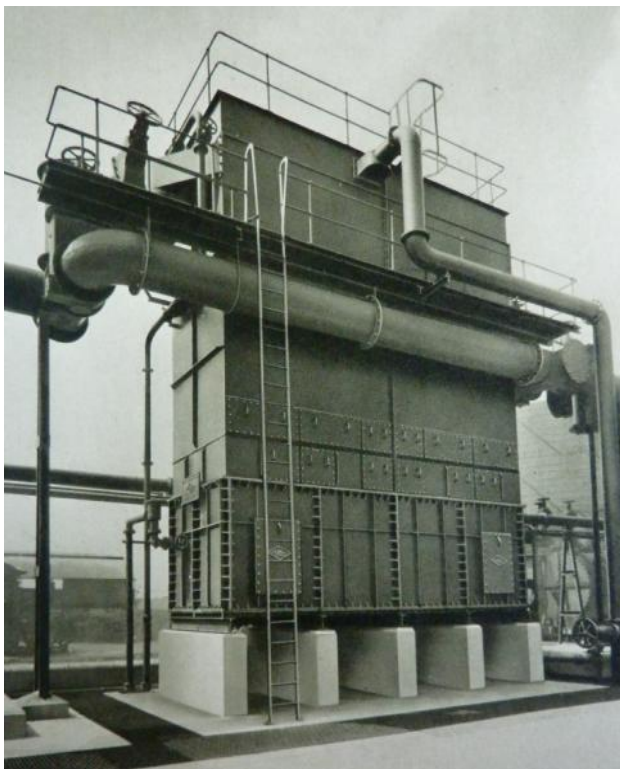
Photograph 26. A multipass vertical tube condenser mounted on a tar and liquor separator at the former Romford gasworks.

It contained a cylinder of perforated sheet iron which formed the condenser. The sides of the condensing chambers were two thin sheets of iron, with a concentric space between the inner sheet (which had fine perforations) and the outer sheet with larger slots. Passing through the fine perforations, the gas was forced into jets which would strike against the solid surface, depositing the tar.

Exhauster

The exhauster kept the gas flowing and was often referred to as the heart of the gasworks. It withdrew the gas from the retort at the rate it was produced, to prevent the build up of pressure. The gas was then pulled through the condensers. The exhauster would push the gas through the washer and scrubber and the remaining purification plant into the gasholder. If primary and secondary condensers were used, the exhauster would normally be positioned between the two. Without an exhauster, the processing plant and gasholder would push against the retorts causing significant back pressure. By swiftly removing gas from the retorts, it prevented the build-up of carbon deposits. It also prevented the loss of gas through the retort walls, caused by the slightly porous nature of the silica and fireclay.
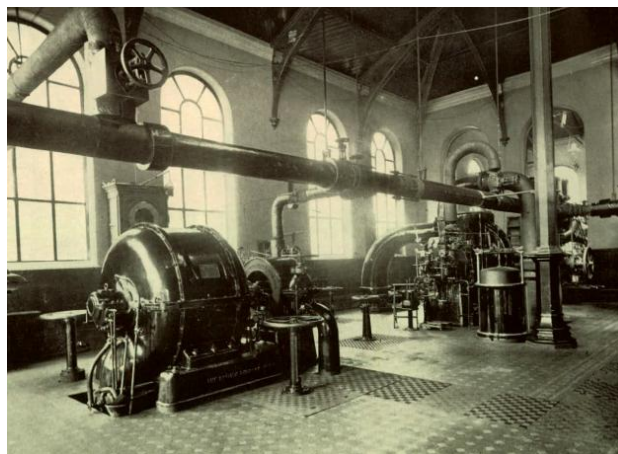
Photograph 27. Gas exhausters at Windsor Street gasworks, Birmingham.

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 such as Grafton's exhauster was the earliest type, developed *circa* 1839. 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.
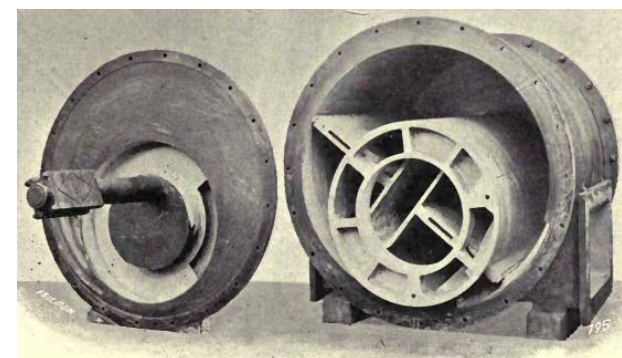
Photograph 28. The internal workings of an exhauster.

The rotary exhauster (Photographs 27 and 28) was a later development. It consisted of a cylindrical vessel within which was a centrally mounted rotating shaft. Attached to this shaft was a second cylinder which was concentrically mounted and had blades attached. As the internal

cylinder rotated, the blades pushed the gas through the pipes.

Electrostatic Detarrer

After 1930, some large gasworks used a process called the electrostatic detarrer (Photograph 29). Gas passed through the cylindrical plant as it would a condenser, but an electrical current was used to remove the tar instead of cooling.
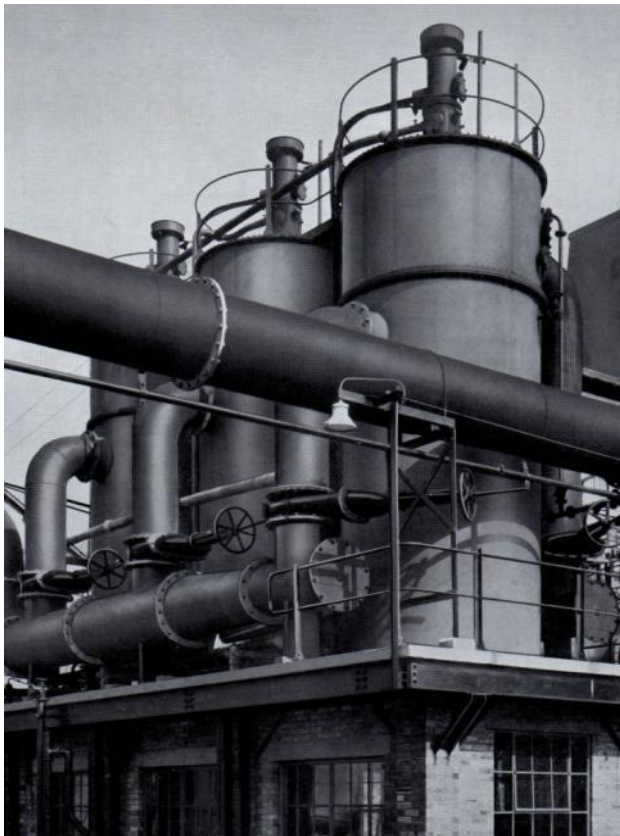
Photograph 29. Electrostatic detarrer.

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.

The first electrostatic detarrer was installed at the gasworks in Hinckley, Leicestershire, in 1926, and was believed to be an American design. The first British-designed electrostatic detarrer was built by Simon-Carves 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 installation on a gasworks was at Southall Gasworks in West London in 1931. This type of technology is still used today to remove particulate matter from the smoke in power station chimneys and in other processes that generate dust.

Tar Washers

Gas washing systems were employed for two purposes: to remove remaining tar trapped in the gas, and remove soluble components such as ammonia.

Having passed through the condenser, the gas still contained small amounts of tar which needed to be removed. Prior to the introduction of electrostatic detarrers, and for a majority of gasworks which were too small to justify their purchase, another piece of plant was required to remove the trace amounts of tar: the tar washer.

The commonly used version was the Livesey washer (Figure 18 and Photograph 30), developed by the famous gas engineer George Livesey of the South Metropolitan Gas Company. The gas was bubbled through small perforated holes in gauze under water. The tar collected on the surface of the gauze whilst the gas passed through and out of the tar washer. The tar was collected and drained to the tar well.
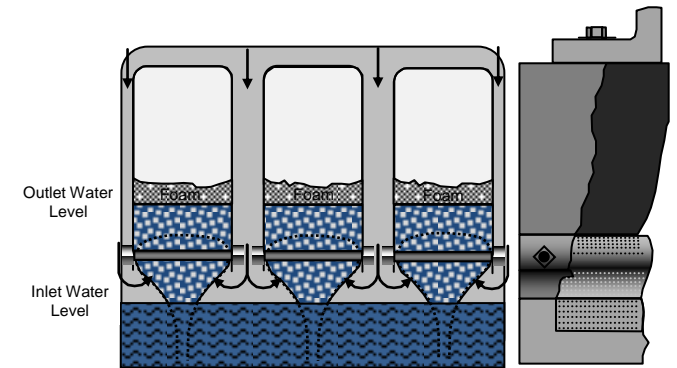
Figure 18. A schematic of the inside of a Livesey washer. Source: Russell Thomas.

Photograph 30. A Livesey washer.

Ammonia Washing and Scrubbing

Having passed through the condensers and tar washer almost all of the tar would have been removed, along with around 50% of the soluble impurities of ammonium and phenolic compounds.

To remove the remaining 50%, the gas required further washing and scrubbing. For most of the 19th century, non-mechanical means were used to perform this function. From the 1880s onwards, mechanical plant started to be introduced.

The purpose of the washers and scrubbers was to achieve the most intimate contact between the gas and washing medium, to enable 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.

The washing medium dissolved the ammonium and phenol in the gas, forming ammoniacal liquor (or increasing the strength of the 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.

The washing of the gas would take the form of bubbling through seals or perforations, or passing through weirs of liquor. The scrubbing of the gas was the exposure of the gas to wetted surfaces. The liquor used in a washer was much stronger than that used in a scrubber.

The washer/scrubber could come in a wide range of designs, but there were three main types of plant employed to further wash the gas: the tower scrubber, the mechanical washer and the washer scrubber.

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 (Photograph 31) filled with coke, bricks, wooden boards or ceramic rings.

Photograph 31. Two tower scrubbers.

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.

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. 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 in order 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.

Later scrubbers employed rotating horizontal (Photograph 32 and Figure 19) or vertical cylinders. The gas and water ran counter current, as in the tower scrubber. The Kirkham, Hullett and Chandler's Rotary Washer-Scrubber was the best-known example of the washer scrubber. A cross section of this horizontal washer scrubber is shown in Figure 19. The rotary washer scrubber was filled with the corrugated iron filter material shown in Photograph 33.
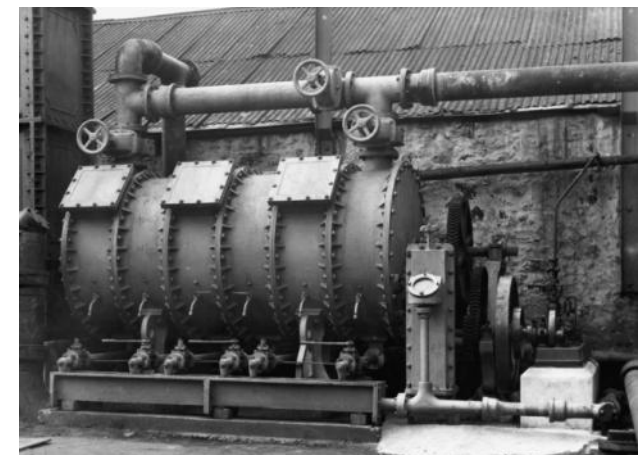
Photograph 32. A rotary mechanical washer.
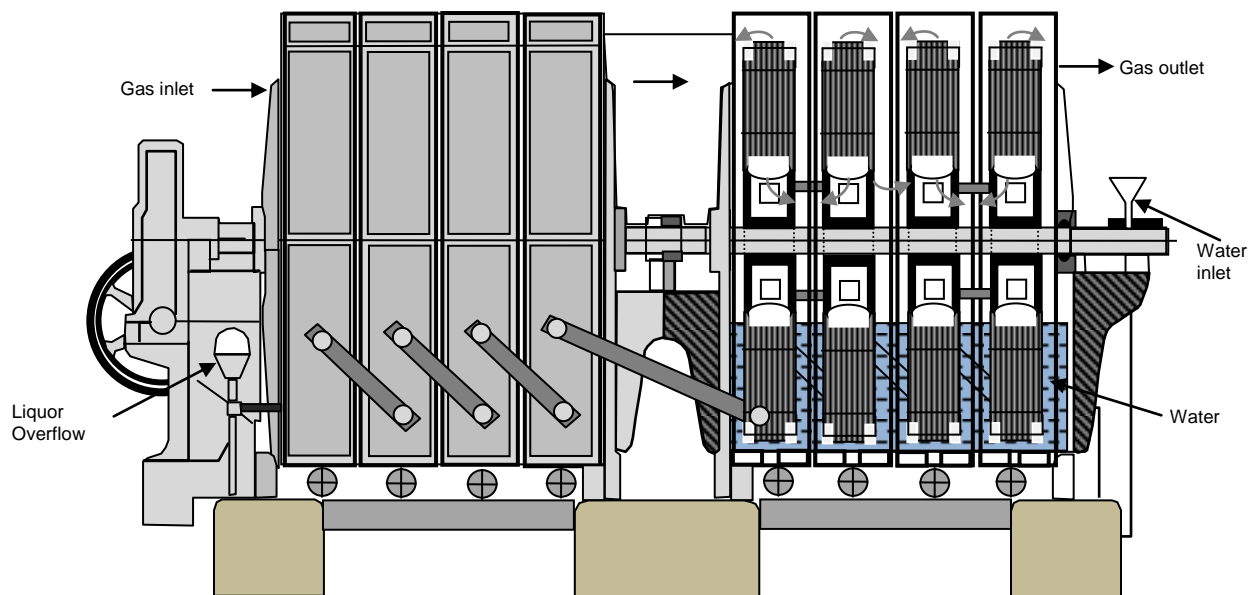
Figure 19. A schematic of a Kirkham, Hullett and Chandler's standard rotary washer-scrubber. Source: Russell Thomas.

Gas inlet

Gas outlet

Water inlet

Water

Liquor Overflow

Photograph 33. The corrugated filter material used inside the standard washer-scrubber. Source: *Modern Gasworks Practice*, 1916.

Purifying the Gas

Once the coal tar and ammoniacal liquor were removed from the gas, two other poisonous substances were removed: hydrogen sulphide and hydrogen cyanide. Hydrogen sulphide was present in the gas at a much higher concentration than cyanide, and was the primary problem. If sulphur was not removed from the gas, it formed noxious fumes of sulphur dioxide when burnt, which would then form sulphuric acid. Sulphuric acid would cause the corrosion of gas fittings and deterioration of property within houses. It should be noted that a range of sulphur compounds were present within the gas in addition to hydrogen sulphide, including organic sulphur compounds such as carbon disulphide.

Gas purification to remove sulphuretted hydrogen (hydrogen sulphide) was first tried (unsuccessfully) when Samuel Clegg placed lime

within the water in the base of a gasholder. He later developed a paddle system to agitate the lime, at a gasworks he installed in Coventry.

By 1812, Clegg had developed a separate tank which contained an agitated wet lime based purification system (Figure 20). This system was incorporated in the small gasworks built by Clegg for the famous Soho publisher Mr Rudolf Ackerman.

Figure 20. The wet lime purifier developed by Samuel Clegg. Source: Bibliography ref 3.

The wet lime purifier was further developed by Clegg, Malam and others. The better-known dry lime purifier did not appear until later. The main driver for the replacement of the wet lime system was not performance, but issues with the disposal of the waste product known as 'Blue Billy', the blue pungent wet lime waste created from the process caused problems for the gas companies with regard to transportation and disposal.

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. This was later rectified by adding a solid base and a removable lid (Photograph 34).

Photograph 34. An example of box purifiers at the Fakenham Gas Museum, Norfolk.

The lime used was actually 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.

Lime was later superseded by the use of bog iron ore, although they were sometimes mixed and used together. Bog iron ore (hydrated iron oxide) was developed for use in gas purification in 1849-1850, and was the invention of Richard Laming and Frank Hills. It was adopted for use worldwide in the 1860s, with the exception of Britain.

The British Sulphur Act was enacted in 1860 to require the removal of the relatively high levels of sulphur from gas. The net effect of this act was to make it impossible to replace lime purification with iron oxide purification, which was not quite as effective. Bog iron ore was more economical and less troublesome than lime. This was not rectified until 1905 when a new sulphur act was brought in, enabling iron oxide to completely replace lime.

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 (Photograph 34), and could be built on a huge scale (Photograph 35).

Photograph 35. A large purifier house.

Later, much larger tower purifiers (Figure 21) were used on some large gasworks and coking works. The slaked lime or hydrated iron oxide would be laid on wooden (often oak) grids inside the boxes in layers 30cm (12 inches) to 45cm (18 inches) 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.
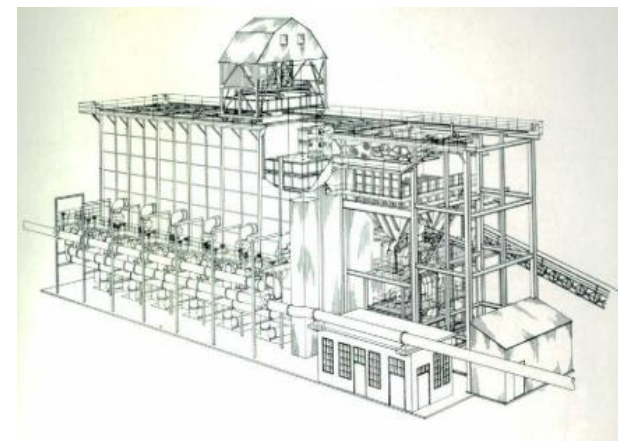
Figure 21. A schematic of a tower purifier at the former Southall Gasworks.

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.

Foul lime (Photograph 36) was 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 (Photograph 37) was a blue/green material of low pH (4) used as a by-product for the production of sulphuric acid, but also occasionally used as a weed killer.

Photograph 36. Foul lime excavated on a former gasworks. Source: Parsons Brinckerhoff.

Photograph 37. Spent oxide. Source: Russell Thomas.

<u>Liquid Purification</u>

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.

Another method developed was the Thylox process, which washed the hydrogen sulphide from the gas using ammonium thioarsenate. The solution 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. As may be expected, there were health and environmental issues in using an arsenic-based solution so the process only achieved limited success.

The most successful of these liquid processes was the Stretford process, developed by the North Western Gas Board and the Clayton Aniline Company in England to remove hydrogen sulphide from town gas. The original process used an aqueous solution of carbonate/ bicarbonate and anthraquinone disulphonic acid (ADA). The process initially suffered as the solution used had a very low capacity 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. These problems were largely overcome by using alkali vanadates 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 when converting the hydrosulphide ions to sulphur, it was still a slow reaction, which limited its use. It also resulted in a significant amount of thiosulphate as a by-product.

<u>Storing the Gas</u>

The purified and metered gas was stored in a gasholder to be distributed later. The gasholder has been an integral part of the gasworks since Murdoch's early Soho Gasworks, built in 1802.

The purpose of the gasholder was to act as a buffer. Generally containing a gas supply of 24-36 hours of production, it would afford the gasworks greater operational flexibility, meaning that it did not need to operate 24 hours a day.

The gasholder consisted of a cylindrical vessel closed at the top but open at the base, which sat in a water-filled tank. As gas entered the gasholder, it made the vessel rise up in the tank. The water-filled tank acted as a seal to prevent the gas from escaping. The pressure imparted by the weight of the tank would then pressurise the gas mains via the control provided by the governor. Booster pumps were later developed; these acted as powerful fans which could push the gas through the mains and also pressurise the gas mains.

The earliest gasholders were rectangular and constructed from heavy iron with a wooden frame, holding about $14 \, m^3$ ($500 \, ft^3$) of gas. Rectangular gasholders continued to be built until 1815, when they were replaced by a larger cylindrical design. The tanks of these early gasholders were built above ground and normally constructed from wood. They were not robust and were prone to leaking and collapse. The gas engineer John Malam improved the cylindrical gasholder design by reducing the weight of the internal framing and using counterbalance weights and chains. Underground brick tanks were only introduced in 1818, with stone and concrete tanks following later.

The first gasholders using underground tanks were of single-lift construction. The movement of the tank up and down was aided by wheels running along guided tracks on the supporting columns.
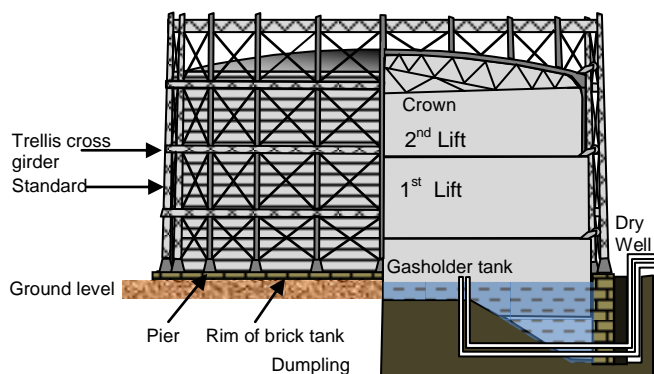
Figure 22. A schematic diagram of a guide-framed gasholder with a below-ground tank. Source: Russell Thomas.

With the advent of the telescopic gasholder developed by Tate in 1824, additional storage capacity could be added without increasing the footprint. The telescopic gasholder (Photographs 38 and 39, and Figure 22) consisted of vessels situated one inside the other. When the inner vessel (otherwise known as a lift) was fully extended, it would couple to the outer lift through engagement of the cups and dips. Telescopic gasholders could have as many as six lifts, one inside the other.
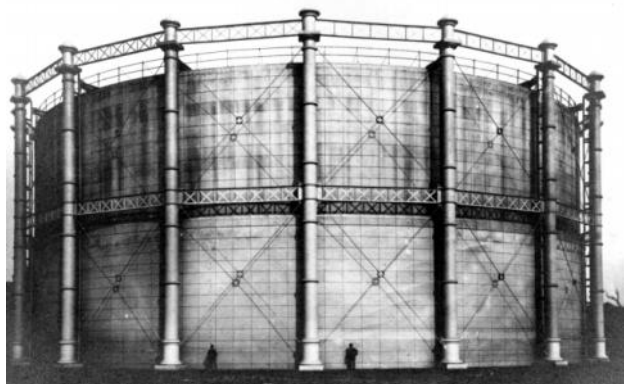
Photograph 38. A column-guided gasholder with two sets of horizontal trusses and diagonal bracing.

Many gasholders had underground water-filled tanks. Built from brick, stone or concrete, these tanks were generally made watertight by a layer of puddle clay on the outside face of the tank walls and beneath the base of the tank. Building the tank underground helped to reinforce the tank wall, as it was supported by the compacted ground around it.

Later developments of the gasholders led to the construction of above-ground tanks made of iron, steel or reinforced concrete.

The next major invention was the development of the spiral-guided gasholder (Photograph 39), the invention of William Gadd of Manchester. The first spiral-guided gasholder in the UK was built at Northwich, Cheshire, in 1890. These gasholders saw the removal of external columns or guide frames, replacing them with spiral rails on the inside or outside of the lift. As the gasholder filled or emptied, it moved up or down in a screw-like fashion. It was cheaper to construct than the design with columns or guide frames, but more delicate to operate, especially in the winter.
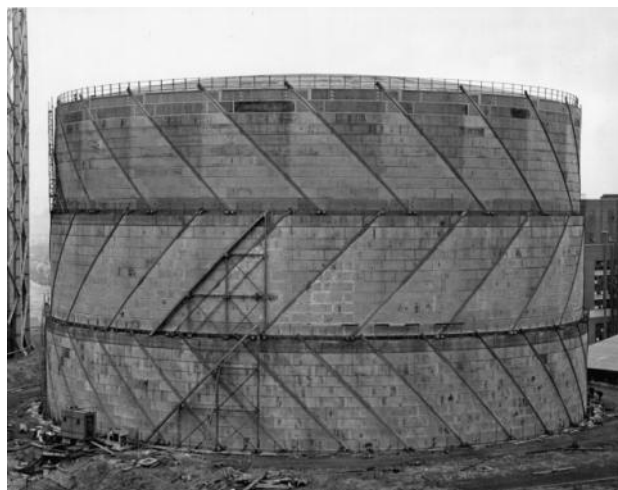
Photograph 39. Spiral guided gasholder.

Waterless or dry gasholders were introduced to the UK from Germany (MAN and Klonne) and the USA (Wiggins, Photograph 40). These allowed for a simplified system, where the only major moving part was the piston. The outer cylindrical shell remained static and of the same diameter, and the roof of the structure was permanently fixed. The piston was able to rise and fall inside the shell by means of guide rollers. The Wiggins holder also used a piston, but the gas was stored within a large neoprene/nylon 'bag' within the holder. A major benefit of this design was that they did not require a water tank. Many of these vessels are still used by the steel industry worldwide for the storage of coke oven and blast furnace gases.

Photograph 40. Waterless gasholder of the Wiggins design.

Another later form of gas storage was the high-pressure static vessel. These vessels had no tanks or moving parts, and received and stored gas at a much higher pressure than those vessels listed above. Their bullet-shaped or spherical tanks are shown in Photograph 41. In more recent years, use has been made of gas storage within high-pressure gas mains as liquefied natural gas, and within depleted gas fields or salt caverns. The subject of gasholders is discussed in more detail within *Gasworks Profile B - Gasholders and their Tanks*.
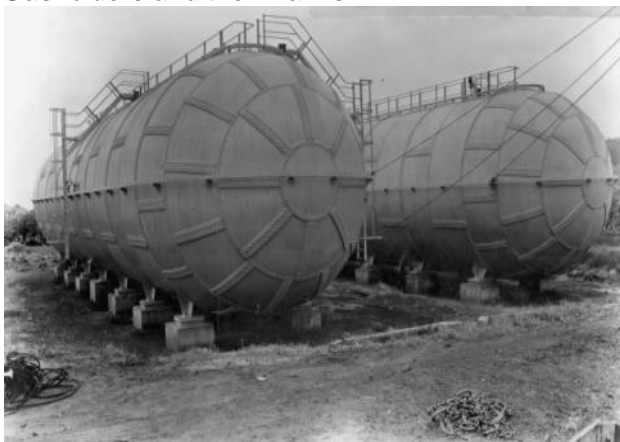
Photograph 41. High-pressure bullet tanks.

Station Meter and Governor

The station meter was generally housed within its own building or along with the station governor. As its name suggests, the purpose of the meter was to register the amount of gas produced at the gasworks. These meters were quite ornate, as can be seen from Photograph 42.

The meter was a cast iron drum approximately 1.2 m (4 ft) in diameter and 1.5 m (5 ft) long and half filled with water. Inside was a tin drum divided into compartments from which the flow of gas displaced water, making the drum rotate. The drum rotations were counted, and clock face type dials on the front of the meter allowed a reading to be taken.

Photograph 42. Station meters (right) in the meter house.

The gas would also be metered at the site where it was received. This meter was essential to the early gas industry as it allowed the gas companies to provide some measure of how much gas consumers were using and how much they should be billed. Prior to the gas meter, consumers were allowed a certain number of gas lamps lit for a certain period of time, but this was not easy to enforce.

The role of the station governor was to ensure that gas delivered from the gasworks was at a uniform pressure at all times, and free from fluctuations. The governor was located between the gasholder and the district gas main. It would control the pressure exerted by the gasholders onto the gas mains, keeping it at a level that was sufficient for supply, but no more. The governor would automatically keep the gas pressure uniform despite fluctuations in production and consumption.

The station governor would consist of a small tinned iron bell floating freely in a cast iron tank containing water. As gas mains developed and became more complex, it became more difficult to regulate the gas pressure in the system. As a result, district governors were introduced; these were particularly important for districts at different altitudes.

Hanging down from below the inside of the crown was a parabolic plug. The gas entered through the gas main and was directed up through the centre of the governor through a conical seated flange which exactly fitted the parabolic plug. By adjusting the gasholder, the degree to which gas could pass through the flange was altered. Weights were placed on the gasholder to alter the gas pressure to the mains. Without any weights, the gasholder would rise and the parabolic plug would fill the conical flange, cutting off the gas supply; fully weighted, the reverse would happen.

Tar Tanks and Wells

The tar and ammoniacal liquor recovered from the hydraulic and foul mains, condensers, electrostatic detarrer, washers and scrubbers was usually drained by gravity (pumps could also be used) to underground tar and liquor tanks (Photographs 43 and 44, and Figure 23). These tanks had a wide range of designs, from simple cylindrical structures cut into clay to large cast iron, steel, brick or concrete structures.

Many early gasholders on former gasworks were converted to 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 Photograph 43. In small gasworks, tar tanks were often simply brick tanks lined with puddle clay and covered with wooden planks (Figure 22), relying on gravity to separate the tar and the liquor. Other larger tanks

incorporated a series of weirs to separate the tars from the ammoniacal liquor.

Photograph 43. Interior of a tar tank at the former gasworks, Sydenham.

Tar tanks are poorly covered in the gas manufacturing text books and are often not marked on gasworks plans.

Tar and liquor were removed separately. 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. It would then be transferred to road or rail tanks

and taken to a tar distillers or chemical works. Some large gasworks would have their own tar distillation plant, a topic mentioned later in the section on tar distillation.
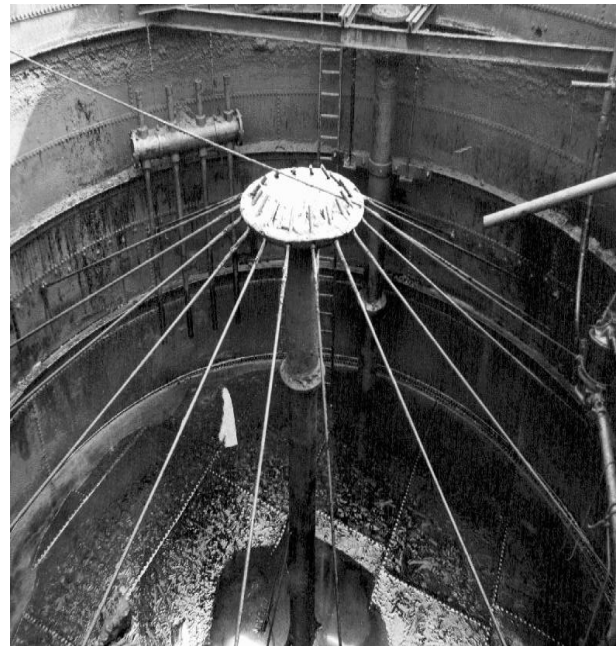
Photograph 44. Interior of a tar tank at the former Linacre Gasworks, Liverpool.
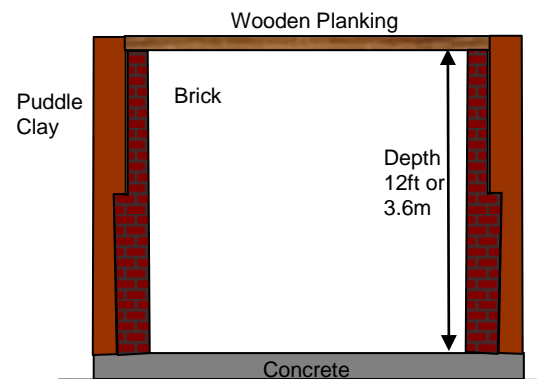
Figure 23. A schematic of a simple tar tank on a small gasworks site. Source: Russell Thomas.

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. They could precipitate out and gum up the mains at the gasworks, and also 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 (Photograph 45). It worked in much the same way as the ammonia washer, but using gas oil as a solvent instead of water.
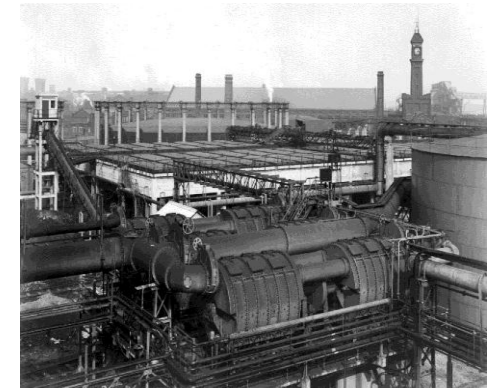
Photograph 45. Naphthalene washers at the former gasworks in Beckton.

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.

Benzole Plant

Benzole was a light oil consisting mainly of benzene and toluene. It could be removed by washing with a solvent (as for naphthalene) or by using activated carbon. If removed by solvent washing then the process would be almost identical to that described for naphthalene. Benzole was recovered from the oil using fractional distillation, sometimes under vacuum to reduce the steam requirements.

With the activated-carbon method, the gas was passed through the activated carbon (Photographs 46 and 47). 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 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 a base product for manufacturing explosives.

Gas Dehydration Plant

In the 1920s, gas dehydration (dry gas) plants (Photograph 48) were developed to reduce the moisture content of the gas. Moisture in coal gas
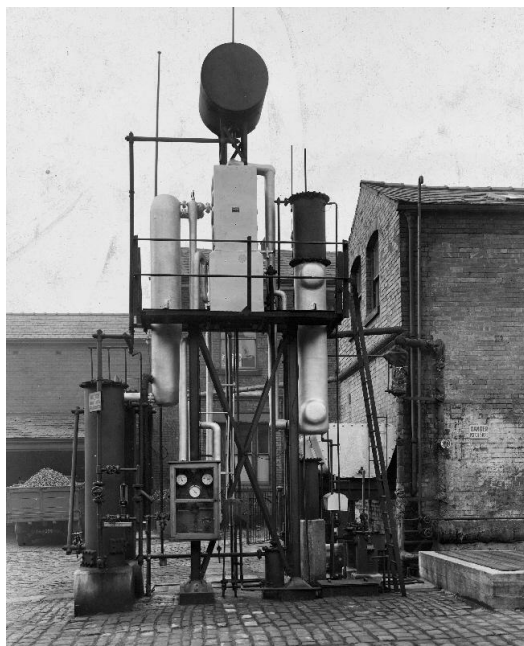
Photograph 46. A small benzole plant at the former gasworks in Middleton.

had a tendency to accumulate in the distribution system and customer meters. This moisture would often contain substances which would corrode the gas mains and damage the meters.

These substances included ammonium sulphate, ammonium sulphide, ammonium thiocyanate and ammonium ferrocyanide as well as carbon dioxide. At the gasworks, the calorific value of gas would be measured under the standard conditions of 15.5°C and 101 kilopascals (60°F and 30" mercury pressure).

If moisture was lost from the gas through condensation, it effectively concentrated the gas and raised its calorific value. Dry-gas systems removed this problem.

The gas dehydration plant could be located before the station meter (if a dry meter was used), before the gasholder, or after the gasholder (if wet meters were used).

Photograph 47. Large benzole plant at the former Carr House gasworks in Rotherham.

Photograph 48. WC Holmes dri-gas plant at the former Beckton gasworks.

Various systems were used for drying gas. The gas could be washed with a solution of calcium chloride (38-40%), which would absorb the moisture. Any excessive quantity of ammonia in the gas would waste the calcium chloride by reacting with it. The calcium chloride solution could be used in rotary washers or tower scrubbers which would resemble those described previously. A less popular method was dehydration using glycerin, which operated on similar principles as those for calcium chloride.

Another system involved the use of refrigeration: the gas was washed by chilled brine (salt water) which was recirculated and recooled. It was only used on sites producing more than 160,000 m^3 (6,000,000 ft^3) of gas per day. Naphthalene and its associated compounds would precipitate from the gas using this method and had to be removed from the brine solution. The gas could also be dehydrated by compressing and cooling the gas.

Ammonium Sulphate Plant

Ammoniacal liquor was processed to manufacture ammonium sulphate fertiliser (Photograph 49). The process was quite simple and involved driving off the gaseous ammonia (NH$_3$) and reacting it with sulphuric acid (H$_2$SO$_4$) in line with the following reaction:

$$2NH_3 + H_2SO_4 = (NH_4)2SO_4$$
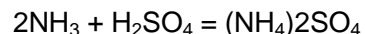
A small gasworks that did not have access to steam would use an under-fired still or boiler to drive the ammonia from the liquor. This process was not ideal and was not used in large works. When the liquor reached near-boiling point, a great number of odorous gases such as hydrogen sulphide would be 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.

The 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. From the superheater, the liquor passed into the top of the still; the latter contained a series of perforated trays which would contain the liquor to a depth of 6.3 cm (2.5 in). 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.
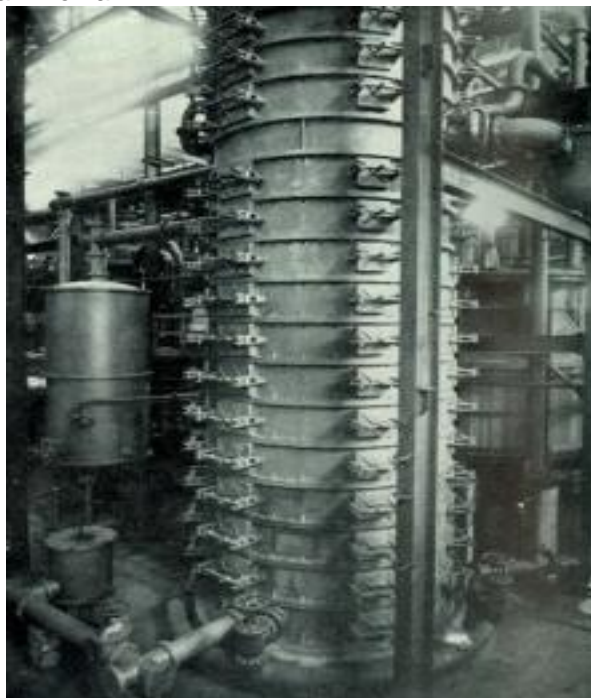
Photograph 49. Sulphate of ammonia plant, showing liquor tower (still, centre), liming unit (left) and saturator (right).

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. 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 distribution (Photograph 61).

Coke Screening Plant

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. 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.

Early grading plants were relatively simple and used basic screens for grading. They were similar to that shown in Photograph 50. At larger more modern gasworks, the coke was graded in large concrete bunkers which looked similar to retort houses. Using screens and conveyors, the coke would again be sorted into different sizes and stored in bunkers prior to weighing and dispatch into wagons.

Photograph 50. Early coke screening and bagging plant, Adderley Street, Birmingham.

Butane Air Plant

Butane air (Photograph 51) was an alternative form of gas supply used in some remote parts of the country to replace coal gas systems. As the butane had a low vapour pressure, it needed to be vaporised using a specialised piece of plant before being mixed with air and distributed.

The butane air gas produced would have a calorific value no lower than 18.6 MJ/m^3 (500 Btu/ft^3), the same as coal gas. The small town of Whitland (Wales) was the first town in Britain to use this process alone to supply a town. It was used elsewhere to supplement gas supplies when demand required, especially at times of extreme seasonal demand, such as in a cold winter.

Boosters

Gas boosters were used to raise the pressure of gas in pipelines to provide sufficient gas pressure for specific purposes. On a gasworks, this was usually to transport gas at higher pressures to nearby holder stations. However on larger works, such as Beckton, booster pumps were required to enable the gasholders to be filled (Photograph 52).

Photograph 51. A small butane air plant.

The use of boosters to help transport gas became more common as smaller gasworks were closed for production, but retained as holder stations; they were also needed when more remote locations were added to the gas network.

The gas was pumped using booster pumps to increase the pressure of the gas in the pipeline. This compressed the gas, allowing more gas to be transported from the remaining larger gasworks to these smaller satellite holder stations. Booster pumps were either rotary fans or blowers operating at between 7-27 kPa (1-4 psi) or reciprocating compressors operating at between 138-207 kPa (20-30 psi).

Booster pumps replaced gasholders as the way to provide pressure in the local gas network. Boosters are still used to ensure the correct pressure in the low-, medium- and high-pressure gas pipelines as well as the National Transmission System (NTS). Within the NTS, rotary machines driven by gas turbines are used. Governors were used to regulate the change in gas pressure between the different pressure rated pipelines.

Photograph 52. Four high-pressure turbine-driven boosters at the former Beckton gasworks.

Tar Distillation

Coal tar had many uses, both direct and indirect. Coal tar could be distilled into fractions then used as wood preservatives, fuels, disinfectants and various pitches for roads, roofing tar, and as a binder for electrodes and insulation (Figure 24). The first tar distillery was built in Leith, Edinburgh, in 1822; it produced a spirit used for dissolving rubber in the manufacture of waterproofs. Use of middle and heavy oils as timber preservatives was one of the earliest uses of coal tar and led to its adoption as a valuable product.

As coal tar became the base feedstock for the production of chemicals *circa* 1870 until the availability of petroleum-based oils, it was further processed to produce chemicals used in the manufacture of dyes, flavours, aromas, explosives, sweeteners and drugs, amongst other items.

This wide variety of uses and products is shown in Figure 24. The distillation of coal tars was more common at larger gasworks although a few small and medium-sized gasworks would also distil tar.

Figure 24. Products obtainable from coal through gas works, coke ovens and chemical works with chemicals and derivatives which were once manufactured in Great Britain. Source: Russell Thomas.

Flue Dust
Brown oxide paint, anti-corrosion paint, liquid metal polish, valve grinding composition

Coal Bituminous

Coal gas

Lubricants, crucibles, electrodes & pencils.

Producer gas

Coke

Retort furnaces

Water gas

Calcium carbide

Carborundum

Graphite

Abrasives

Ammonium thiocyanates

Hydrogen sulphide

Hydrogen cyanogen

Ammoniacal liquor

Crude benzol (crude spirit)

Crude tar

Town gas

Calcium cyanamide

Acetylene

Thiourea

Cyanogen liquor

← Ammoniacal liquor

Ammonia

Acetaldehyde

Plastics

Nitric acid

Aceatic acid

Yelow Prussiate
Ferrocyanides
Case hardening, blueprints, gold extraction

Calcium cyanides
Reagent

Dephenolation process

Methyl cyanide (acetonitrile)

fertiliser

Acetone

Light oil

Middle oil (carbolic and naphthalene oil)

Creosote oil

Anthracene oil

Pitch

Prussian blue
Printing inks, paints

Red prussiate
Printing pigments

Sodium nitroprusside
Reagent

Syn. Vitamin B1

Crude Tar Bases

Dimethyl naphthalenes
solvents, heat transmission oil

Road tar
Surface dressing Tarmacadam, Tar Carpet, Retread, Tar emulsions

Ethyl cyanide (propionitrile)

Spent oxide
Sulphur

← Hydrogen sulphide exit gas

Photographic chemicals

Pure pyridine
vitamins drugs

Pyridine bases
90/40 90/60 90/80

Quinoline, Iso-quinoline, Quinaldine
Vitamins Medicines Photographic chemicals

Methyl naphthalenes
Vitamin K, Printing inks, baking enamels, heat transmission oil & solvents

Fluorene

Refined tar
iron and steel protection insulation water proofing

Sulphuric acid

Ammonia

Piperdine
Rubber accelerator

Lutidines

Acenaphthene

Tri-methyl naphthalene
solvents heat transmission oils organic synthesis plastics

Soft pitch

Medium pitch

Hard pitch

Surplus acid to chemical industry
Superphosphate, bleach, alkali, hydrochloric acid, alum, nitric acid, iron pickling, oil refining, explosives etc

Ammonium sulphate

Conc. ammonical liquor

Anhydrous ammonia
Refrigeration

Ammonium salts, as nitrate, sulphate, chloride etc

Picolines

Nicotinic Acid
Niacin

Coal tar fuel
liquid furnace fuel

Hot process tar, waterproofing, insulating coatings & materials, lampblack, pitch mastic, roofing felt, coal tar fuel.

Briquetting (small coal) paints, varnishes, flooring, insulation, pitch mastic & coal tar fuel

Coal tar fuel, electrodes, core compounds, insulation & optical work

Fertiliser, ammonium chloride, galvanising & calico printing

Liquid ammonia

Waterproof & rotproof textiles, baking powder, brewer's caramel, cleaning agents

hexamine

Urea
Plastics

Nitric acid
Ammonium nitrite

Crude naphthalene
Fire lighters soil insecticides

Total Creosote
Light Creosote, Ordinary Creosote & other blends. Wood Preservatives, fuel oil, wash oil, coal tar fuels, brick oil, lampblack, disinfectants, fruit tree spray, fluxing oil road tar

Crude anthracene

Tablet fuel, medicines, plastics

Plastics

Crude phenols →

Crude Phenols

Refined Phenols

Anthracene

Phenanthrene

Heavy oil

Pitch coke

Anthraquinone

Carbazole

Flux for road tar, Carbon black

Electrodes, foundry coke, etc.

Refined light oil

Phenol

Cresols

Xylenes

High boiling phenols

Refined naphthalene
moth repellent, disinfectant, Plant insecticide, fumigant, deodorant, plant hormones

Alizarin

Phenanthraquinone

Dyes

Dyes

Intermediates & dyes

Carbon Disulphide
Artificial silk, insecticides

Motor Benzol
Benzol petrol mixtures

Benzene

Xylenes

Heavy Naphtha

Cresylic acid

Vitamin B2
Dettol

Cyclopentadiene & Dicyclopentadiene
For organic synthesis

Paints, varnishes, lacquers, dopes, dry cleaning, detergents, leather treatment, intermediates, dyes, sulphonamide

Paints, varnishes, lacquers, dopes printing inks, perfumes, terephthalic acid plastics, enamels

Paints, varnishes, protective coatings, solvent, insecticides

Cyclohexanol Cyclohexanone

Tri-Cresyl Phosphate
plasticiser

Naphthols, Naphthylamine
Dyestuffs, antioxidant

Nitronaphthalene
Dyes, Explosives

Chlorinated naphthalene 'Seekay wax'

Hydrogenation

Naphthalene sulphonic acids

Benzene hydrochloride
Insecticides

Nitrobenzene

Nylon plastics

Solvents, plasticisers, synthetic resins, detergents

Methylcyclohexanol Methylcyclohexanone

Phthalic Anhydride

Benzoic acid

Anthraquinone

Tetralin & decalin
Solvent turpentine substitute

Aniline salts

Aniline
Dyes, photographic chemicals, intermediates & drugs.

Toluene

Solvent Naphtha

Coumarone Resins

Adipic acid

Picric Acid
Explosives

Phenylacetin
Medicines

with ammonia

with phenol

with benzene

Dyes, photographic chemicals & intermediates

Salacylates
Medicines, antiseptics & perfumes

Phthalimide

Phenol-phthalain

Dyes, coloured smoke

Dimethyl-aniline

Paints, varnishes, lacquers, dopes, enamels, drugs, intermediates, dyes, anti-knock fuels

Paints, varnishes, lacquers, rubber solver, waterproof textiles & lacquers

Rubber compounding, tiles, linoleum, paints & varnishes.

Salacylic acid

Asprin
Medicines

Anthranilic acid

Food preservatives, perfumes, medicines, antiseptics & solvents

Synthetic phenol

Toluidene

Nitro-toluene

Saccharin
Art. sweetener

Benzaldehyde

Benzoic acid
Food preserve, perfumes, medicines, antiseptics & solvents

Dyes (Indigo)

Indicators, medicines & dyes

Halogenated benzene
Intermediate dyes & photographic chemicals

Benzene sulphonic acid

TNT
Explosives

Chloramine-T

Dyes, perfumes & flavourings

Intermediate dyes

Antiseptics

Hydrogenation

Solvents

Methyl-cyclohexane

polystyrene
Plastics

Styrene

Maleic acid
Plastics & plasticiSers

Cyclohexane

Solvents

Synthetic rubber

Butadiene

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

The best examples of tar distillation plants on gasworks would be the by-products plants at the former gasworks at Beckton and Southall.

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.
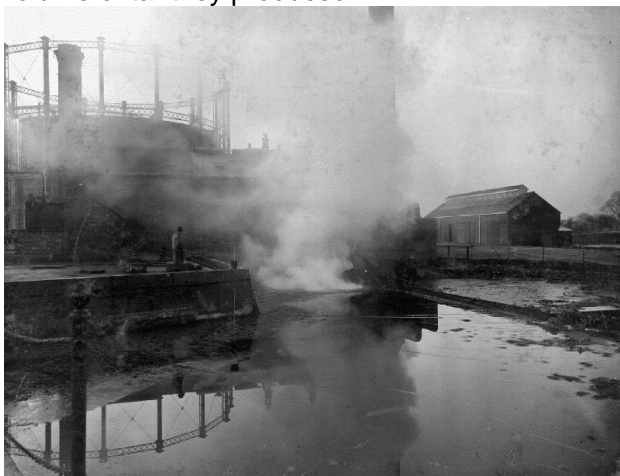
Photograph 53. Running off pitch into pitch beds.

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 (Figure 24), the residue which remained. The pitch was the greater portion of the tar and the hot pitch was allowed to run into large open pits, called pitch beds (Photograph 53), where it would cool and harden before being broken into lumps and sold.

In 1939, Great Britain produced about 2 million tonnes of coal tar. Most was used as road tar (750,000 tonnes) and pitch (750,000 tonnes). Creosote accounted for 450,000 tonnes, and other sundry uses for 50,000 tonnes.
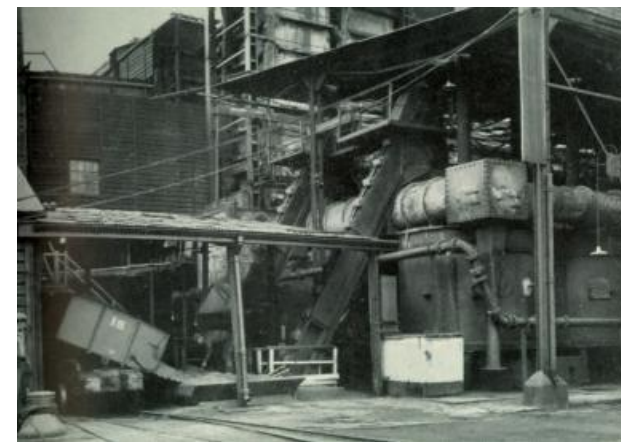
Sulphuric Acid Plant

Sulphuric acid was one of the most important industrial acids and its production was always in high demand. The main source of sulphur for the production of sulphuric acid was the spent oxide (or other spent purifying material) which would typically consist of about 50% sulphur. Gasworks were the source of most of Britain's raw material for sulphuric acid production *circa* 1910. A number of large gasworks such as Beckton manufactured sulphuric acid (Photographs 54 and 55).

**Photograph 54. The sulphuric acid plant at the Beckton gasworks.**

A few different methods were used to produce sulphuric acid, the most common method using a burner, chamber plant and Glover and Gay-Lussac towers. The sulphur-containing material was burnt within a Herreshoff-type furnace, resulting in the formation of sulphur dioxide.

Photograph 55. Spent oxide being unloaded from rail wagons into buckets en-route to burning in the furnaces of the sulphuric acid plant.

The chamber was constructed of lead, as other construction materials would have suffered corrosion from the sulphuric acid. These chambers were often supported on a wooden or iron frame above ground to allow leaks to be detected. These chambers were 30.5 m (100 ft) to 61.0 m (200 ft) long, 6.1 m (20 ft) to 9.1 m (30 ft) wide, and 4.5 m (15 ft) to 7.6 m (25 ft) high.

The overall reaction for the process was:

$$SO_2 + \tfrac{1}{2}\,O_2 + H_2O = H_2SO_4$$
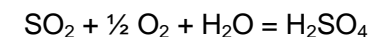
However, this reaction was very slow and required the presence of nitric acid or oxides of nitrogen to proceed efficiently. The overall chemistry of the process, including the chemical reactions with nitrogenous intermediates, is much more complex. The burner gas from the furnace was pulled through the system into the base of the Glover tower, either from a draught produced by a chimney or by mechanical means. In the tower it was washed with a mixture of sulphuric

acid with nitric oxide and nitrogen dioxide dissolved within it.

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.

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, condensed on the walls, and then collected on the floor of the chamber. The acid produced in the chambers contained between 62% and 68% H_2SO_4.

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.

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.

Other Buildings and Plant

Other buildings were found on former gasworks. These included: the boiler house, where steam was raised in boilers, using coke as a fuel; generating or power houses, where electricity

was produced by generators driven by gas or steam engines; pump houses, where water would be pumped from boreholes or rivers to supply the heavy water demand of a gasworks; a variety of stores for items including fireclay, meters and stoves; ancillary buildings such as stables, workshops, toilets, laboratories, blacksmiths, mess facilities, offices and accommodation.

5. Gas Manufactured from Coke and Oil

5.1 Water Gas

One of the major issues with coal gas was the time needed to get the plant operating and producing gas, making it unsuitable in periods of high demand when a quick response was required. To handle peak demands for gas, gas plant would have to be operated inefficiently or additional gas storage would be required.

Another process was developed, one that could produce gas much more quickly and cope with periods of peak demand. Known as 'water gas', its use was particularly widespread in the USA. The process worked by steaming coke to produce a gas consisting of hydrogen and carbon dioxide. The operation was split into two phases, the blow and the run phases. The purpose of the blow was to store as much heat in the generator fuel bed as possible. Hot gases from the generator heated the carburettor and superheater. During the run, steam was injected into the generator and reacted with the carbon, forming carbon monoxide and hydrogen. The run phase would gradually cool the fuel bed, increasing the proportion of inert substances (carbon dioxide) in the gas. A regular switching between the blow and run was required, making it an intermittent process. Water gas was a relatively poor quality gas, but it could enriched by injecting oil into the carburettor. Called Carburetted Water Gas

(CWG), it was used at many medium- to large-scale gasworks in Britain and across the world, becoming a vital gas manufacturing process. In parts of the USA, this became the primary form of gas manufacture. A photograph of water gas plant at the former East Greenwich Gasworks can be seen in Photograph 56. This subject is discussed in much greater detail in *Gasworks Profile C - Water Gas Plants*.

Photograph 56. The interior of the water gas plant building at the former East Greenwich Gasworks.

5.2 Producer Gas

Producer gas plants were used on former gasworks primarily to heat retorts and occasionally to supplement gas supplies at times of peak demand. A brief summary of gas producers is given below.

Producer gas plants started to become popular in the early 1880s and were in widespread use by 1910. Many varied types evolved from the time that the first plant was built by Bischof and their demise in the mid 20th century. In 1857, Frederick Siemens developed Bischof's gas producer into a combined gas producer and regenerative

furnace. This system was gradually improved and introduced to the UK through William Siemens. Producer gas plants provided a great benefit to those industries which required high and uniform temperatures. It was of great assistance to those industrial processes which were unable to use directly fired solid fuel furnaces, or found it very difficult to do so, and could not obtain a suitably priced gas supply. It saved fuel by enabling the gas to be at the exact point required, achieving higher temperatures, rather than relying directly on radiant heat. Gasworks were one of the major users of gas producers, using them to heat the retorts, with the by-product coke used in the generator. They were also used to heat coke ovens in the same way. This subject is discussed in more detail in *Gasworks Profile D - Producer Gas Plants*.

5.3   Oil Gas

The production of oil gas dates back to the start of the gas industry. In its earliest years, the coal gas industry faced competition from gas made from oil, primarily whale oil, although other fish and vegetable oils and resins (rosin) were used. These gasworks were built in places such as Bristol and Edinburgh. They were short-lived and faced closure after a few years because of oil shortages and being uneconomic to run. Some converted to coal gas production. Oil gas was more successful on the European continent.

Oil gas was also the gas of choice on the railways, and was used for lighting carriages. This method of lighting was developed by Julius Pintsch, a German engineer. The gas, a form of vaporised naphtha oil, was produced at Pintsch gas plants located at stations or works. It was stored in mobile gasholders, which would provide gas to the carriages for burning in special lamps.

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 crude petroleum oils and derived distillate fractions were present in abundant amounts from oil refineries, providing a cheaper viable alternative. Early types of oil gas plant which had seen popularity on the west coast of the USA (Jones process) were never popular in Britain.

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.

An advantage of oil gas over coal gas was the lack of ammonium and cyanide; this reduced capital costs as well as the amount of land required to undertake 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 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 increased pressure.

The combustible components of a typical oil gas may be composed of 48.6% hydrogen, 26.3% methane, 12.7% carbon monoxide, and 3.8% illuminants.

Non-Catalytic Cyclic Method of Gas Production

The first major use of petroleum-based oils for the manufacture of town gas occurred on the Pacific coast of the USA. Referred to as the 'Pacific

Coast Oil Gas Processes', the main method was the Jones process.

Severe cracking conditions were used to produce a gas with a calorific value (CV) of 18.6 MegaJoules per cubic metre (MJ/m^3), equivalent to 500 British Thermal Units per cubic foot (Btu/ft^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 lampblack) and small amounts of viscous tar, which was rich in naphthalene and carbon black content.

This process was later extended to a wider range of oil feedstocks and also adapted to enable increased carbon black, a useful by-product which could be sold. In this case, a gas with a lower energy density of 13 MJ/m^3 (350 Btu/ft^3) was produced, forming little or no tar. Carbon black could be sold at a price which made such a lower calorific value viable.

Jones Process

The only known Jones process plant in Britain was at the Gloucester Hempsted gasworks (Photograph 57). The economics of the process were based on the price received from the sale of the carbon black, the primary product; the gas produced had a energy density of 13.4 MJ/m^3 (360 Btu/ft^3).

The system consisted of four vessels, but the two outer vessels contained chequer bricks and were only used as heat exchangers. Gasification took place in the two main generator units. These larger vessels contained oil sprays and vaporiser spaces at the top. The generators were heated and oil was injected into them for five minutes; air was then blown into them, allowing them to reach between 870-925ºC. 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.

Air was blown into the generator to burn off the carbon, cleaning the unit and reheating it at the same time. This process produced about 28 m^3 (1,000 ft^3) of gas from about 32 litres (7 gallons) of oil.

A method called the straight shot was a similar process 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 28 m^3 (1,000 ft^3) of gas from about 39 litres (8.6 gallons) of oil.

In both manufacturing 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 similar to that of CWG except for the removal of carbon black. 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 CWG fuel or sold for other industrial purposes including the production of tyres, paint and ink.

Hall Process

The Hall process was also used at the Hempsted gasworks in Gloucester (Photograph 40). It produced a high CV gas of 37.2 MJ/m^3 (1,000 Btu/ft^3) which was equivalent to natural gas.

Photograph 57. The Hempsted gasworks Gloucester, where a range of oil gasification processes were constructed, including the Hall, Jones and Gas Integrale processes.

The process was originally undertaken using 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 efficiency of the Hall process varied from 82% of the thermal value of the feedstock on light distillate, to 50% on heavy fuel oil. The tar produced would range from less than 5% for light distillate to 20-30% for heavy fuel oil.

Other types of non-catalytic oil gas plant were also developed.

Cyclic Catalytic Processes

Catalytic gas manufacturing processes were 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 naphthenes and aromatic compounds, then provision would have to be made to remove the naphthalene and tars using a naphthalene washer and electrostatic detarrer.

SEGAS Process

The SEGAS (South East Gas) plant produced a gas similar to town gas. The plant had a regenerative design, using a catalyst in the form of cylindrical pellets. These contained magnesia and free lime as the active agent, which would last for three years.

A gasification efficiency of 70% was achieved, giving a CV of 18.6 MJ/m^3 (500 Btu/ft^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 a number of such plants were built across the UK, a notable example being on the Isle of Grain.

Onia-Gegi Oil Gas Process

The Onia-Gegi process was developed by the French 'Office National Industriel de l'Azote' in co-operation with the 'Gaz à l'Eau et Gaz Industriels', hence the name Onia-Gegi. Originally developed for the production of 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 similar to town gas with a CV of 18.6 MJ/m^3 (500 Btu/ft^3), using a nickel catalyst. The system operated at atmospheric pressure and at 900°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.

Micro-Simplex Process

The Micro-Simplex (MS) process 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 11.9 MJ/m^3 (320 Btu/ft^3), producing small amounts of tar which could be removed by electrostatic precipitators or deposited in dry purifiers.

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.

Continuous Catalytic Reforming of Petroleum Gases and Light Distillate

A range of continuous catalytic reforming processes (Photograph 58) were developed. These processes continuously reformed hydrocarbon feedstocks with a low sulphur content at pressures ranging from atmospheric to 40 atmospheres and at temperatures between 700-950°C. 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 benzole which were recovered and could be burnt to heat the reformer. If leakage occurred, the main potential contaminant from these processes would be the light distillates feedstock, although volatilisation would quickly take place.

Photograph 58. Reforming plant at Ambergate, Derbyshire.

6. The Composition of By-Products and Wastes Produced During the Manufacture of Gas

A number of by-products and wastes were produced from the processes used to manufacture gas. Most of the by-products from the gas-manufacturing industry were used elsewhere. During the history of the gas industry, there were times when the by-products had limited markets and required disposal. Sometimes these were disposed of on site or in tips. Some further information on the by-products and wastes produced are discussed in more detail below.

6.1 Coal Tars

In the early years of the gas industry, coal tar was regarded as a nuisance. Its main use was as a fuel. It could not always be sold, so would have been dumped on site or in available tips. Later, in the course of the history of the industry, the market for coal tar would disappear and it needed to be disposed of. In these situations, the coal tar was sometimes dumped on site and allowed to drain in the ground in areas of wasteland on or near the gasworks. Such areas are characterised by a thick layer of tarry pitch at or just below the original ground level. The thickness of the tar can be mistaken for tarmac.

Coal tars are a complex mixture of organic compounds. The exact composition of the coal tar was dependent on many factors, the most important being the type of retort, temperature of retort, and type of coal used.

In terms of elemental composition, coal tar is approximately 86% carbon, 6.2% hydrogen, 1.8% nitrogen, 1% sulphur with the remaining 5% being composed of oxygen and metallic and inorganic components of ash. In terms of the types of compounds present, the composition is given below.

Saturates	15%
Aromatics	37%
Resins	42%
Asphaltenes	5%

The US EPA 16 Polycyclic Aromatic Hydrocarbons (PAH) are thought to compose approximately 17% of the coal tar. There is also entrained free carbon within the tar, which can be as much as 22%.

The main contaminants of concern within coal tar are:
- PAH
- Phenolic compounds (e.g. phenol, cresol, xylenol etc)
- Benzene, toluene, ethyl benzene and xylene (BTEX) compounds
- Aromatic and aliphatic petroleum hydrocarbons
- Oxygen, nitrogen and sulphur heterocyclic compounds, e.g. carbazole, dibenzofuran, azobenzene, carbon disulphide
- Inorganic components, ammonium, cyanide and sulphur-based compounds

The most predominant fraction of coal tar (approximately 67% on average) is, however, 'medium pitch'. This is solid at room temperature and relatively inert chemically and toxicologically. Therefore, these contaminants of concern do not form the majority of the composition of crude coal tar.

Coal tar was distilled on some gasworks, either in relatively crude stills or much more advanced fractionating plant which would split the coal tar into specified fractions according to temperature range, an example is shown below:

- 2-8% light oils (mainly benzene, toluene, xylene)
- 8-10% middle oils (mainly phenols, cresols, and naphthalene)
- 8-10% heavy oils (naphthalene and derivatives)
- 16-20% anthracene oils (mostly anthracene)
- 40-70% pitch

Once distilled, the resulting fractions had quite different properties, the lightest being Light Non Aqueous Phase Liquid (LNAPL) oils and the heaviest being pitch, which would set solid at room temperature. These fractions were sold for further processing into tarmac or products such as tar oil wash for fruit trees (Photograph 59) or a host of other uses as shown in Figure 24.

Photograph 59. Spraying apple trees with tar-oil.

Should these fractions be present in the ground on gasworks, then their fate and transport would vary significantly from crude coal tar.

On small gasworks, coal tar was sometimes mixed directly with clinker/aggregate to produce a rudimentary form of tarmac. Such tarmac would take a long time to set as it still contained volatile and semi-volatile components, which were liquid at standard air temperature and pressure. This problem could be avoided by using a tar dehydration plant, where the coal tar would be heated to drive off the volatile and semi-volatile components, making the tar more solid at standard air temperature and pressure.

Coal tar may be found in the ground around buildings, condensers, scrubbers/washers, tar wells/tanks and the pipes connecting the aforementioned. Coal tar may also be found in the base of tar tanks and gasholders. Coal tars are predominantly Dense Non Aqueous Phase Liquids (DNAPLs), although LNAPLs were also produced.

As mentioned in section 4.4 on coke ovens, a few low-temperature coke ovens operated in Britain, and these would have produced coal tars of a different composition. The most notable issue would have been the formation of polychlorinated dibenzodioxin congeners, compounds which would not normally be found in the by-products of higher temperature gas-making or coke-making processes.

6.2   Ammoniacal Liquors

Ammoniacal liquors were removed in the hydraulic main, foul main and condensers and also produced by spraying the gas with water in the washers and scrubbers. This dissolved the soluble ammonia and phenolic compounds in water. The ammoniacal liquor consisted of up to 1% ammonium and a lower concentration of sulphate, phenol, ferrocyanide and thiocyanate.

Photograph 60. A tanker used for spraying ammoniacal liquor on agricultural land.

Ammoniacal liquor could be used directly or diluted as a liquid fertiliser (Photograph 60) if there was an immediate local need, although this was often not practical.

As there was a low concentration of recoverable products in the liquor, it was often heated in a concentrated ammoniacal liquor plant. The concentrated liquor was then sent to a chemical works for processing to make ammonium sulphate fertiliser (Photograph 61).

Ammoniacal liquors may be found in the ground around scrubbers/washers, tar wells/tanks, pipes connecting the aforementioned and also in the base of tar tanks and gasholders

Photograph 61. Bagging sulphate of ammonia fertiliser.

6.3 Blue Billy, Foul Lime and Spent Oxide

Blue Billy, foul lime and spent oxide were all wastes of the gas purification process which would remove sulphur, cyanide and organic sulphur compounds from the gas. Blue Billy was the waste produced from reacting the gas with wet lime; foul lime was the waste produced from reacting the gas with hydrated lime; and spent oxide was the waste produced from reacting the gas with iron ore. Both foul lime and spent oxide are likely to be encountered on former gasworks sites, but Blue Billy is less likely. These processes were discussed earlier in the section on purifying the gas.

The cyanide present in spent oxide (Photograph 62) formed up to 6% of the total weight and is predominantly in the form of thiocyanate and complex metal cyanides. Spent oxide also consists of approximately 3-9% iron, 0.08-0.36% manganese, 2-3% sulphate and 36-60% free sulphur. Spent oxide was often used as a weed killer. The amount of cyanide, sulphur and sulphate within foul lime was similar to that for spent oxide.

Photograph 62. Spent oxide in soils at a former gasworks. Source: Russell Thomas.

Foul lime and spent oxide may be found in the ground near the purifiers and land used to revivify the spent material. They may also be found in any location where ground levels have been raised. Their presence may be detected by blue staining on walls and paving and stunted growth in vegetation.

6.4 Ash/Coal Dust

Ash was the waste material remaining after the coal or coke had been burnt in the furnace; it contained heavy metals (e.g. As, Pb, Cu, Cd, Ni, Zn) though generally only at low concentrations. Ashes were often used for raising ground levels or for use on cinder paths. Coal dust, although not a significant contaminant from a gasworks, would have elevated concentrations of PAH including benzo(a)pyrene.

Photograph 63. Disposal of waste ash in a former canal basin.

Ash/coal dust may be found in the ground close to the retort house/coal store and anywhere that ground levels have been raised (Photograph 63).

6.5 Coke

Coke was the useful solid remaining after gasification. It was sold for domestic and industrial use (Photograph 64). It was almost a pure form of carbon, although it would also contain metalliferous and inorganic components, depending on the original composition of the coal. The amount of these additional substances, which would not combust, would be called the ash content.

The substances would include metals such as arsenic and lead, which would concentrate in the ash once burnt. The ash was used for burning in fires to heat domestic properties. Hard coke was

produced in horizontal retorts and was most suitable for use on blacksmith's hearths and enclosed stoves.

Photograph 64. Loading coke onto a wagon.

7. The Environmental Legacy of the Gas Industry

Over 4,000 gasworks were built in Great Britain, which have left a considerable environmental legacy. The manufactured gas industry is now largely a footnote in Britain's history, with little visible evidence of its past on the landscape. The last remaining gasholders are gradually being decommissioned, removing the final traces. It should be noted that coal carbonisation does still continue at the few remaining British coking works.

Most of the former gasworks land is now subject to different ownership and uses, from supermarkets to residential properties. Some sites have been remediated, others have not, and some have been partially remediated. The main route for remediating former gasworks has been redevelopment through the planning system; this requires them to be investigated and, if required, remediated to make them suitable for their intended use.

The local authority has a duty to investigate contaminated land. It may inspect former gasworks sites using its powers under Part 2A of the Environment Act 1990 to ensure they do not pose a Significant Possibility of Significant Harm (SPOSH) to those living on, working on or visiting the sites.

There is also a requirement to ensure against Significant Pollution of Controlled Waters (SPoCW) or Significant Possibility of Significant Pollution of Controlled Waters (SPoSPoCW), possibly involving the Environment Agency or Scottish Environmental Protection in investigating the site. Controlled waters include important ground or surface water resources.

If a desk-based preliminary risk assessment gives the local authority sufficient concern that the site could be contaminated, an intrusive investigation would be required. This would involve the excavation of hand-dug trial pits into the shallow soil, machine excavated trial pits (where suitable), and the excavation of boreholes into deeper strata. Hand-dug pits are used to assess the immediate risk from potential contamination in the top 500mm of soil. The machine-excavated trial pits and boreholes are used to investigate deeper structures such as underground tar or gasholder tanks. Boreholes are installed to assess the pollution of groundwater, or the risk of gases or volatile substances escaping from the soils.

Tar tanks are often the major concern on former gasworks and dealing with these to remove any remaining coal tar can be a key part of most gasworks remediation jobs.

Where an intrusive investigation of a former gasworks has identified SPOSH or (SPo)SPoCW, remediation would be required to break the pollutant linkage(s), often by removal or treatment of the pollutant source. A number of former gasworks sites have been inspected and remediated through this route.

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Appendix 1: Description of Carbonisation, Gasification and Pyrolysis

In the manufacture of gas, three words are often used in describing the process, sometimes interchangeably: carbonisation, gasification and pyrolysis. These are described below.

Carbonisation is the destructive distillation of a substance (e.g. coal) by heating it in a closed container (e.g. retort) in the absence of oxygen and collecting the volatile products (e.g. coal tar). The carbon content of the material being carbonised increases in the final product. The solid residue of coal carbonisation is coke, which is largely composed of carbon and mineral ash residue.

Gasification is the process of changing a substance into gas form from solid or liquid form. It is a process that converts organic or fossil-based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700°C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas is called syngas or producer gas. Coke is gasified during the water gas process.

Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. It involves the simultaneous change of chemical composition and physical phase, and is irreversible. In general, pyrolysis of organic substances produces gas and liquid products to leave char, a solid residue richer in carbon content. Extreme pyrolysis, which leaves mostly carbon as the residue, is analogous to carbonisation.