

Gasworks Profile C: Water Gas Plants

A profile of water gas plants, their history, design, development, application and the type of contaminants which may be associated with them.

Supported by

**PARSONS
BRINCKERHOFF**

nationalgrid

CL:AIRE

Gasworks Profile C: Water Gas Plants

Contents

1.	Introduction.....	C1
2.	The Early Development of Water Gas.....	C1
3.	Different Systems Used for the Manufacture of Water Gas.....	C3
4.	The Development of Intermittent Water Gas Plants.....	C3
5.	The 'Run' and 'Blow'.....	C5
6.	Types of Intermittent Water Gas Plant.....	C7
7.	Blue-Water Gas Plants.....	C8
8.	The Operation of an Intermittent Carburetted Water-Gas Plant...	C9
9.	Types of Fuel used.....	C16
10.	Oil Feedstocks used to enrich Water Gas.....	C17
11.	Oil Gas.....	C18
12.	Water Gas Composition.....	C19
13.	The Advantages and Disadvantages of Water Gas Systems in Gas Manufacture.....	C19
14.	Contaminants Associated with Water Gas Plants.....	C20
15.	Selected Bibliography.....	C22

Units

All units used in this profile have been converted to SI Units. Some are also shown as their former imperial units, as the data was taken from documents using this format. One unit commonly used in the gas industry and still in partial use is the British Thermal Unit (Btu), a common unit for the measurement of energy in the gas industry. 1 Btu is equivalent to 1.055 Kilojoules (0.001 MJ). The Btu was often expressed as Btu/ft³; this has now been replaced by the Megajoule per cubic metre, expressed as MJ/m³.

Gasworks Profiles

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

Gasworks Profile B: Gasholders and their Tanks

Gasworks Profile C: Water Gas Plants

Gasworks Profile D: Producer Gas Plants

ISBN 978-1-905046-26-3 © CL:AIRE 2014

Published by Contaminated Land: Applications in Real Environments (CL:AIRE), 32 Bloomsbury Street, London WC1B 3QJ.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any other means, electronic, mechanical, photocopying, recording or otherwise, without the written permission of the copyright holder. All images courtesy of the National Grid Gas Archive, unless stated.

The Gasworks Profiles have been prepared by:

Dr Russell Thomas,

Technical Director

Parsons Brinckerhoff

Redland, Bristol, UK

Tel: 0117-933-9262

Email: thomasru@pbworld.com or gasworkshistory@gmail.com.

The author would like to thank the National Grid Gas Archive, Warrington, UK, without whose assistance this publication would not be possible. The author would also like to thank Maria Laffey of Parsons Brinckerhoff and John Horne of IGEM Panel for the History of the Industry, for their assistance in reviewing this document.

Disclaimer: The purpose of this document is to act as a pointer to the activities carried out on former water gas plants. The Author and Publisher will not be responsible for any loss, however arising, from the use of, or reliance on, this information. This document ('this publication') is provided 'as is', without warranty of any kind, either expressed or implied. You should not assume that this publication is error-free or that it will be suitable for the particular purpose which you have in mind. The Author and Publisher assume no responsibility or liability for errors or omissions in this publication. Readers are advised to use the information contained herein purely as a guide and to take appropriate professional advice where necessary.

1. Introduction

This profile describes the manufacture of gas using the water gas process. Early water gas plants were based on retorts used for coal carbonisation; however, later water gas plants (Photograph 1) more closely resembled producer gas plants in the design of the generator and in their mode of operation. Water gas plants were popular in the UK and worldwide, particularly in the USA where they were first successfully commercialised.

One of the major issues with producing gas by carbonising coal was the length of time taken to get the gas plant operational and producing gas. This led to a heavy reliance on storage in gasholders. Without sufficient gas storage, the retorts would have to be kept heated on standby to accommodate rapid increases in gas production. This was both inefficient and uneconomic for the gas manufacturer. An alternative method to meet peak demand for gas was required, leading to the development of water gas plants.

Water gas plant could produce gas much more rapidly (within 1-3 hours) than traditional coal carbonisation plant, allowing gas companies to satisfy peak demand more effectively. Whilst this process was commonly employed on many larger town and city gasworks to supplement coal gas supplies, plant was also developed for smaller gasworks. In Britain, water gas was mixed with coal gas (30% water gas to 70% coal gas) prior to distribution.

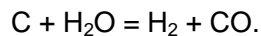
2. The Early Development of Water Gas

The discovery of water gas was attributed to the Italian physicist Felice Fontana in 1780. He



Photograph 1. The inside of the water gas plant building at the former East Greenwich Gasworks. Source: National Grid Gas Archive.

discovered that when steam was passed through incandescent carbon, the oxygen of the water molecules in the steam had a greater affinity for the carbon than the hydrogen to which it was bonded. This led to the formation of carbon monoxide and hydrogen from the water and carbon in the reaction:



This finding predated William Murdoch's discovery of a commercial process to produce coal gas. Given its composition, water gas had little or no illuminating power when burnt, so little use was made of the discovery. Henry Cavendish, Antoine Lavoisier, Charles Meusnier and others also later made the same discovery as Fontana.

The first patent taken out for water gas production was believed to have been by W. Vere and H.S. Crane in 1823. The patent described the use of admitting water or steam into a retort containing coal, oil or other suitable material undergoing decomposition, but was not developed further.

In 1824, John Holt Ibbetson made the first attempt to utilise water gas on a commercial scale. He experimented by steaming the coke which remained in the horizontal retorts at the end of the period of carbonisation. Ibbetson published a patent in 1826 but did not develop the technology further. On 6 October 1830, Michael Donovan received a patent for lighting by water gas. To improve the illuminating ability he mixed the gas with vapours of turpentine, tar, naphthalene and other illuminants. This was tested on the street lights of Dublin. The scale of this demonstration is uncertain; however, it did not meet with much success and soon failed.

Despite earlier work by others, George Lowe is often quoted as the first exponent of a carburetted

(oil enriched) water gas process when he discharged hot coke into a water gas generator and intermittently injected steam and air. His patent described that the gas produced should be enriched with essential oil. The process did not achieve commercial success.

A Belgian scientist (M. Jobard) successfully experimented with water gas production *circa* 1833. It is reported that he sold his invention to Alexander Selligie of Paris and Florimont Tripier of Lille. Selligie was then recognised as the inventor. Under Selligie's name, the water gas process was introduced to Dijon, Strasbourg and Antwerp, as well as parts of Paris and Lyon. The Jobard/Selligie process started by decomposing the water; the resulting hydrogen was then mixed with hydrocarbon (either oil vapour or heated resin) which then passed into a retort containing hot coke. The process lost popularity when Selligie was unmasked as a fraud.

The next major interest in water gas occurred in 1847 when Stephen White of Manchester took out a patented 'hydrocarbon process' which had similarities to that of Jobard. White's idea was to produce a very rich gas, from fat, oil or tar, and dilute it to a reasonable candle power using a cheap, low-grade carrier gas. White's success was boosted by favourable reports from Samuel Clegg and Dr E. Frankland. White's method was tested on a large scale at a mill gasworks in Manchester and at the gasworks of the South Metropolitan Gas Company in London. Whilst these trials did not lead to permanent installations, White's method was adopted as the original form of gas lighting in the town of Stockport in Lancashire until 1853. White claimed that 60% more gas could be produced from his method than from conventional coal carbonisation.

White's usual method was to set the stop-ended retorts in a single setting (above one furnace).

The central (water gas) retort contained hot iron scrap (or coke) onto which a trickle of water would fall, producing water gas. The other two 'coal' retorts made rich coal gas, being operated in the conventional way and receiving a supply of water gas by a connecting pipe from the mouthpiece of the central retort.

Ruthin in Wales, and Comrie and Dunkeld in Scotland, also adopted White's process for gas manufacture. The town of Petersfield, Hampshire adopted White's method but using coke instead of scrap iron in the central retort. The main failure of White's process was the greater complexity of controlling this water gas process compared with coal gas. The relative amounts of rich gas and water gas produced had to be carefully controlled to ensure correct gas quality.

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

Joseph Gillard made major advances in his works at Narbonne, France in 1856. Gillard managed to light the town by burning blue-water gas with argand burners over which platinum wire cage mantles were placed. Argand burners were the first scientifically designed burners, originally designed for oil lamps but later adapted for use in the gas industry. They consisted of a cylindrical wick housed between two concentric tubes. Air rose in the internal tube through supporting combustion on the inner surface of the flame as well as the outer surface. A glass chimney increased the draft. The blue-water gas flame heated a platinum mantle, which would emit a bright light. The high price of platinum made the cost effectiveness of this process very poor, and it failed.

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

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

In the 1870s, Mr R.P. Spice made water gas in horizontal retorts at a gasworks he leased in Chichester (England) for experimental purposes. He went on to build a fairly large water gas plant at Wormwood Scrubs, London. This used vertical retorts developed for Scottish shale-oil practice and was successful, but the gasworks' lease reverted to the Great Western Railway in 1880 and the water gas plant was no longer used.

A historical review led by John Cresson for the Philadelphia Gasworks and reported in Scientific

American in 1861 concluded that water gas failed mainly because of economics, it being more expensive than coal gas. Deterioration of the plant and difficulties in controlling the process also contributed to its lack of success. At the time of the review, water gas was being produced at the Northern Liberties Gasworks in Philadelphia.

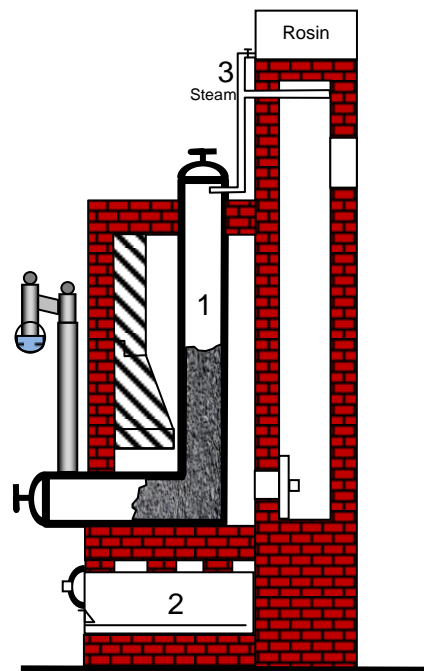


Figure 1. The design of the Sanders water gas apparatus. Source: Russell Thomas.

3. Different Systems Used for the Manufacture of Water Gas

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

however, short descriptions of the others are provided for historical reference.

The intermittent system with 'run' and 'blow' phases succeeding each other at regular intervals was the most widely used and thought to be the only practicable method. This is described in detail in section 5 of this document.

The continuous system was heavily investigated in the early development of water gas as it sought to make the process more efficient (by independent external heating of the vessels) and enable the continuous production of gas. It suffered from practical difficulties due to problems with heat transfer and general process inefficiency.

The third system was the neat oxygen method which produced a gas practically free from nitrogen, but containing 65-70% carbon monoxide. Steam entered the base of the generator along with a stream of pure oxygen. Whilst steam combined with a portion of the carbon to form water gas, the heat lost by the endothermic reaction was replaced by the exothermic combination of the oxygen with the carbon. If steam and oxygen were regulated correctly, the process would work effectively; its drawback was the difficulty obtaining pure oxygen economically.

All water gas processes were gasification processes where the fuel (coke/oil) was converted to gas.

4. The Development of Intermittent Water Gas Plants

Intermittent water gas systems were introduced *circa* 1873 when two similar methods were developed in the USA: the 'Strong process' and

the 'Lowe process'. These systems were both based on alternate periods of 'run' and 'blow', described in more detail on page 5.

The Strong process (not shown) employed a high generator made from firebricks and two secondary chambers also packed with firebrick. These latter chambers, heated up during the blow, were employed as superheaters for the steam. Strong aimed purely at making a gas suitable for the purpose of heating.

Thaddeus Sobieski Coulincourt Lowe set out to make a gas for illumination purposes. The original Lowe plant design was very similar to that employed in later water gas plants. The Lowe system consisted of a generator, a brick-lined cylindrical vessel (labelled 1 on Fig. 2), the outer shell of which was made from wrought iron. The fuel was placed in the generator on grate bars above a closed ash-pit. Air and steam were introduced alternately into the generator. Air was used to heat the chamber by combustion of the coal, with the steam injected to generate the water gas which was passed on to a large superheater (labelled 2 on Fig. 2). The superheater was packed with firebricks. Lowe's original idea of 1874 was to spray oil on to the coke in the generator to enrich the gas. Lowe's later design of 1884 incorporated an additional chamber called the carburettor, between the generator and superheater. This was a similar brick-lined vessel into which the oil was sprayed and gasified.

Lowe's development coincided with the availability of cheap naphtha and oils in the USA which could be used to enrich the gas. These had come from the production of lamp oils and lubricating oils from petroleum in the USA. This gave the development of Carburetted Water Gas (CWG) a massive boost and by 1882 a considerable portion of gas production in the USA

was made using this process. Possibly, Lowe's main contribution was constructing the plant from refractory material in a steel shell; this gave the plant both rigidity and flexibility to cope with the temperature changes caused by the cyclical nature of the intermittent process.

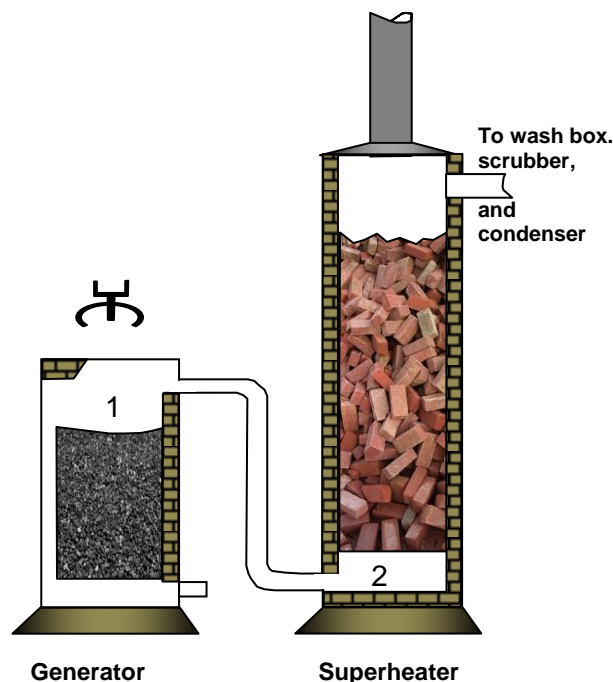


Figure 2. The Lowe water gas system. Source: Russell Thomas.

The first water gas plant built in Britain was a small plant erected by the British Water-Gas Syndicate in 1888. This company was wound up in 1893 by its Chairman, Samson Fox, a proponent of water gas.

Two of the biggest companies involved in the manufacture of water gas plant were the United Gas Improvement Co. and Humphreys and Glasgow Ltd, two closely related companies.

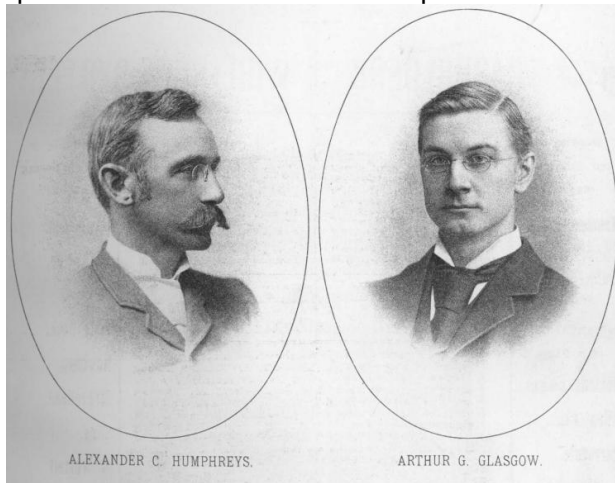
United Gas Improvement Co (UGI) was incorporated in 1882 in Pennsylvania to exploit the new process of water gas manufacture developed by Lowe.

UGI manufactured, sold and installed equipment needed for the Lowe process. The company also leased the production and distribution facilities of existing gasworks, operated the plants and sold the gas. UGI moved into the supply of gas and electricity, eventually moving away from the manufacture of gas, and into natural gas. The company still exists in the form of the UGI Corporation. Whilst UGI was very big in the American market, it had limited interest in the European market. The Gas Light and Coke Company (GL&C Co) of London took an interest in the development of water gas and sent its chief engineer to visit UGI. As a result, two 14,000 m³ (500,000 ft³) per day plants were ordered by the GL&C Co. Arthur Glasgow (Photograph 2) was dispatched by UGI to assist the GL&C Co to commission the water gas plants which were to be built at Beckton, near London. On Glasgow's return to the USA, he tried to persuade UGI to expand into Europe, without success.

Glasgow then persuaded Dr Alexander Humphreys (Photograph 2), then a senior UGI executive, to set up Humphreys and Glasgow in London in 1892. Both were American and experienced gas engineers, Dr Humphreys having undertaken much of the pioneering work on water gas at UGI. Humphreys and Glasgow (H&G) had an agreement with UGI to use its patents and any improvements developed.

H&G became the major player in the British and European market. H&G's first contract was to build two water gas plants in Copenhagen. Its first contract in the UK was at the Belfast Corporation Gasworks in Northern Ireland. H&G established operations in London, Brussels and

New York. It was very successful and its gas plants were to be installed all over the world. By 1898, it had undertaken 91 water gas plant installation projects and by 1914 had installed 1,303 water gas plants across the world. H&G prospered until the 1960s, with many contracts from the Area Gas Boards in post-war Britain. The company diversified into petrochemicals but its fortunes declined as Britain switched to natural gas. What remains of its on-shore operations is now owned by Jacobs Engineering Group. H&G was later bought by an American company and split into on-shore and off-shore operations.



Photograph 2. Dr Alexander Humphreys and Arthur Glasgow, founders of Humphreys and Glasgow.

The Power Gas Corporation Ltd (PGC) was a very keen competitor of H&G and produced many British water gas plants. The PGC was formed by Dr Ludwig Mond to exploit his Mond Gas process patents. PGC became a major supplier of both producer gas and water gas plant (Figure 12), and later expanded into petrochemical technologies. The remains of the PGC business exist within Davy Process Technology, part of Johnson Matthey.

Many other companies produced water gas plants (e.g. R & J Dempster built Dellwik plants in the UK) and some of these are also featured in this document.

In Britain, water gas allowed the gas undertakings to meet peak gas demand whilst utilising by-product coke and enabling some control over the price of coke by reducing its supply. Most medium and large town gasworks in Britain operated water gas plant at some point during their operational history. In the north-eastern states of the USA, CWG became the pre-eminent method of gas production, being cheaper to produce than coal gas. It was often supplemented by coke oven gas, where available. Another regional variation in the USA occurred on the western Pacific coast, where coal and coke were dispensed with completely and gas was made directly from oil (oil gasification).

The water gas process generated gas through the action of steam upon red-hot carbon (generally in the form of coke). The generator (Figure 3) would be filled with fuel, ignited and brought to temperature through the 'blow' phase. Once brought to temperature, the system would enter the 'run' phase and steam would be admitted.

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

5. The 'Run' and 'Blow'

The 'run' and 'blow' were the principal components of the manufacture of water gas, each working in sequence to produce the water gas in a cyclical fashion.

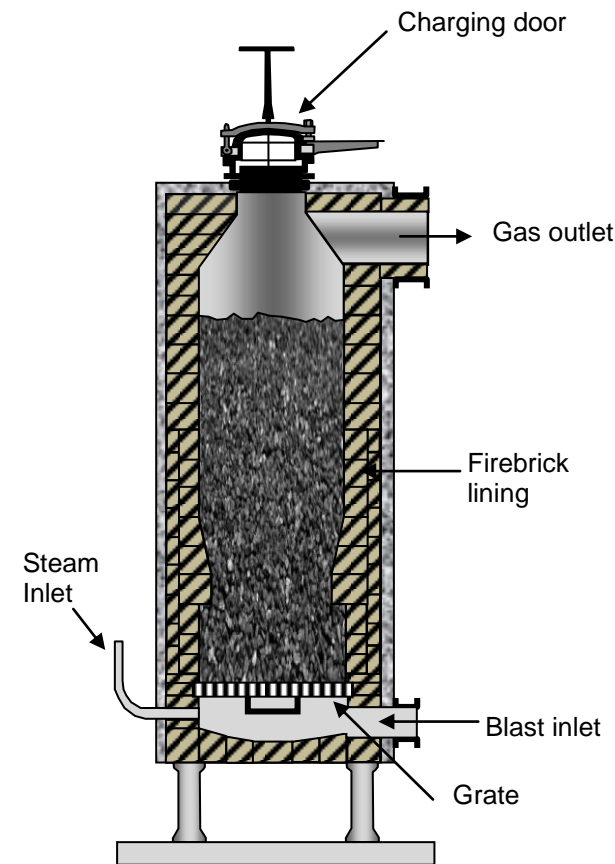
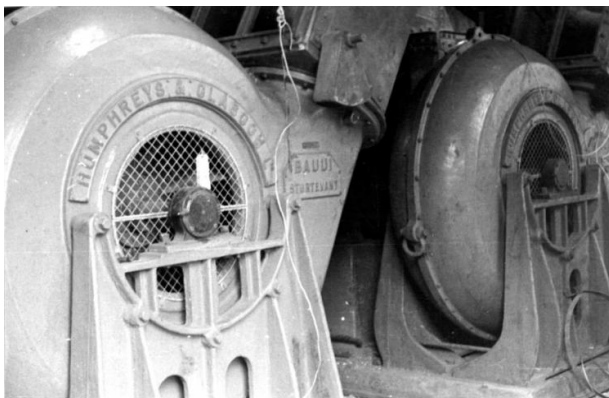


Figure 3. A hand-clinkered water gas generator, typical of those used on smaller gasworks. Source: Russell Thomas.

The objective of the blow period was to store the maximum quantity of heat in the generator fuel bed (usually coke) which could then be used in the endothermic steam:carbon reaction during the run stage.

During the blow, air was blown by fans (Photograph 3) into the base of the fuel bed, providing oxygen to allow the fuel to burn and heat the generator.



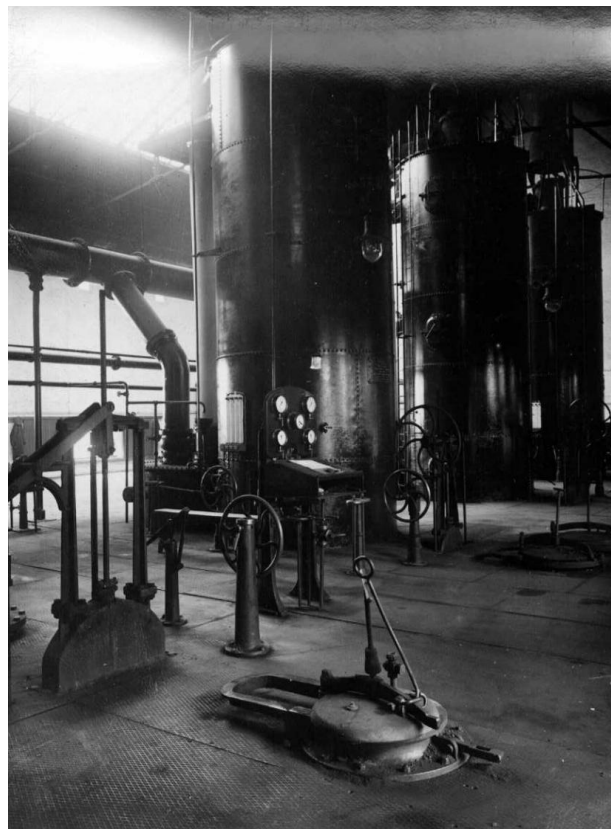
Photograph 3. Blowers (fans) used to provide the blast air on an H&G Water Gas Plant. Source: National Grid Gas Archive.

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

- (i) $C + O_2 \rightarrow CO_2$ - exothermic
- (ii) $C + CO_2 \rightleftharpoons 2CO$ - endothermic
- (iii) $2C + O_2 \rightarrow 2CO$ - exothermic
- (iv) $2CO + O_2 \rightarrow 2CO_2$ - exothermic

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

The gas exiting the generator was similar to a poor-quality producer gas which would be burnt in the subsequent carburettor and superheater, heating them. Burning carbon to carbon dioxide released about three times as much heat as when it was burnt to carbon monoxide only.



Photograph 4. The upper floor of a water gas plant. Source: National Grid Gas Archive.

As the blow proceeded, the temperature of the fuel bed rose, increasing the amount of carbon monoxide in the gas leaving the generator. The blow had to avoid excessive combustion of the carbon (coke), so the air supplied was carefully controlled.

By the end of the blow, the generator, carburettor and superheater would all be sufficiently hot for the run to take place.

During the run, steam was injected into the generator and reacted with the carbon. As the run

proceeded, the fuel bed started to cool, and gradually the proportion of carbon dioxide in the gas produced increased. This had the effect of increasing the amount of inert substances in the gas, reducing its heating qualities.

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

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

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

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

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

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

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

A schematic of the H&G water gas plant is shown in Figure 4.

Down Run

Experience showed that if steam was continually admitted to the base of the generator, the lower portion of the fuel-bed (which had continually to perform the heaviest duty of decomposing the steam) became cool and inactive over time, and the steam condensed instead of being converted into gas. The succeeding blow, therefore, further chilled the lower layers of the fuel bed instead of rekindling the fire.

To rectify this, one of the developments introduced by Dr Humphreys was the 'down run' (Figures 11 and 12). He discovered that the control of the water gas generator and also the management of the clinker could be greatly improved if the operation of the generator was periodically reversed. After every few runs, the steam was admitted to the top of the generator above the fuel and it descended through the fuel bed and was withdrawn at the bottom.

Following this, the gas flowed to the carburettor as usual.

6. Types of Intermittent Water Gas Plant

Although a wide variety of water gas plants were developed, the main difference between the plants was whether they produced raw 'blue' water gas or enriched 'carburetted' water gas (CWG). As mentioned earlier, the blue gas was purely an unenriched gas comprising primarily carbon dioxide, carbon monoxide, hydrogen and nitrogen. It derived its name from the blue colour of the flame, which gave little light.

Many plants originally built as blue-water gas plants were later retrofitted with a small carburettor, enabling them to yield enriched gas.

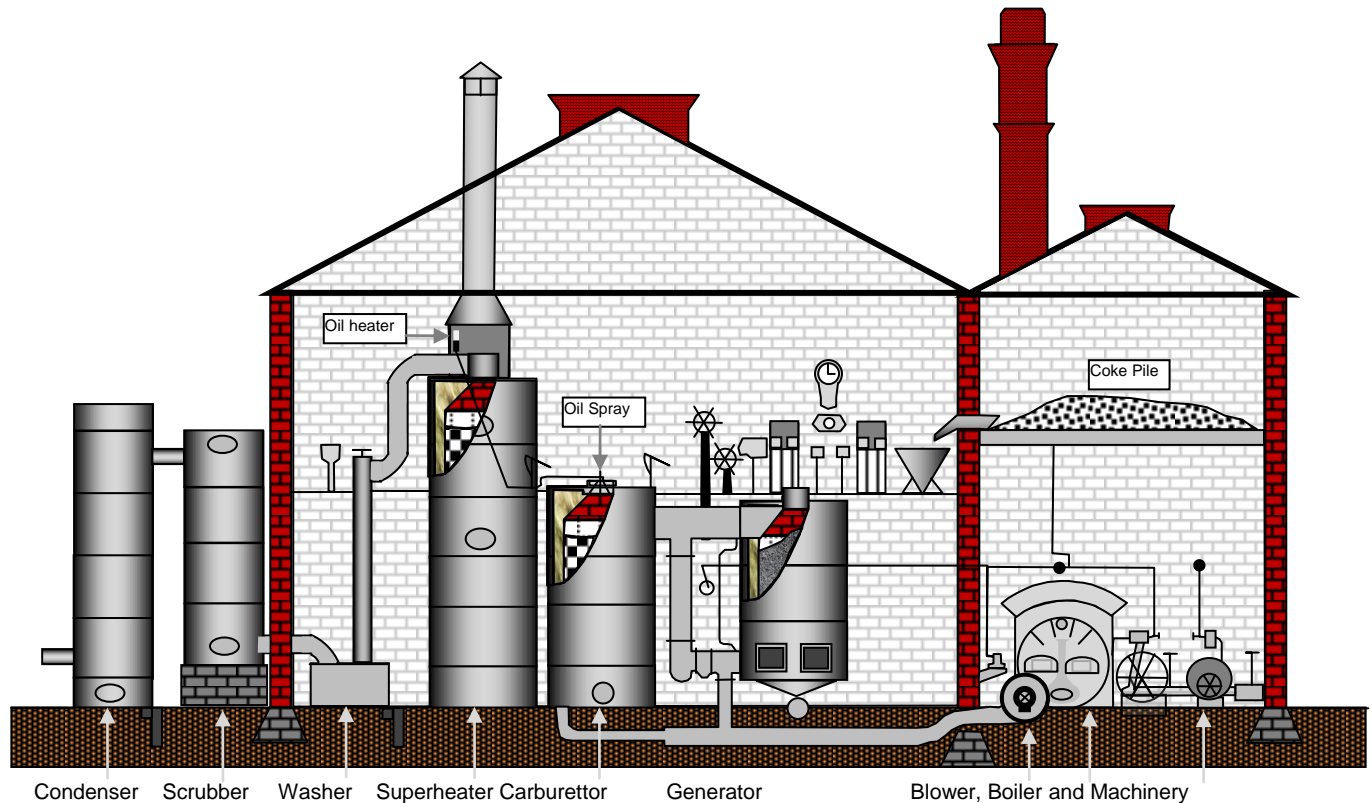


Figure 4. A schematic of a carburetted water gas system based on the Humphreys and Glasgow design. Source: Russell Thomas.

CWG was the same as raw blue-water gas which was then enriched by oil (and in some cases resin or tar) to improve its calorific value and illuminating power. This enriching process is described in more detail in sections 10 and 11.

Blue-water gas had a calorific value of 10.8-11.1 MJ/m³ or 290-300 Btu/ft³ (British Thermal Units per cubic feet were the standard units of measurement at the time). The enriched CWG had a calorific value of approximately 14.1-18.6 MJ/m³ (380-500 BTU/ft³); by comparison, natural gas which is currently used in Britain has a calorific value of between 37.5-43.0 MJ/m³ (1009-1154 BTU/ft³).

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

Later, when illumination was not so important, unenriched blue gas became more popular, especially at times when oil costs were high.

7. Blue-Water Gas Plants

Two popular blue-water gas plants were those built by Kramers and Aarts (K and A, Figure 5), and the Dellwik plant (Figure 6).

The K and A Plant (Figure 5) had two generator vessels as opposed to the single generator vessel used on the Lowe-type system. During the run, the generators were used in series, while during the blow they were used in parallel; this reduced the duration of the blow to a quarter of that used on a Lowe-type plant, allowing more gas to be produced.

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

and carbon monoxide and then enter the regenerator.

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

When the plant was run again, the direction of flow through the system was reversed, making the final generator the first generator and *vice versa*. K & A plants were supplied in Britain by the K & A Water-Gas Co. Ltd. of London. The Dellwik blue-gas plant developed by Karl Dellwik produced a gas which was very similar in composition to the K and A plant, but the plant was structurally very different, using a single generator preceded by a superheater. The latter heated the steam before it passed into the generator. The gas then passed directly from the generator to the superheater, and then through a coke scrubber. Karl Dellwik was

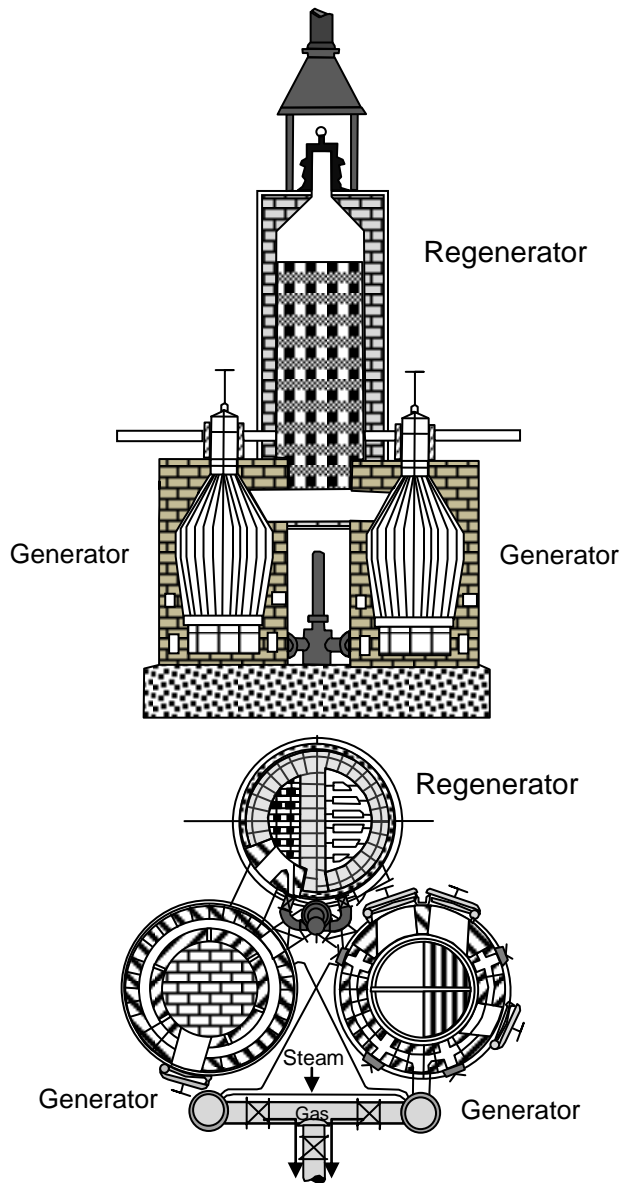


Figure 5. A schematic of Kramers and Aarts blue-gas plant. Source: Russell Thomas.

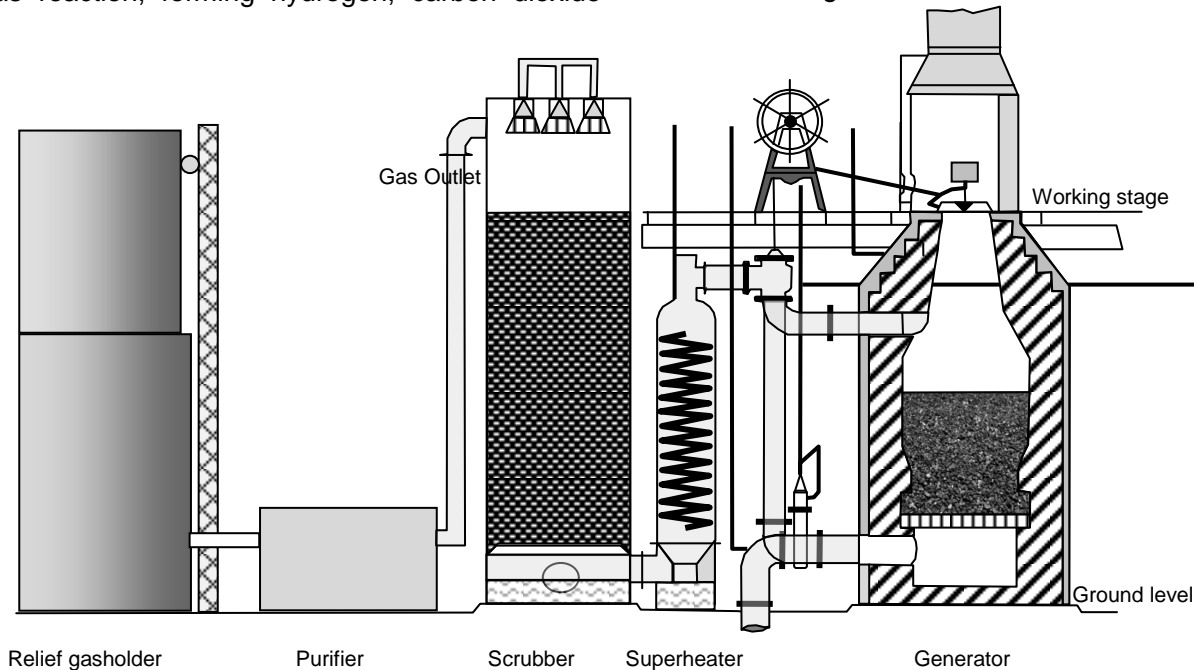


Figure 6. The Dellwik blue-gas plant. Source: Russell Thomas.

known for his work in restructuring the air supply to the water gas plant. This minimised carbon monoxide production during the blow, increasing the heat generated in the water gas plant during the blow and maximising the amount of water gas production during the run. Dellwik plants were built by R & J Dempster of Manchester in Britain.

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

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

A variation of the water gas plant was the single superheater plant (SSP) which varied significantly from the traditional layout shown in Figure 4 for the Humphreys and Glasgow plant. In the SSP, the carburettor and superheater were merged into a single large vessel, similar to the original plant developed by Lowe and shown in Figure 2. One of the benefits of this plant over the Lowe-type water gas system was the reduced capital expenditure.

8. The Operation of an Intermittent Carburetted Water Gas Plant

From looking at the figures in this document, it can be seen that there were many different configurations of a carburettor water gas plant.

There follows a description of the key plant involved in the process.

A typical CWG apparatus is shown in Figure 4, consisting of a generator, carburettor,

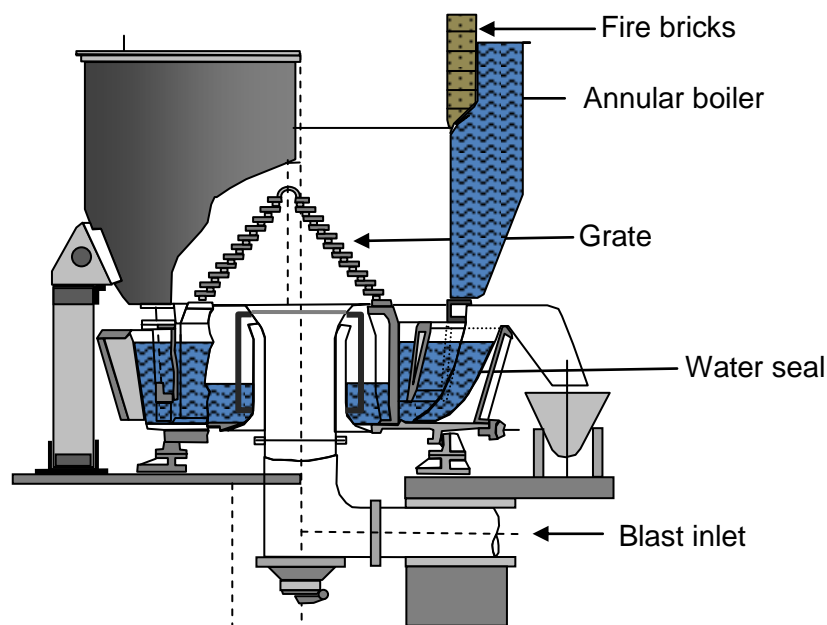


Figure 7. A water-sealed self-clinking grate.
Source: Russell Thomas.

superheater, oil heater, washer and condenser. The cylindrical generator, carburettor and superheater all looked similar, the outer shell of the units constructed from steel plates and lined with firebricks. More modern CWG plants can be seen in diagrammatic form in Figures 11 and 12. A flow diagram of the CWG process can be seen in Figure 8.

Generator

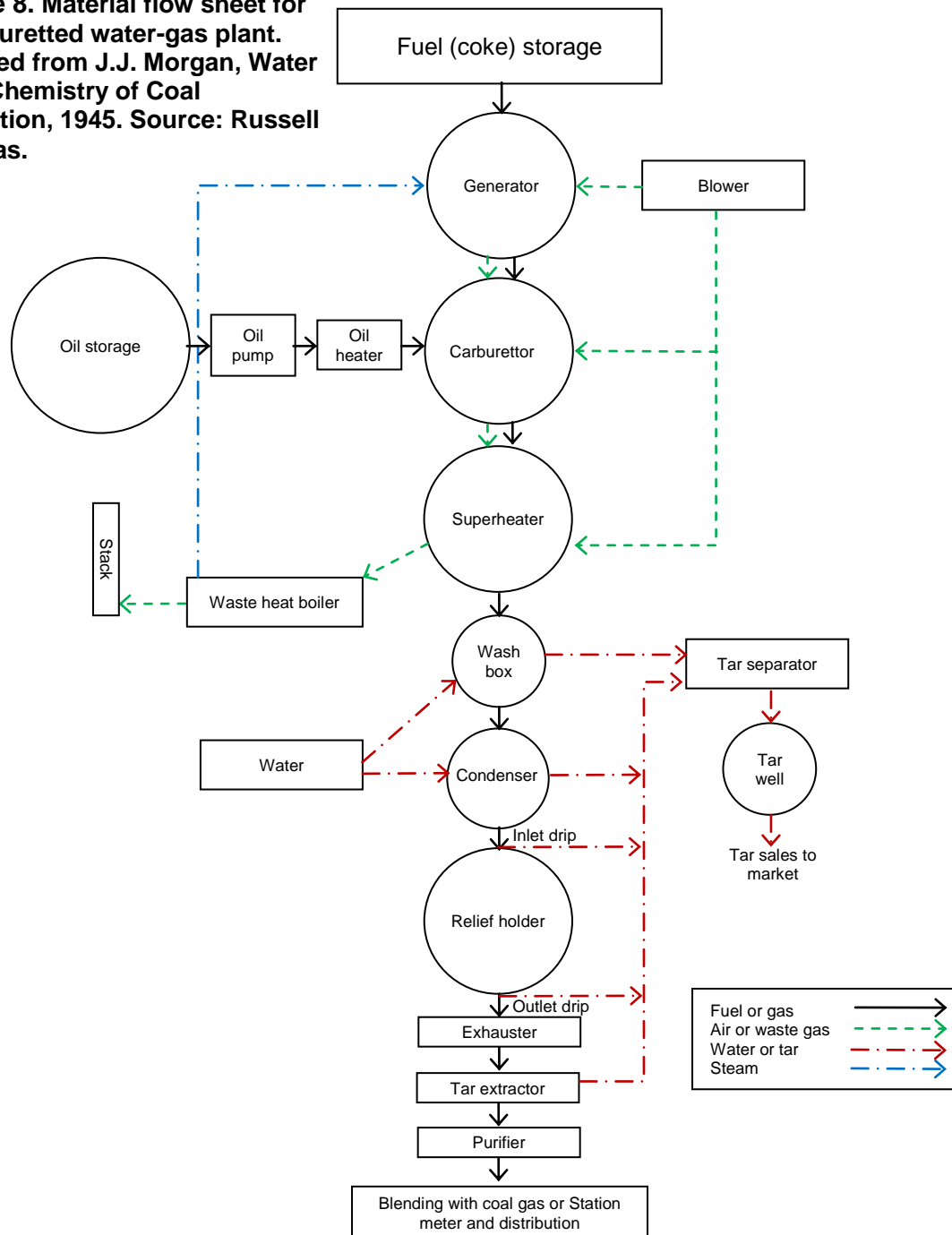
The function of the generator was to contain the fuel bed which, as described earlier, was used for heating the system and generating incandescent carbon to decompose the steam during the run. These processes and reactions have been described already so will not be described further here.

The generator was quite simple in design, being a circular vessel lined with firebricks. It contained a grate at its base supporting the fuel bed,

underneath which were two pipes, one which supplied steam and one which supplied blast air. At the top of the generator was a charging door through which fuel could be added. Below this was the outlet through which the gas was removed. The grate was a very important feature of the generator, as removing the ash could be problematic, especially if clinker formed instead of ash, as it often did. The clinker would affect the reactions in the fuel bed and reduce the amount of control which could be exerted on the system.

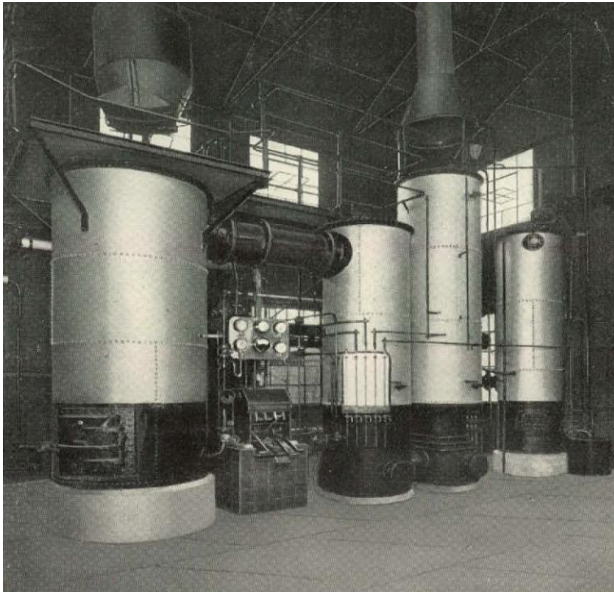
Removal of clinker by hand was very arduous and could reduce the amount of time the generator was making gas by 10%, as well as giving rise to additional unwanted heat loss. A diagram of a simple hand-clinkered water gas unit is shown in Figure 3. Most CWG plants producing over 28,000 m³ (1,000,000 ft³) of gas per day were mechanically operated with a self-clinking grate. Circa 1948, mechanically operated plant with a capacity of 280,000 m³ (10,000,000 ft³) of gas per day were routinely being used at large gasworks.

Figure 8. Material flow sheet for a carburetted water-gas plant.
 Adapted from J.J. Morgan, *Water Gas, Chemistry of Coal Utilisation, 1945*. Source: Russell Thomas.



Whilst the grate in a hand-clinkered unit was little more than a set of iron bars, a Kerperley-type grate was used in a self-clinkering unit. These had a pyramidal or cone shape appearance (Figure 7). The grate was mounted eccentrically on the generator base. The base plate and the grate rotated slowly and, as this happened, the clinker and ashes were crushed in the annulus between the grate and generator wall. The crushed ash was removed by a stationary plough dipping into the outer water seal. The base of the generator had water lutes internally and externally, providing a water seal (Figure 7). The depth of the water seal was dependent on water pressure. Where high blast pressures were used, a dry seal (Figure 9) was preferable as deep water seals could surge under high pressure.

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



Photograph 5. A small CWG plant. Source: National Grid Gas Archive.

The firebricks within the generator were prone to wear and tear, and so generators would have an inner lining (to take the wear and tear) and an outer lining (to act as an insulator) of fire bricks (Figure 3). This double layer often only extended two thirds of the way up the fuel bed, to avoid disturbing the latter.

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

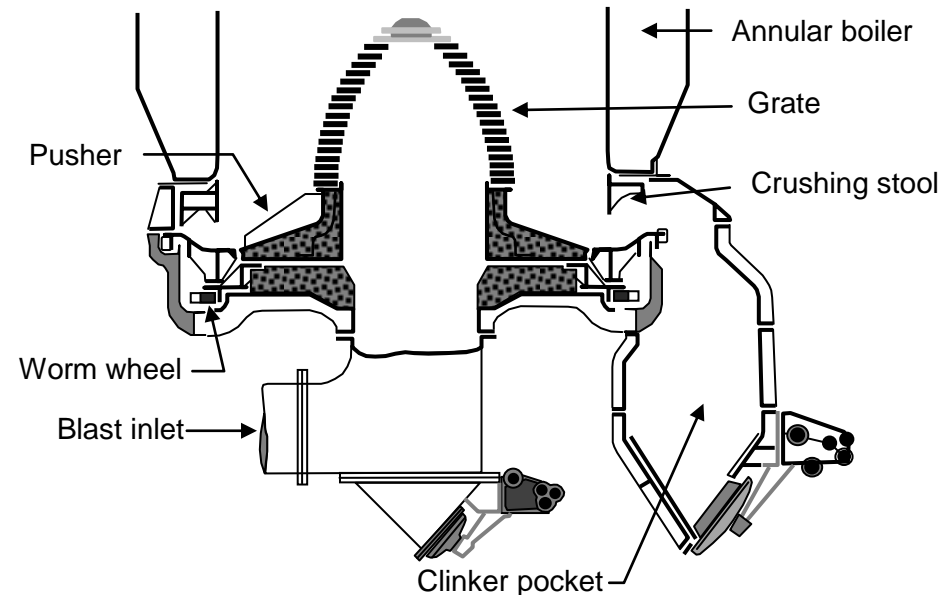


Figure 9. A Humphreys and Glasgow dry-sealed grate. Source: Russell Thomas.

Carburettor

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

It was important that both the generator and subsequent superheater were operated at the correct temperatures, the chequerboard firebrick

was maintained in good condition, and the rate of oil spray and its distribution in the generator was such that the gasification of the oil was maximised.

Superheater

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

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

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

Purification Plant

Like coal gas, water gas required purification after production. The non-carbureting water gas plant was relatively 'clean' when using coke, producing little or no tar and placing a limited burden on the purification plant. However, the CWG purification process was very demanding, given the burden of tar and oil which had to be removed from the gas. The difficulties and amount of tar produced were dependent primarily on the type of oil used and whether coke or coal was used as the fuel.

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

The Washer/Seal/Wash Box

The first part of the purification process was the washer (also known as the seal or wash box). The role of the washer was to provide a safety seal which prevented the gas from being pushed back into the superheater (by the pressure exerted by the relief holder) during the periods of the blow. Another role for the washer was to remove

considerable amounts of tar formed from CWG plant (tar formed from blue-water gas plants using coke would be negligible). As the gas bubbled through the washer, some of the residues from the gas were removed. Certain washers (e.g. Western seal tar batter) were designed with baffles and water sprays to aid tar removal.

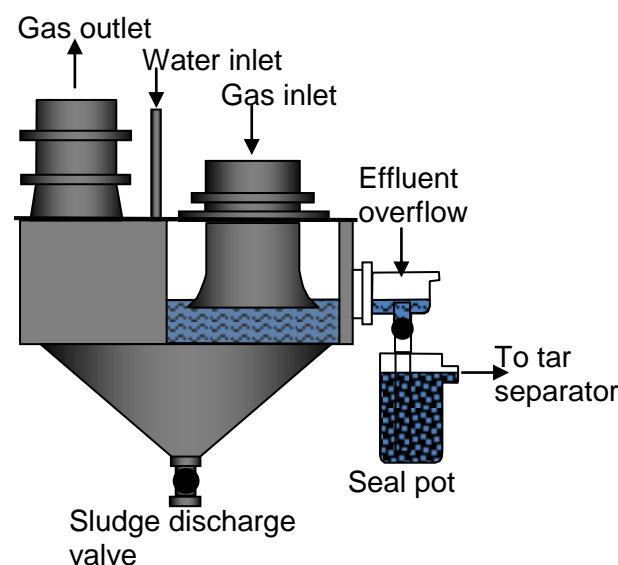


Figure 10. A cut-through diagram showing a conical-bottomed washer. Source: Russell Thomas.

Whilst operational, the water within the washer was kept hot by a continuous flow of water from the boiler. Tar condensing out would leave the washer by the effluent overflow and via the seal pot to the tar separator (Figure 10). During the run (up-run and back-run), gas would exit through the washer.

The Scrubber and/or Condenser

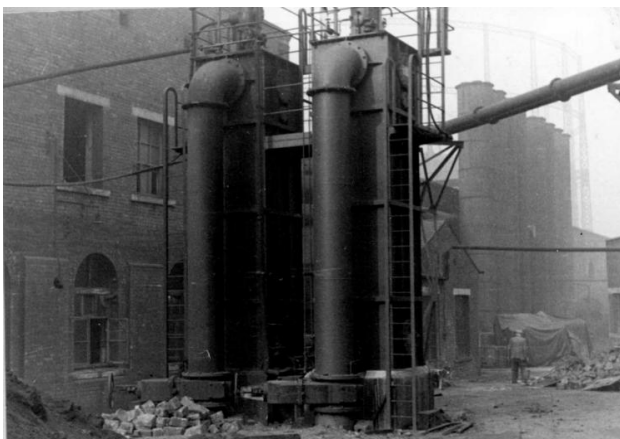
The purpose of both the scrubber and condenser was to cool the gas and remove tar, oil and any dust/free carbon which remained suspended in

the gas. A scrubber tended to be used on plants which produced below 28,300 m³ (1,000,000 ft³) of gas per day; above this volume a condenser was used.

From the washer, the gas passed into the scrubber, a cylindrical tank fitted with trays made from wood, containing coke or other inert material; this provided a large surface area, kept moist by a spray of water.

Most of the tar residues were removed here and drained to the base of the scrubber. The scrubber also cooled down the gas to a normal temperature prior to condensation. The gas was generally free from ammonia (when coke was used), but occasional traces existed and would be removed by the scrubber. Within the scrubber, the water directly cooled the gas, creating problems for the disposal of the large amounts of potentially polluted water generated.

Condensers were used with large water gas plants. The condensers could be atmospheric air cooled or water cooled (the two condensers in Photograph 6 were the latter). To cool the gas, the air-cooled condenser relied on the differential between the ambient air temperature and that of the hot gas. This process was more successful in the winter, when the outside air temperature was cold.



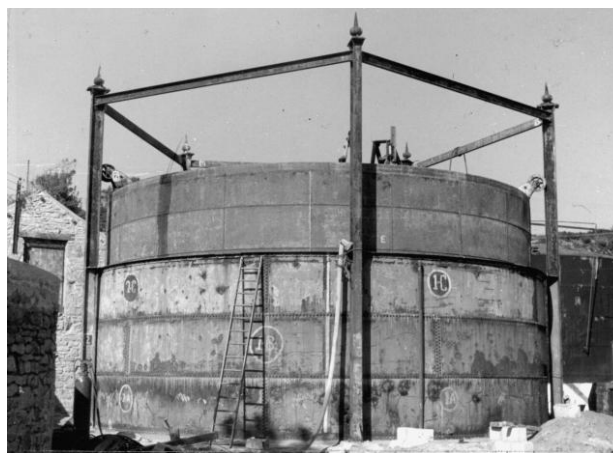
Photograph 6. Condensers used on an H&G carburetted water gas plant. Source: National Grid Gas Archive.

Within a water-cooled condenser, the gas was passed through rows of pipes cooled by water flowing in a countercurrent direction. There was no direct contact between the cooling water and the gas, so the water did not need to be treated and instead could be recycled. Later plant used more efficient and complex spiral-tube condensers. The cooled gas was temporarily stored in a relief gasholder

Relief Holder

Although constructed in the same way as a normal gasholder, a relief gasholder had a different function: to buffer the cyclical run and blow phases of gas production (Photograph 7).

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



Photograph 7. A gasholder typical of the type employed as a water gas relief holder. Source: National Grid Gas Archive.

Exhauster

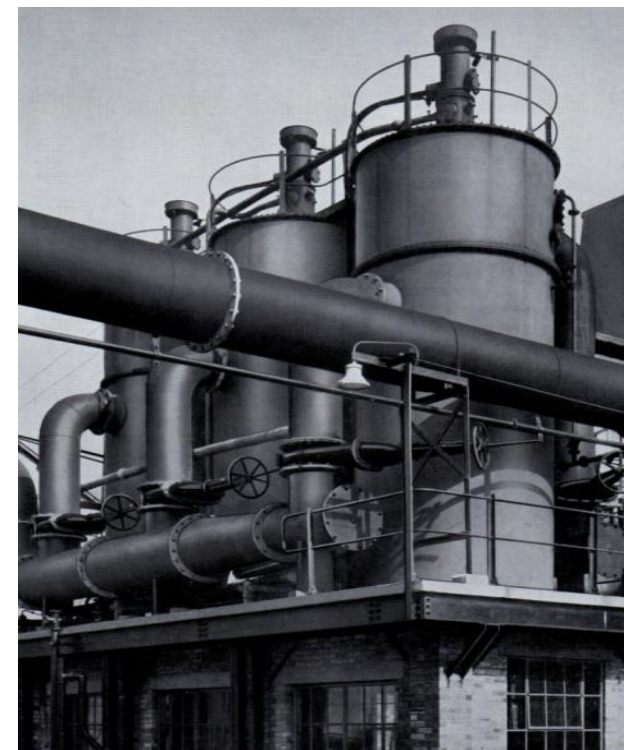
The exhauster was a gas- or steam-driven pump which would draw the gas from the relief holder and push it through the tar extractor and purifiers until finally being mixed with coal gas in the gasholders. Water gas was mixed with coal gas at a proportion of approximately 30% water gas to 70% coal gas.

Tar Extractor

Prior to tar extraction, the gas was sometimes passed through filter boxes filled with layers of coke (as they did at the Garston Gasworks in Liverpool). The coke would remove any heavy tar which remained trapped within the gas.

A range of tar extraction systems were developed, but the most popular (prior to the development of electrostatic detarrers) was a Pelouze and Audain tar extractor. This consisted of an outer cylindrical casing with the gas inlet entering through the centre of the base. A bell similar to a small gasholder was suspended over the inlet pipe and had its base sealed in liquor. This created various

perforated walls through which the gas would have to travel, providing the greatest possible disturbance to the gas and maximising the possibility for removing tar. This machine was automatic and could increase its surface area if gas flows increased.



Photograph 8. Electrostatic detarrer. Source: National Grid Gas Archive.

The electrostatic detarrer was introduced into Britain on some larger gasworks post-1930. It removed tar using an electrostatic attraction. As the gas passed through the electrostatic detarrer (Photograph 8), it was exposed to a very high negative voltage, giving the tar particles a negative electrical charge. As the gas continued through the detarrer, it was exposed to a high positive voltage. The negative charge obtained by

the tar particles would then attract them to the positive electrode, where the tar would be removed.

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

Tar Separator

Tars from the processing plant described above would be passed to the tar separator. The latter was a relatively simple device operating on the principle of gravity separation. Tar separators used on gasworks would typically be installed at least 1.8m (6ft) below ground, so the top of the separator was at ground level.

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

Tar Settling Tanks and Lagoons

The tarry emulsions which could form under certain conditions required a large storage capacity to allow the emulsions to settle. The tank of the relief holder often provided part of this storage capacity, but specific tanks were also constructed. These tanks allowed the tarry

emulsions to very gradually settle into the constituent tar and water, so the tar could be decanted off.

Difficult tar emulsions could be treated by heating, reducing the viscosity of the tar, and making it easier for the water droplets to coalesce. High temperatures were required to produce very fine particles of water. These tanks were heated indirectly by steam, and the tar and water decanted off. Heating could also be undertaken at high pressures to aid separation.

Some CWG plants used lagoons for tar settlement; including unlined lagoons constructed as a temporary measure to deal with large volumes of tarry emulsions. Being unlined, they also operated as soakaways and could be a major source of pollution. Such lagoons have been well documented in the USA, however their use in other countries is less well understood.

On larger gasworks' centrifuges, distillation units or spray baths would have been used. The former Tottenham Gasworks (UK) used both centrifuges and cyclones to separate waste-gas tars. Post-1945, chemical treatment (e.g. surfactants) to separate the tar and water phases became a regular practice.

Purifiers

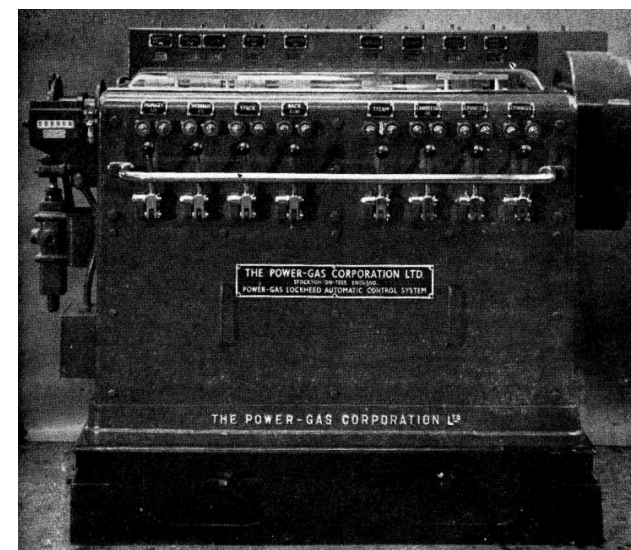
Water gas contained hydrogen sulphide and organic sulphur compounds (e.g. carbon disulphide), which required removal. This was achieved by using a purifier, a square cast-iron box supported on wooden grids and containing layers of iron oxide mixed with wood shavings. If tar reached the purifiers it was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

Waste-Heat Boiler

The blast gases from the blow phase exited the plant via a waste-heat boiler (Figures 11 and 12). This recovered some of the heat and energy from the exiting blow gases, which would otherwise be lost. This was a common feature of plant in excess of 28,000 m³ (1,000,000 ft³) per day.

Operation

Early water gas plants were manually operated. Given the cyclical nature of the process, this was time consuming and could be prone to error. To minimise the risk of mistakes, interlocking gears were developed to prevent operation at the wrong time or out of sequence. This allowed all operations (except removal of clinker) to be controlled mechanically from the raised floor at the top of the generator (Photographs 4 and 5). Later, the removal of clinker also became mechanically automated.



Photograph 9. A Power Gas carburetted water gas plant hydraulic operator. Source: National Grid Gas Archive.

As water gas plants increased in capacity, the manual effort required to operate them became so great that, in 1915, hydraulic operating systems (Photograph 9) were introduced. These systems had progressed so much by 1921 that a single centralised operating unit was introduced, automating the whole process. In the early 1920s, automatic coke-charging units were introduced, allowing continuous operation of the plant.

Up-run and Back-run

As the water gas process became more advanced and sophisticated, the run became split into two separate phases: the up-run and the back-run (Figures 11 and 12).

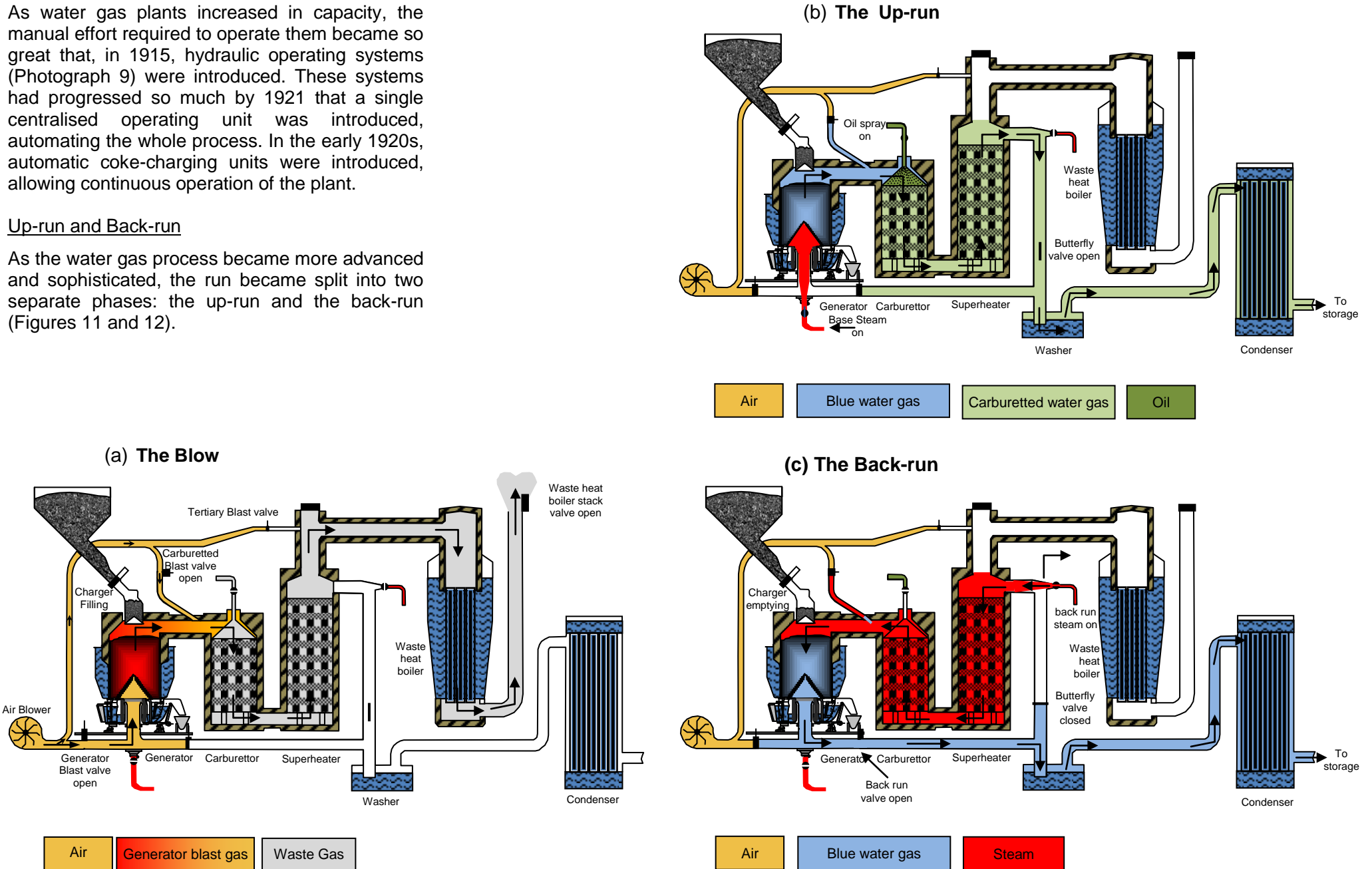


Figure 11. Operation of a water-sealed Humphreys and Glasgow type water gas plant, showing the Blow (a), Up-run (b) and Back-run (c). Source: Russell Thomas.

The up-run (Figure 12) was the phase during which all the enriching oil was added to the gas. It was the main gasmaking phase, analogous to the 'run' described earlier.

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

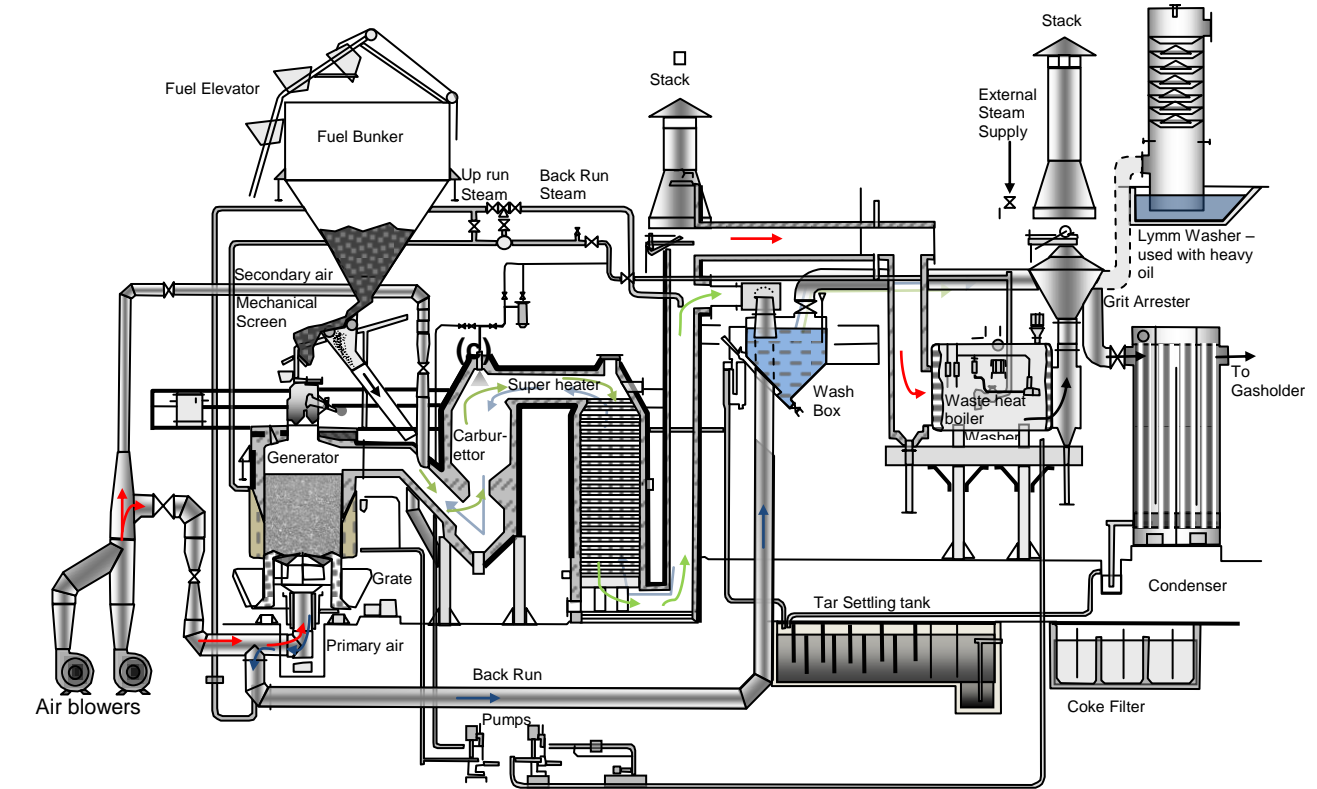
During the back-run, the plant was run in reverse. Steam was admitted to the top of the superheater, travelling down and up through the carburettor, and absorbing heat in the process. It then entered the fuel bed (generator), returning the heat and also producing blue-water gas.

9. Types of Fuel used

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

Coke

Coke was the preferred fuel source for water gas plant in Britain. Coke used for gasmaking would be egg-sized lumps of uniform coke and free from fines. If the coke was produced on a gasworks to make water gas, it would be screened to remove breeze below 2 cm (0.8 in) diameter size.



Blow → **Up Run** → **Back Run** →

Figure 12. A section through a CWG plant manufactured by the Power Gas Corporation, using reverse-flow carburettor and superheater. Source: Russell Thomas.

Denser coke would allow more fuel to be stored in the generator, but less-dense coke was thought to be more reactive. The important factors were a low sulphur content and low ash content.

Anthracite

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

Bituminous Coal

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

continued to use this coal after 1918. It presented three main problems:

- i) Reduced plant capacity due to problems associated with maintaining the burning fuel bed.
- ii) The chequer brick in the carburettor and superheater became covered in fine fuel from the generator.
- iii) Smoke generation from the incomplete combustion of the tarry matter from the coal when freshly charged.

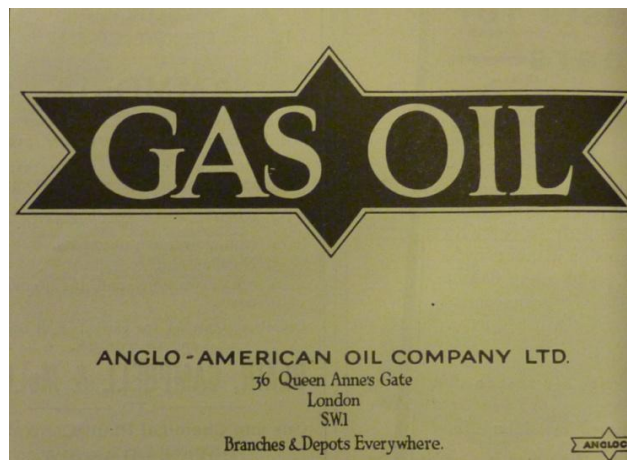
When used in the water gas plant, bituminous coal would act in a similar way to coking coals in a coke oven. Most of the activity would be confined to the peripheral edges of the fuel bed; the latter would then shrink away from the wall, forming a plastic mass in the centre of the fuel bed. This was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

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

10. Oil Feedstocks used to enrich Water Gas

The choice of oils used in CWG production was originally limited to gas oil as prescribed by Lowe. Given the fluctuations in the availability and cost

of oil feedstocks, a variety of oils were eventually used, ranging from light fractions such as naphtha to heavy fuel oils such as Bunker C or #6 fuel oil.



Photograph 10. An advert for gas oil by the Anglo-American Oil Company (circa 1920), a company set up by Standard Oil of New Jersey.

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

Across the world and in the USA in particular, different practices developed in operating water gas plants largely as a result of the availability and cost of generator fuels and oils. Gas oils became more expensive as they became in greater demand for motor vehicles. At the same time, demand for oil opened up new fields in the US Mid-Continent and Gulf Coast. These new fields contained oils with much greater asphaltic content

than the previously used paraffinic oils from Pennsylvania.

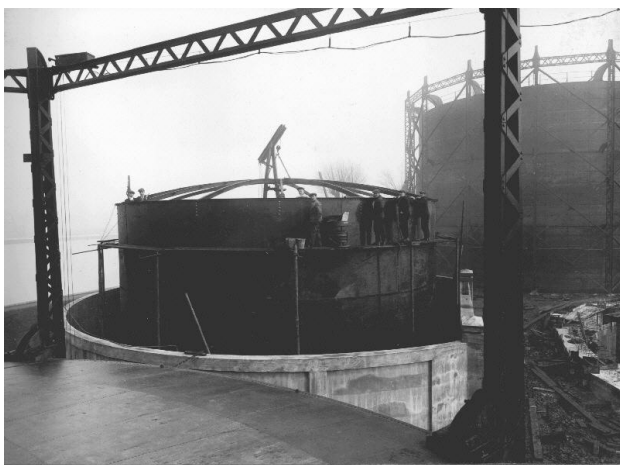
In Britain, early supplies of oil came from Russian/Azerbaijani oil fields, Romania or Scottish oil shales. Oils from the USA and Middle East became available later. As oils with a greater asphaltene content and a higher carbon-to-hydrogen ratio were used, more tar was formed. For heavy oils, as much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

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

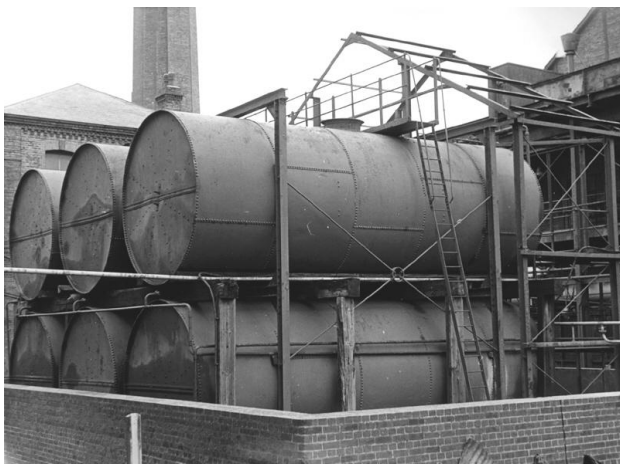
Storage of Gas Oil

Gas oil was almost always stored in above-ground cylindrical tanks constructed from steel. These tanks were generally placed vertically (Photograph 11) but could also be horizontal (Photograph 12). Some later tanks were built from reinforced concrete, and special paints were developed to make the tanks impervious to oil.

These tanks often had minimal or no bunding. Logically, the oil tank would have been located near the CWG plant, but often this was not the case. This was due to site space constraints, the practicality of importing oil to the site from roads or rail sidings, or the historical development of the site using oil tanks from previous builds of CWG plant.



Photograph 11. Construction of a traditional above-ground oil storage tank at Brentford Gasworks in 1929, showing the perimeter wall protecting the tank and the construction of the tank roof and walls. Source: National Grid Gas Archive.



Photograph 12. Horizontal cylindrical gas oil tanks at the Glynne Gap Gasworks in 1962. Source: National Grid Gas Archive.

11. Oil Gas

'Oil gas' was sometimes incorrectly used as a name for water gas, in particular CWG. This is a slightly contentious point as CWG is a combination of blue-water gas and oil gasification.

Oil gasification was first practiced in the early 19th century where gas was made from fish and vegetable oils. It was manufactured by heating the oil in an iron retort, producing a gaseous mixture of hydrocarbon vapours resulting from the direct conversion of oil into gas by thermal cracking. The oil gas would have an illuminating power of 60 to 70 candles. As with the CWG process, the cracking of the oil produced a tarry residue consisting of free carbon, light oils and high molecular weight hydrocarbons which had not been converted to gas. The gas was washed with oil to remove any hydrocarbons in a non-gaseous phase, the residue remaining as a coke. This early type of oil gas led to a number of oil gas companies being established in Bristol, Plymouth, Edinburgh and Dublin. Many soon failed and those that survived switched to coal gas production. Many of these companies were established in the European continent and were longer lived in areas where coal was not easily available.

Conventional oil gasification, as practiced in the USA, was never a popular process in the UK, as a ready local supply of oil was not available. Exceptions to this were found in areas of Scotland such as Broxburn, where the Broxburn Gas Company was established to make gas from the local oil shales.

Oil gas manufacturing processes which were popular in the USA, such as the Jones process and Hall process, used carburettors for a similar function to the CWG process: to crack the oil into

gas-phase hydrocarbons. These plants were not particularly popular in Britain, the most notable installation being at the Gloucester Gasworks. Later, catalytic oil gas plant such as the SEGAS and ONIA-GEGI did become popular at gasworks across Britain. These plants sprayed oil onto a hot catalyst to crack it into gas-phase hydrocarbons. One industry which did use oil gas in Britain was the railway industry, which produced oil gas using the Pintsch oil gas process. This was used for lighting railway carriages and stations.

Gasmaking from oil and refinery by-products became more popular with the introduction of cyclic and continuous catalytic reforming processes (Photograph 13). This complex technology is discussed in more detail in *Gasworks Profile A - The History and Operation of Gasworks (Manufactured Gas Plants) in Britain*. Reforming was a more intensive process than the typical cracking process, and would require higher temperatures and the use of catalysts. Reforming processes were generally 'clean', and did not produce significant quantities of tar.



Photograph 13. Oil reforming plant at the former Tipton Gasworks. Source: National Grid Gas Archive.

It should be highlighted that, as an added point of complexity, some water gas plants were adapted to undertake fuel bed reforming, a common practice in some parts of Britain, such as South Wales. These processes would have also produced tars where heavy oils were used and could add yet another level of complexity to understanding the implications of the types of tars produced by CWG plants.

12. Water Gas Composition

Tables 1 and 2 provide a comparison of the various types of water gas and coal gas.

Table 1. Composition of manufactured gases.

	% composition			
	Coal Gas	Carburetted Water Gas	Blue-Water Gas	Dellwik Fleisher gas
H ₂	47.0	30.3-35.0	52.0	50.8
CO	7.75	29.1-32.0	38.0	39.65
CO ₂	3.5	3.4-4.5	4.5	4.65
CH ₄	27.5	21.3-13.0	1.0	0.82
Hydrocarbons	3.5	10.0-12.3	0	0.95
N	10.5	3.1-5.3	4.3	3.83
O	0.25	0.2-0.5	0.2	0.2
Candle Power	13.5	18.0	0	N/A
MJ/m ³	19.3	21.6	11.1	N/A
BTU/ft ³	520	580	300	N/A

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

Table 2. Composition of water gas, based on data compiled in Chemistry of Coal Utilisation (1945) and Gasmaking (1965). BWG = blue water gas and CWG = carburetted water gas.

	US 1 BWG	US 2 BWG	UK 1 BWG	UK 2 CWG with gas oil	UK 2 CWG with light distillate
CO ₂	5.4	4.5	5.3	0.7	4.3
O	0.7	0.1	0.2	0.3	0.2
CO	37.0	40.7	39.2	32.7	27.0
H ₂	47.3	49.2	48.6	42.7	52.6
N	8.3	4.9	5.8	6.7	5.3
CH ₄	1.3	0.6	0.8	4.9	7.7
C ₂ H ₆	-	-	-	1.1	0.1
Hydrocarbons	-	-	-	4.9	2.6
Total heating value in MJ/m ³	10.6	11.0	10.6	14.4	14.4
BTU/ft ³	287	296	285	389	389

13. The Advantages and Disadvantages of Water Gas Systems in Gas Manufacture

The advantages of using water gas were:

1. Water gas plants required a relatively low capital outlay, estimated by the gas engineer Alwyn Meade to be about one-third of the cost of a coal gas plant.
2. The footprint of a water gas plant was considerably smaller than that of a coal gas plant, requiring only a ninth of the space, approximately. Water gas plants were effective in reacting to sudden increases in demand and could produce gas within 1-3 hours of starting operations, compared to much longer timescales for a retort bench.

3. The calorific value of the gas could be easily adjusted by regulating the amount of oil added for gas enrichment.
4. Coke use could be reduced by not having to have retort furnaces operating on a slow burn.
5. Coke could be used for water gas production; as coke was a by-product of coal-gas manufacture, it gave greater flexibility and independence with regard to coal supplies.
6. As water gas could be made from coke, the water gas plant exerted influence over the coke market, avoiding the build-up of large stocks of coke.
7. The sulphur impurities in water gas were much lower than in coal gas, between 76% and 85% less hydrogen sulphide and between 80% and 58% less carbon disulphide and other sulphur compounds.
8. Operating a water gas plant required less manual labour than a coal-gas plant.
9. The wear and tear involved in a water gas plant was less than for a horizontal-charged coal-gas plant.
10. The system was relatively flexible; it could be used with a range of petroleum-derived oils and a variety of fuels from coke to bituminous coals.

The disadvantages of using water gas were:

1. Water gas contained a very high percentage of carbon monoxide, three or four times the amount found in coal gas. Carbon monoxide is highly toxic and therefore water gas posed a greater risk of poisoning.
2. At times of high oil costs, the manufacturing costs of carburetted water

gas were higher than for coal gas. The relative costs of oil and coal varied throughout the history of the gas industry, with coal eventually losing out when the price of oil fell.

3. The process required good quality coke or it was liable to fail.
4. As the CWG process used oils, it made the water gas process much more potentially polluting, especially if using heavy oils and/or bituminous coals; these made the tar much more difficult to separate and dispose of.
5. CWG was dependent on the availability of reasonably priced oil or oil by-products.

14. Contaminants Associated with Water Gas Plants

Water gas plants posed slightly different environmental risks to traditional coal carbonisation plants. Whilst the blue-water gas process was relatively 'clean', producing little or no tar, the CWG process produced more contaminating by-products, especially water gas tars. The properties of these tars were highly dependent on the oil feedstocks used to enrich the gas.

Ash

Ash was the waste material remaining after the burning of the coke in the generator, and it was removed from the base of the same (Photograph 14). It contained heavy metals (e.g. arsenic and lead), though generally only at low concentrations, and some polycyclic aromatic hydrocarbons (PAH) such as benzo(a)pyrene. Ashes were often used for raising ground levels or on cinder paths.



Photograph 14. The base of the H&G water gas plant installed at the former Southall Gasworks. Source: National Grid Gas Archive.

Ammonia/Ammonium

Ammonia was not a problem generally associated with water gas production, as most nitrogenous components of coal which would form ammonia were removed from coke during the prior carbonisation process. Any residual ammonia forming in the gas would have been removed in the washer/seal or scrubber. Ammonia would become a more serious issue if bituminous coals were used in the generator. This situation would then be analogous to gas produced from coal carbonisation, and larger washers and scrubbers would be required to remove ammonia.

Tars

Blue-water gas plants would not generate significant amounts of tar. By comparison, CWG plants could generate significant concentrations of tars, especially if they used heavy oil to enrich the gas. The exact composition of the tar produced was dependent on many factors, the most important being the type of oil used for carburetting the gas.

In Britain, CWG plants were operated primarily with coke or anthracite (a high rank coal described earlier), but bituminous coals may have also been used. In the USA, the country where the CWG process developed into a commercial reality, coke and anthracite were used; however, there was also a tendency to use bituminous coals as generator feedstock, especially in the Midwest.

Circa 1903 there was a shift from eastern (Pennsylvanian) paraffinic oils to Texan and Californian asphaltic oils, which produced more tar. These problems were exacerbated when direct contact cooling became prevalent around 1907.

In the 1920s, there was competition from motor vehicles for gas oil, increasing its cost. For this reason there was also a tendency to use crude or other heavy oils such as Bunker C or #6 fuel oil within the carburettor. This change to heavier oils was also observed in Britain, although to a lesser degree.

Tars produced in the CWG process from coke and gas oil were not particularly voluminous or difficult to treat. Switching to heavier oil increased the amount of tar produced by up to 30% of the volume of the oil gasified. It also increased the moisture (water) content of the CWG tars, creating what came to be known as 'tar-water

emulsions'. These had greater than the 4-5% water content limit which was generally imposed by purchasers of gasworks tar (the tar distilling industry). Tar emulsions could contain up to 85% water content. To combat this issue, 'tar separators' were developed to separate the CWG tars and gas liquors, as described earlier.

Emulsions became an issue with the switch to heavier oils. Emulsions are a mixture of two or more liquids that are normally immiscible (unblendable), such as egg yolks and oil or milk.

The mixing of such fluids incorporates small particles of one into the other. In the case of CWG tar, fine droplets of water would become incorporated in the tar (the reverse could also occur). The characteristics of these tar and water emulsions could be quite different to the characteristics of the water and tar separately. As water content increased, the tars became more viscous.

It was shown in research undertaken in the 1920s and 1930s that the emulsified water droplets were surrounded by an outer layer of carbon-based particles (composed of particles of elemental carbon and pitch) and a membrane of asphaltene. These prevented the water droplets from coagulating and kept them stable within the emulsion.

These carbon particles acted as nucleation points, enabling the emulsions to form. The free carbon may have originated from fine particles of carbon exiting the generator or from smoke/soot produced when bituminous coal was used but insufficient air supplied. Alternatively, it could have been caused by using too high a temperature in the carburettor, forming carbon black from cracking heavy oils.

CWG tars are problematic in that they were often neutral Non-Aqueous Phase Liquids (NAPL), which makes them much more difficult to recover from the ground than dense or light NAPLs, as they formed the emulsions described above when agitated.

The composition of one particular CWG tar is given in Table 3. This CWG tar was produced using Russian 'Solar' type oil, probably sourced from the oilfields near Baku in the country now known as Azerbaijan.

Table 3. Composition of water gas tar manufactured using Russian oil (Royle, 1907).

Component of water gas tar	% composition by weight
Benzene	1.19
Toluene	3.83
Light paraffin	8.51
Solvent naphtha	17.96
Phenols	Trace
Middle oils	29.14
Creosote oils	24.26
Naphthalene	1.28
Anthracene	0.93
Coke	9.80
Other unidentified compounds	3.10

Sludges would form in the base of the washer as shown in Figure 10, and contained dust and grit carried over, as well as tars; these would have drained to a sludge tank prior to disposal. The main contaminants of water gas tars and sludges were:

- Aromatic and aliphatic petroleum hydrocarbons (including paraffins & naphtha).
- PAH.
- Phenolic compounds (e.g. phenol & cresol).
- Benzene, toluene, ethyl benzene and xylene (BTEX) compounds.
- Ammonia, organic and inorganic forms of sulphur, styrene, carbazole and dibenzofuran.

Spent Oxide

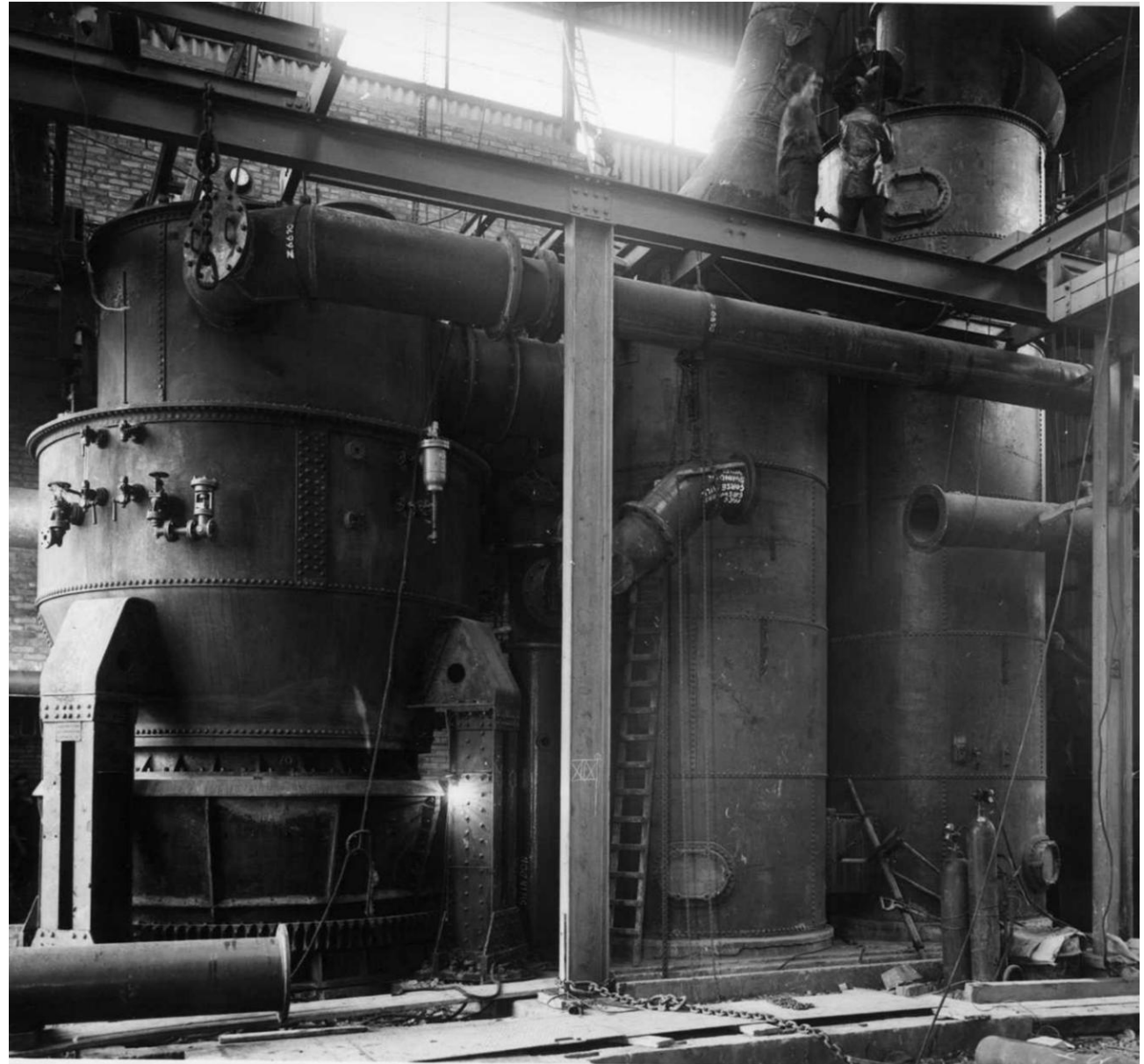
Bog iron ore, a fine granulated form of iron, was used to purify gas from water gas plants. Like coal gas, water gas would also contain hydrogen sulphide and organic sulphur compounds such as carbon disulphide, which would require purification prior to distribution. Like ammonium, the nitrogenous compounds which would form cyanide would have been removed from the coke during carbonisation, so little cyanide would be expected in the resulting spent oxide. Additionally, hydrated lime may have also been used in combination with the the iron ore in the purification of the gas.

The sulphur-saturated bog iron ore could be regenerated up to three times by exposure to the atmosphere, after which it became spent oxide, which contained about 50% sulphur. Any cyanide contained in the spent oxide would be much less than the approximate 8% cyanide found in spent oxide from coal carbonisation.

15. Selected Bibliography

Below is a selected bibliography of books which may be of interest to the reader:

1. British Petroleum – Gasmaking, 1959 and 1965, The British Petroleum Company Ltd, London.
2. Chandler, D. and Lacey, A.D. The rise of the gas industry in Britain, 1949, British Gas Council.
3. Griffith R.H., The Manufacture of Gas, Ed. Hollings, H., Volume 1 – Water Gas, Ernest Benn Ltd., London.
4. King C. Editor – Kings Manual of Gas Manufacture, 1948, Chapter 7. Water Gas and Complete Gasification, Walter King Ltd.
5. Lowry, H.H. – Chemistry of Coal Utilisation, Vol 2, Chapter 37, Water Gas, 1945, John Wiley and Sons Inc.
6. Meade, A., Modern Gas Works Practice, 1916, 1921, 1934, Benn Brothers, London.
7. Morgan, J. J., A Textbook of American Gas Practice, 1931, Published by the Author.
8. Morgan, J. J., and Stolzenbach C. F., Heavy Oil Tar Emulsions in the Water Gas Process, 1934. American Gas Association Monthly, July.
9. Odell, W., Water-Gas Tar Emulsions, Technical Paper no. 304, U.S. Bureau of Mines, 1923.
10. Royle, H.M., The Chemistry of Gas Manufacture, Crosby, Lockward and Son. London, 1907
11. Terrace, J., Terrace's Notebook for Gas Engineers & Students, 1948, Ernest Benn Ltd., London.



Photograph 15. Installation of a CWG plant at the Swindon Gasworks, showing from left to right the generator, carburetter and superheater. Source: National Grid Gas Archive.