

# Water Gas Plants

A profile of the history, processes undertaken and type of contaminants present.

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## Introduction

The history of gas production has been described in a previous article (Country House Gasworks); this particular article describes the production of gas from a specific process, called Water Gas. Water Gas plants have a lot of similarity to Producer Gas Plants also described in another article previously (Producer Gas Plants).

One of the major issues with producing 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 gas holders or alternatively by operating gas plant inefficiently so there was always gas available to meet peak demand.

As satisfying peak demand for gas became ever more problematic an alternative solution was required. The saviour in response to this problem came in the form of Water Gas. This process could produce gas much more rapidly than traditional coal based plant, allowing gas companies to satisfy peak demand in a more cost effective manner. Whilst this process was commonly employed on many larger town and city gasworks to produce gas rapidly and supplement coal gas supplies, plant was later developed for smaller gasworks.

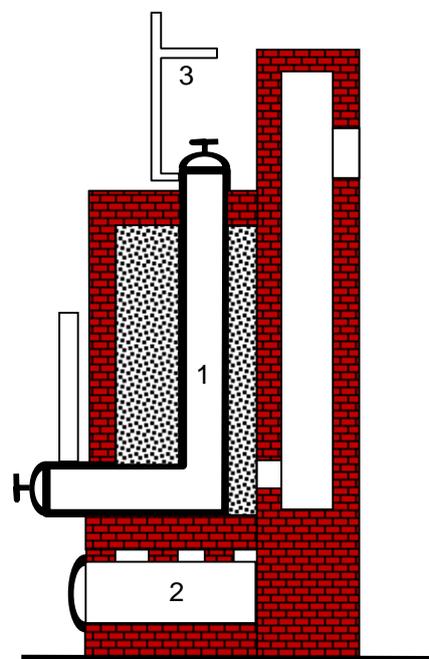
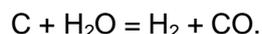


Fig. 1. The design of an early water gas plant by Dr Sanders (USA).

## The Development of Water Gas

The discovery of water gas was made by the French Chemist Fontana in 1780. He discovered that when steam was passed through incandescent carbon, the oxygen of the steam had greater affinity for the carbon than to the hydrogen it was bonded. This led to the formation of carbon monoxide and hydrogen from the water and carbon in the following reaction



Cavendish, Lavoisier, Meusnier and others soon followed the discovery of Fontana.

In 1824 Ibbotson made the first attempt to utilize 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 carbonization.

Many early attempts were unsuccessful until Gillard made major advances in his works at Narbonne in 1856. Gillard managed to light the town using blue water gas in conjunction with platinum wire mantles.

Further developments in America were undertaken by Dr. J. M. Sanders. He erected a plant in 1858 which consisted of L-shaped cast-iron retorts (Figure 1, No.1) which were externally heated by a furnace (Figure 1, No.2). The retorts were filled with charcoal and superheated steam together with melted rosin were admitted to the top of the retorts via a pipe (Figure 1, No.3).

The gas produced from the process was not stable and the retorts deteriorated rapidly which prevented the adoption of the process on a commercial scale.

## Different Types of Water Gas Plant

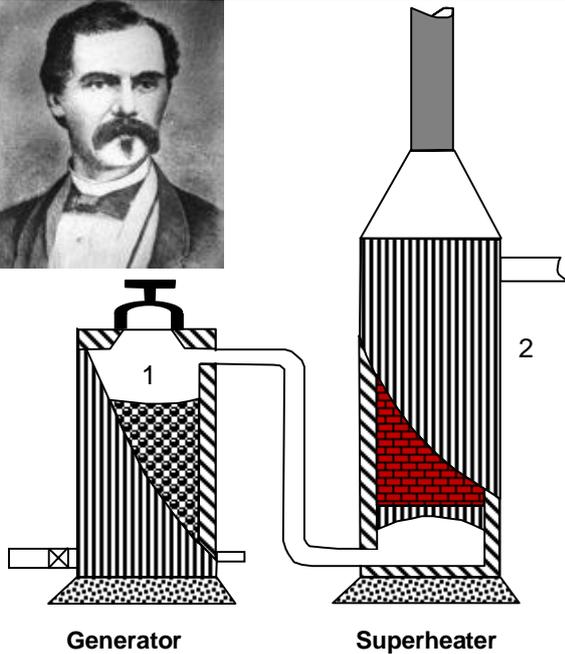
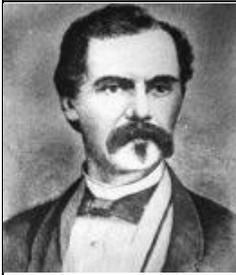


Fig. 2. The Low Water Gas system.  
T.S.C Lowe is shown in the top left

Intermittent Water Gas systems were developed in 1873 when two similar processes, were developed in the United States; the 'Strong process' and the 'Lowe process'. These systems both were based on alternate periods of "run" and "blow".

The object of the "blow" period was to store in the fuel bed the maximum quantity of heat for use in the subsequent endothermic steam carbon reaction; however, this had to avoid excessive combustion of the carbon. As the blow proceeded the temperature of the fuel bed increased, so that the amount of carbon monoxide in the gas leaving the generator also increased.

The "run" is when steam reacts with the carbon, during the run the fuel bed starts to cool, and gradually the proportion of carbon dioxide increases, which has the effect of increasing the amount of inert substances in the gas.

- (1)  $C + H_2O = CO + H_2 - 39300 \text{ cal}$
- (2)  $CO + H_2O = CO_2 + H - 300 \text{ cal}$

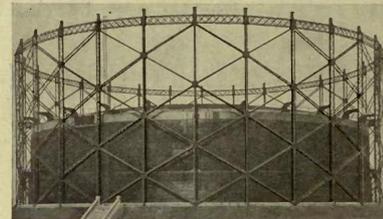
The Strong process employed a high generator made from firebrick and two secondary chambers packed with firebrick. These latter chambers, heated up during the blow, were employed as superheaters for the steam. Strong aimed purely at making a heating gas.

Thaddeus S.C. Lowe, had a different aim and set out to make a gas for illumination. The original Lowe plant design was very similar to that employed in later water gas plants. The Lowe system comprising of a generator (a brick-lined cylindrical vessel labelled 1 on Fig. 2) which was made from wrought iron. The fuel was placed in the generator on grate bars above a closed ash-pit.

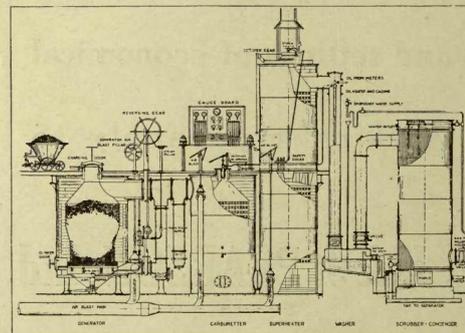
Steam and air were introduced alternately into the generator with the blue gas produced passed on to a large superheater (The vessel labelled 2 on Fig 2). The superheater was packed with firebricks.

Anthracite was the fuel commonly used, while the enriching oil was sprayed on to the top of the fuel, the gas mixture was fixed by passage through the superheater.

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WATER GAS PLANT  
BLUE OR CARBURETTED.  
COMPLETE GASIFICATION PLANTS.

The Lowe system was introduced into the UK in 1889 and was used primarily as a method to supplement coal gas at times of peak demand. It was believed that around 148 gasworks used Water Gas Plant in the UK.

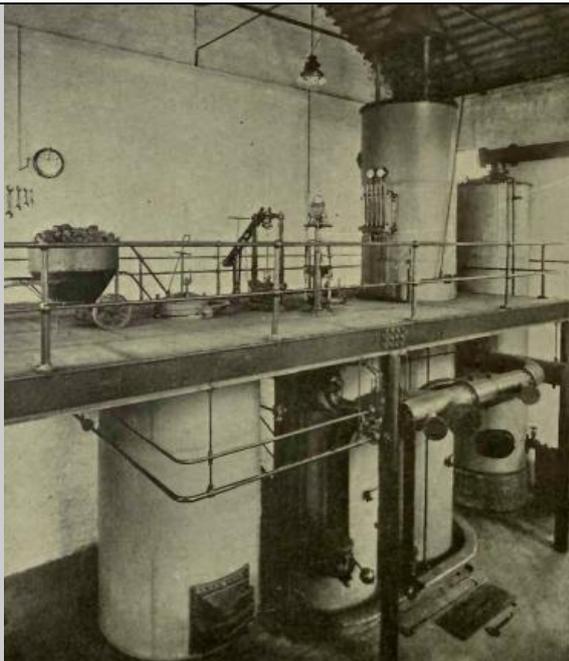
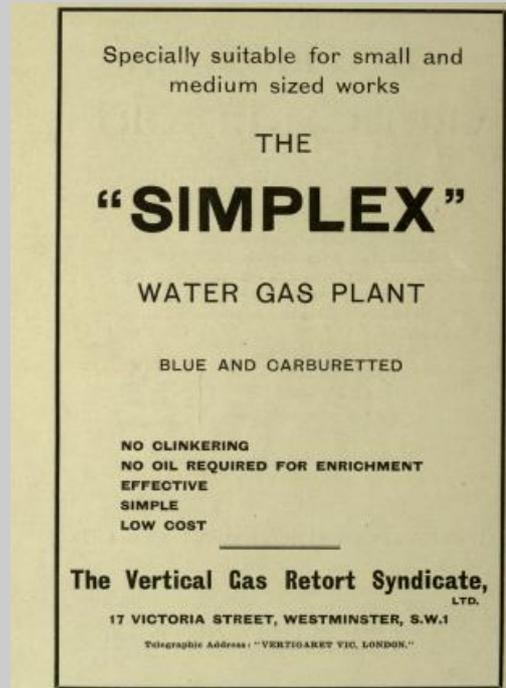
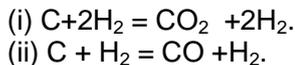
Water gas was originally seen as a cheap method of producing gas, but if CWG was to be produced its economics were dependent on the price of oil. The oil enriched gas was more important when gas was predominantly used for illumination. Later when illumination was not so important unenriched blue gas was more popular, especially at times when oil costs were high.

### How the Water Gas Process works

The process generated gas through the action of steam upon red-hot carbon (generally in the form of coke). The generator 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.

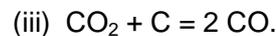
The heated carbon would act as a reducing agent for the steam as it passed through, the oxygen combining with the carbon, giving off hydrogen gas. This occurred because the oxygen had a greater affinity for the heated carbon than it did for hydrogen. The process was believed to operate as:

1. Within the lower part of the fuel bed, the water (steam) reacts with the heated carbon forming carbon dioxide, and some carbon monoxide.



A Small water gas plant as built by Humphreys and Glasgow.

2. As the carbon dioxide gas passed up through the bed of coke it was reduced by further hot coke:



The formation of carbon dioxide and carbon monoxide could be influenced through 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.



## The Manufacture of Water Gas

According to "Modern Gasworks Practice" systems for making water gas could be classified under the following 3 headings: (1) The Intermittent System; (2) The Continuous System; (3) The Neat-Oxygen Method.

The intermittent process, with "run" and "blow" phases succeeding each other at regular intervals was the most widely used and thought to be the only practicable method.

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 firing) and enable the continuous production of gas, practical difficulties due to radiation and general inefficiency.

The third system was the Neat Oxygen Method which produced a gas practically free from nitrogen, but contained from 65 to 70 per cent 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, however, its drawback was the difficulty obtaining pure oxygen economically.

## Types of Water Gas Plant

Although a wide variety of different water gas plants were developed, the main difference were whether the plants used an enriching phase (i.e. carburetting plants) or not (i.e. "blue" gas plants). There was crossover between the two plants as Carburetter Water Gas (CWG) Plants could produce "blue" gas and plants without enriching processes were often later retrofitted with a small carburetter, which enabled them to yield enriched gas

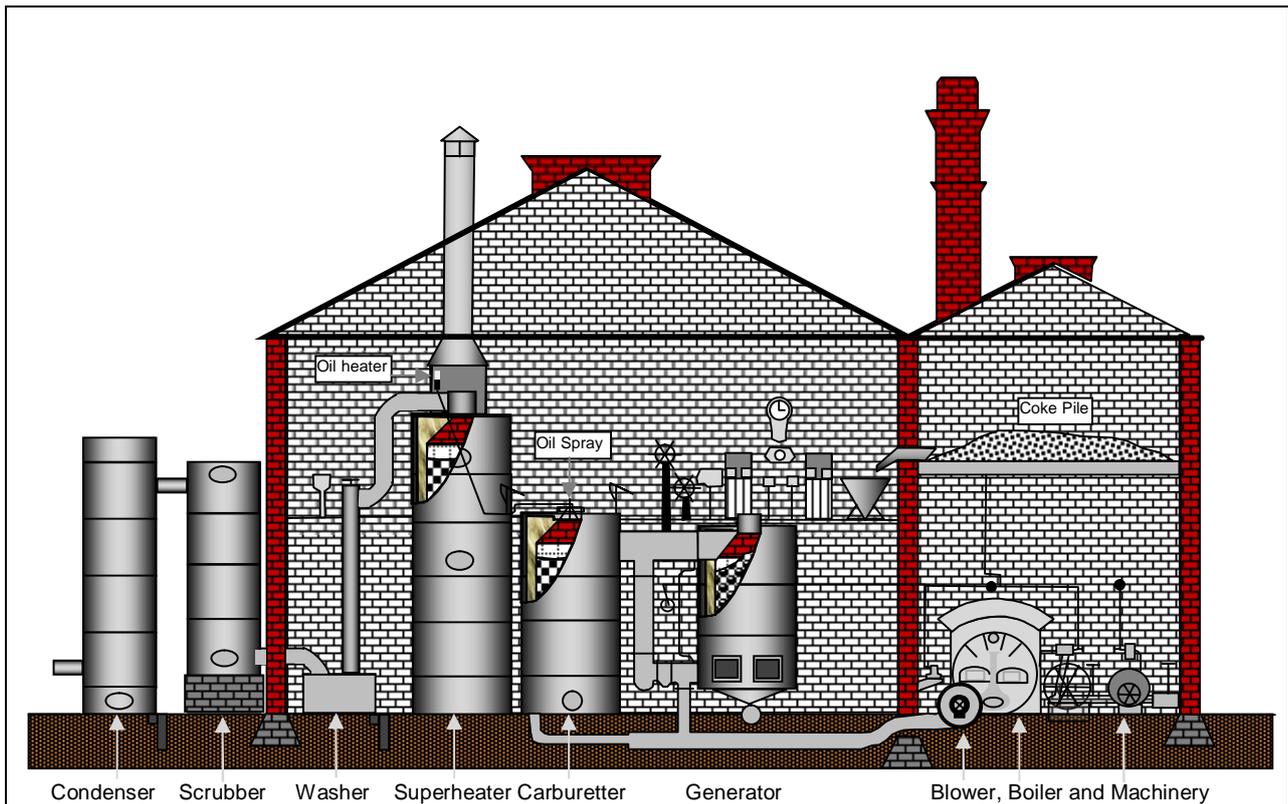
As mentioned previously Carburetter Water Gas was originally developed in the United States by T.S. Lowe, and when introduced into the UK, it was improved on by Humphreys and Glasgow, their system gaining the greatest popularity of the CWG plants.

The CWG apparatus is shown in Figure. 3 and consisted of a generator, carburetter, superheater, oil-heater, washer and condenser. The cylindrical generator, carburetter and super-heater all looked similar, the outer shell of the units constructed from steel plates and lined with firebricks. An annular 2 inch space packed with a material such as slag wool was located between the steel shell and the firebrick lining, to minimise heat loss.

Coke was taken by barrow from the coke pile and loaded into the generator through a circular opening sealed by a door in the top. When the generator required emptying then clinker was removed from the base via the two (iron) doors shown.

**Generator.** The purpose of the generator was to produce the pure water gas, predominantly composed of hydrogen and carbon monoxide as described previously using the "run" and "blow" phases. From the generator the gas passed into the carburetter. The Generator was filled with coke to a depth of between 7 and 10 ft, although this was dependent on the process.

**Carburetter.** Both the carburetter and superheater were filled with firebricks which were arranged in a chequerboard pattern, drawing the blow the firebrick in both were heated by the hot gases from the generator. In the carburetter the surface of the brick provided an extensive heating surface for the permanent gasification of the oil. A centrifugal oil spray was fitted in the top of the carburetter, oil was supplied from a gas oil tank, using a steam pump and passing through an oil heater located in the outlet pipe from the superheater.



**Figure 3. A schematic of a Carburettor Water Gas system based on the Humphreys and Glasgow design.**

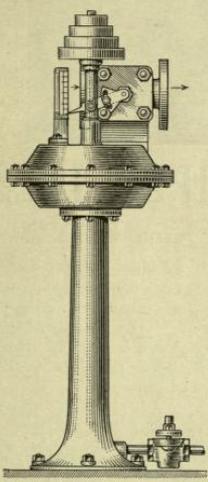
**Superheater.** The superheater was very much a continuation of the carburettor process of fixing the gas. A stack valve was located at the top of the superheater, which was opened during the "blow" during the "run" phase this valve was closed, and the carburetted gas made its way through the remainder of the apparatus (washer, scrubber and condenser).

**Seal/washer.** The role of the seal/washer, was to provide a safety seal which precludes the gas from being pushed back into the superheater (by the pressure thrown by the relief holder) during the periods of the "blow". The water within the washer was kept hot by a continuous flow from the boiler. As the gas bubbled through the seal/washer some of the residues from the gas were removed.

The purpose of the scrubber and the condenser was to remove tar and oil which remained suspended in the gas.

**Scrubber.** From the seal/washer the gas passed into the scrubber, a cylindrical tank fitted with wooden trays or other inert material with a high surface area and 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 the gas down to a normal temperature prior to condensation.

## WATER GAS PLANTS



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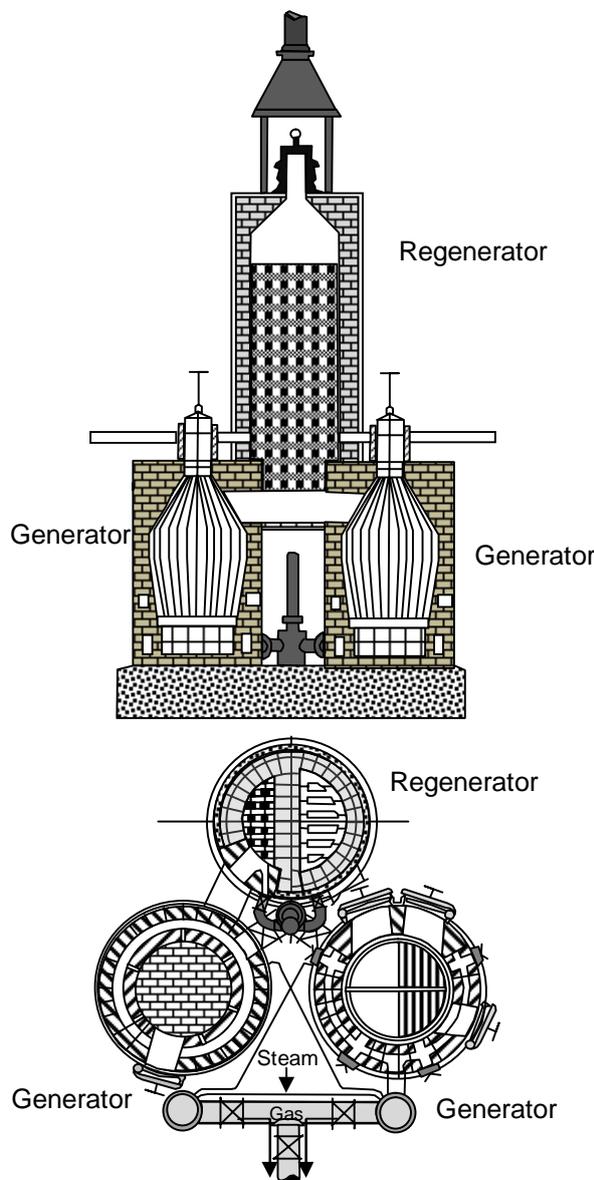


Figure 4. A Kramers and Aarts Blue Gas Plant.

**Condenser.** The gas was passed through rows of water cooled pipes which removed remaining tar from the gas and cooled it prior to storage in the relief gasholder.

**Purifiers.** Any hydrogen sulphide or trace concentrations of cyanide would be removed by the purifiers, metal boxes filled with bog iron ore.

**Relief Holder.** The gas was finally stored in the relief holder (often a old gasholder, which has been reused). Here gas was stored until it was mixed with coal gas prior to distribution.

All operations except the removal of clinker were controlled mechanically from the raised floor level, which was level with the top of the generator.

On some plant steam could be admitted either below or above the coke-bed via a two-way pipe, previously referred to, is employed. Experience showed that if steam was continually admitted to the base of the generator, in time the lower portion of the fuel-bed, which had continually to perform the heaviest duty of decomposition, became cool and inactive, the steam condensed instead of being converted into gas. The succeeding "blow" therefore, instead of rekindling the fire, chilled the bottom layers of the fuel stack. To rectify this, after every few runs the steam was admitted above the fuel and it made its way downwards, following this the gas flowed to the carburetter.

An alternative variation of the CWG plant was the single superheater plant (SSP) which varied significantly from the plant described above. In the SSP the carburetter and superheater were merged into a large single vessel. One of the benefits of this plant over the Lowe type system were a reduced capital expenditure.

Benefits were also derived from introducing the oil through 3 different sprays at an intermediate point in the superheater and against the flow of gas. This caused the most volatile components of the oil to vapourise into the gas immediately whereas the higher molecular weight oils descended to the base of the vessel prior to being carried on the flow of gas from the base to the top of the superheater.

### "Blue" Water Gas Plants

The two most popular "Blue" Water Gas Plants were the plant built by Kramers and Aarts (K and A) and also the Dellwik plant.

The K and A Plant 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 and during the "blow" they were

used in Parallel, this allowed the duration of the “blow” to be reduced to ¼ of a Lowe type plant and 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” steam was introduced into one of the generators where it would be converted into carbon dioxide and carbon monoxide and then enter the regenerator. Within the regenerator the steam was split up and the gas superheated, from here the gas passed through to the second generator where the carbon dioxide would be reduced to carbon monoxide. When the plant is run again the direction of flow through the system is reversed, making the final generator the first generator and *visa versa*.

The Dellwik blue-gas plant (Figure 4) produced a gas of a very similar composition to the K and A plant, but the plant was structurally very different, using a single generator which was preceded by a superheater, this 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.

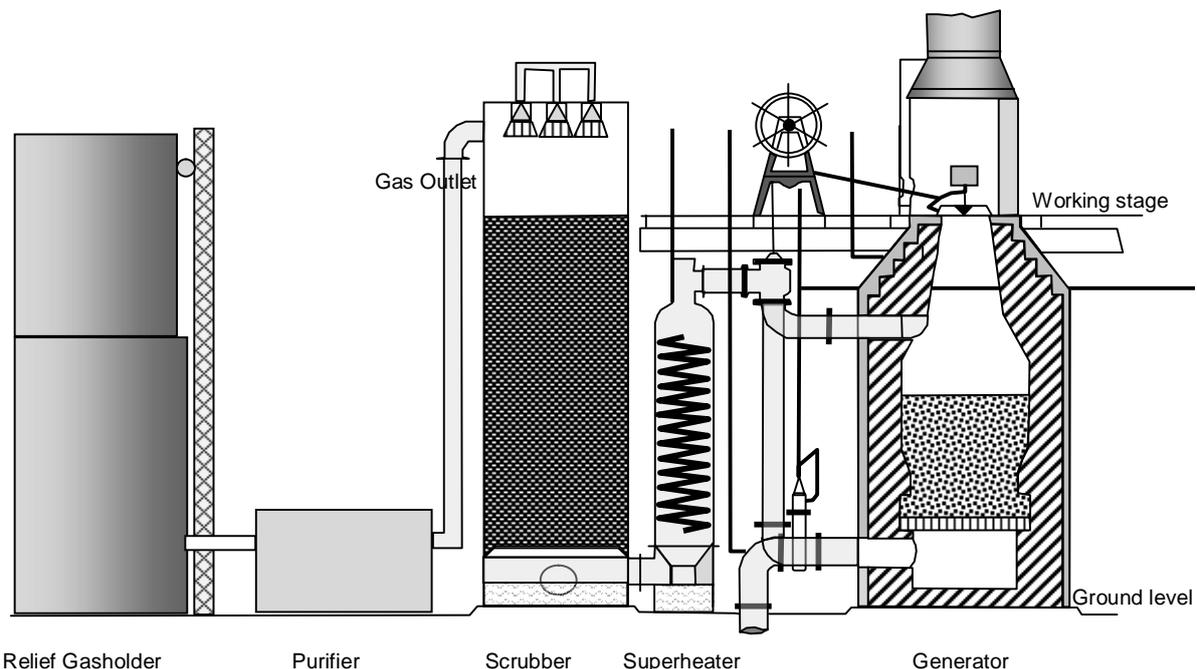


Figure 4. The Dellwik blue-gas plant

The Simplex plant (Figure 5) was designed as a low cost method to produce gas quickly; it was primarily suitable for smaller gasworks. Unlike other Water Gas Plants which used oil in the Carburetter, the Simplex plant used tar. The Simplex plant was also built without the use of an outer steel shell, just brickwork. The layout of the Simplex plant can be seen in Figure 5.

## Gas Oil

Gas Oil used for the enriching of water gas was a product of the petroleum industry, although in some cases such as the simplex plant, coal tar was used for enriching the gas. During the time that water gas plants operated in the UK the worlds oil industry was just emerging and supplies were limited. Oil supplies coming originally from Russia, Galicia (now Poland), Romania (poor quality) and Scottish oil shale prior to new supplies being available from the massive Standard Oil Company of the USA which supplied oil to the UK through the Anglo-American Oil Company. Once available the American gas oils were used preferentially. Gas oil was a very dark, heavy oil with the odour of lubricating oil. Gas oil generally consisted of all those petroleum fractions above Decane, which remained after the petroleum fraction had been removed. In general 1 gallon of gas oil would yield between 70 to 90 CuFt of gas.

Gas oil was almost always stored in cylindrical tanks constructed from steel. In some cases later tanks were built from reinforced concrete, issues were encountered from making the tanks impervious to oil, but special paints were developed to achieve this.

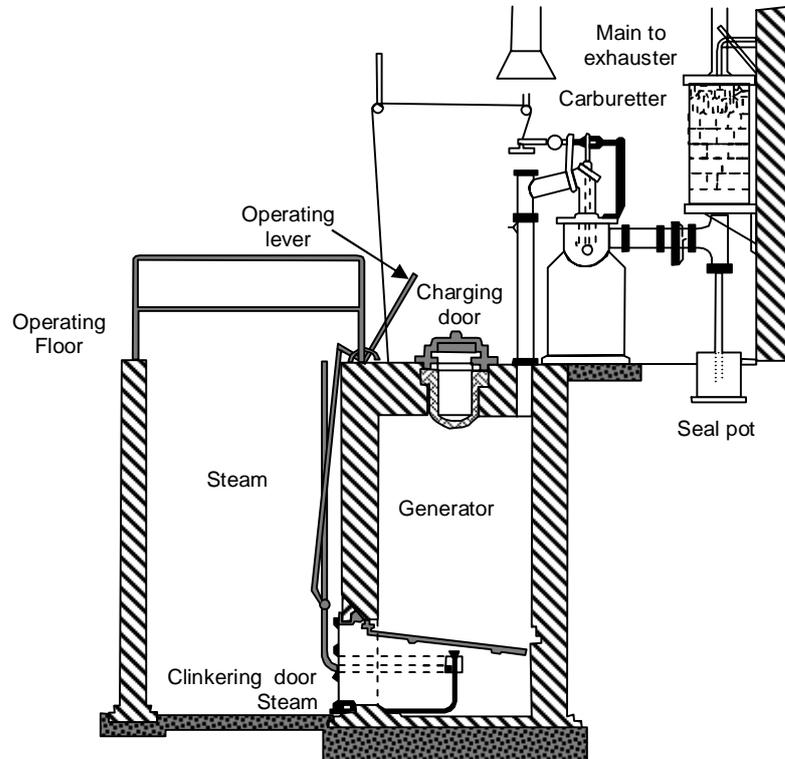


Figure 5. The Simplex Water Gas Plant.

## Oil Gas

Oil Gas was sometime incorrectly used as a name for carburetter water gas. True Oil Gas was manufactured in an iron retort and produced a gaseous mixture of hydrocarbon vapours resulting from the direct conversion of oil into gas, it would have an illuminating power of 60 to 70 candles. The Peebles and the Pintsch processes were both oil gas processes. The gas was washed with oil removing any non gaseous vapours, the residue remaining behind as a coke. In the British Isles oil gas was first made using whale oil in the 1820's at gasworks such as Bristol and Dublin, many of these operations failed and soon reverted to coal. Later on oil gas was made when sources of oil became available from sources such as Scottish shale oils or in situations where mineral oil was obtained with some difficulty animal or vegetable varieties.

## The Advantages and Disadvantages of Water Gas Systems in Gas Manufacture

The advantages in using water gas were:

1. Water gas plants required a relatively low capital outlay, estimated to be about one third of the cost of a coal gas plant ;
2. The ground required for a water gas plant was considerably smaller than that required by a coal gas plant, up to a ninth of the space was required.
3. Water gas plants were effective at reacting to sudden increases in demand and could produce gas within 3 hrs of starting operations, as opposed to three days for a retort bench.
4. The gas quality could be easily regulated to meet the demand of the time.

5. Coke could be used for water gas production and as coke was a by-product of coal gas manufacture it gave greater flexibility and independence with regards 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 stock 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. Water gas plants required less manual labour than a coal gas plant to operate.
9. The wear and tear involved in a water gas plant was less than for a horizontal charged coal gas plant

The disadvantages of using water gas were:

1. Water gas contained a very high percentage of carbon monoxide, three or four times as much as that to be found in coal gas.
2. At time of high oil costs the manufacture of carburetted water gas was greater than that of coal gas. The relative costs of oil and coal varied throughout the history of the gas industry with coal eventually losing out with the reducing price of oil.
3. The process required good quality coke or it was liable to fail

### The composition of water gas

The impurities in water gas consist of sulphuretted hydrogen and carbon disulphide. The gas was generally free from ammonia, but occasional traces of this would be found.

	% composition				
	Coal Gas	Carburetted Water Gas	"Blue" Water Gas	Carburetted Water gas	Dellwick Uncarburetted
Hydrogen	47.0	35.0	52.0	30.3	50.8
Carbon monoxide	7.75	32.0	38.0	29.1	39.65
Carbon dioxide	3.5	4.5	4.5	3.4	4.65
Methane	27.5	13.0	1.0	21.3	0.82
Heavy hydrocarbons	3.5	10.0	0	(Illuminants)12.3	0.95
Nitrogens	10.5	5.3	4.3	3.1	3.83
Oxygen	0.25	0.2	0.2	0.5	0.2
Candle Power	13.5	18.0	0	N/A	N/A
Calorific Power gross per Cuft	520	580	300		

### Contaminants Associated with Water Gas Plants

Water gas plants were not as contaminating as traditional coal gasification plants this was primarily because the feedstock fuel used was coke. The process however, still produced tar when the Carburetted water gas plant was used and purification was still required to remove sulphur and any trace cyanide concentrations. Contaminants associated with water gas production include.

#### **Ash**

Ash was the waste material remaining after the burning of the coke in the generator; it contained heavy metals (e.g. As, Pb, Cu, Cd, Ni, Zn) though generally only at low concentrations and some PAH such as Benzo(a)pyrene. Ashes were often used for raising ground levels or for use on cinder paths.

#### **Tars.**

Significant concentrations of tars were produced by CWG plants. The exact composition of the tar produced was dependent on many factors the most important being the type of water gas process

operated and the type of feedstock used for carburetting the gas. Water gas tar had a similar specific gravity to water and was prone to forming emulsions. The tar had a low concentration of free carbon and was almost absent of phenol or naphthalene. Large amounts of Paraffins are also found in water gas tars. A couple of examples of the composition of CWG tar are given in the table below.

Water gas tar (sp. gr. 1.055) 1000 gallons = 4546 litres. 0.25% free carbon		
Water	40 Gallons - 181.8 Litres	35 Gallons - 159.1 Litres
Benzol	5 Gallons - 22.7 Litres	0.75 Gallons - 3.4 Litres
Toluol	10 Gallons - 45.4 Litres	13.5 Gallons - 61.3 Litres
Solvent naphtha	6 Gallons - 27.2 Litres	28 Gallons - 127.2 Litres
Heavy Naphtha	65 Gallons - 295.4 Litres	14.5 Gallons - 65.9 Litres
Creosote	500 Gallons - 2273.0 Litres	539 Gallons - 2450.3 Litres
Naphthalene	Trace	
Tar Acid	Trace	
Heavy Oil	180 Gallons - 818.2 Litres	
Anthracene	Trace	
Pitch	1 ton 6 cwt - 1.314 tonnes	1 ton 18 cwt - 1.926 tonnes
Source Modern gasworks Practice 2nd Edition 1921		

The main contaminants of concern are:

- Polycyclic aromatic hydrocarbons (PAH),
- Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) compounds,
- Aromatic and aliphatic Petroleum hydrocarbons.
- Paraffins

Water gas tar was sometimes used in naphthalene washers to removed naphthalene from gas, in this application tar with a high naphtha content and low naphthalene content was required.

Although Coke was almost always used in water gas production, in some circumstances other feedstocks may have been used which would have a higher concentration of volatile hydrocarbons such as anthracite or other forms of coal.

### **Spent Oxide**

Sulphur and cyanide compounds were removed originally by precipitation with bog iron ore mixed with sawdust within a metal box called a purifier. Gas was passed through the purifier box until saturated with sulphur, after which it was removed from the box and left to revivify by exposure to the atmosphere and replaced back in the box. The process was repeated a number of times until the bog iron ore was termed "spent" oxide (contained 50% sulphur). The iron ore removed the hydrogen sulphide and hydrogen cyanide from the gas by precipitating it as iron sulphide and iron ferricyanide. The bog ore would be laid on oak grids inside the boxes in layers 12 inch to 18 inch deep.

Spent Oxide may be found in the ground near the purifiers and land used to revivifying the spent material. They may also be found anywhere that ground levels have been made up.

### **Ammonia/Ammonium**

Ammonia generally was not a problem associated with Water Gas Production as ammonia was removed from coke during its production from coal. Any remaining ammonia would have been removed in the washer/seal or scrubber.

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