Gasworks Profile B: Gasholders and their Tanks

A profile of the construction and operation of different types of gasholders, their associated tanks and their occurrence on former gasworks and gasholder station sites.

Supported by

PARSONS BRINCKERHOFF

nationalgrid

CL:AIRE

Gasworks Profile B: Gasholders and their Tanks

Contents

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.

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 is grateful to fellow members of the Institution of Gas Engineers and Managers Panel for the History of the Industry and the staff of the National Grid Gas Archive for their kind assistance.

1. Introduction

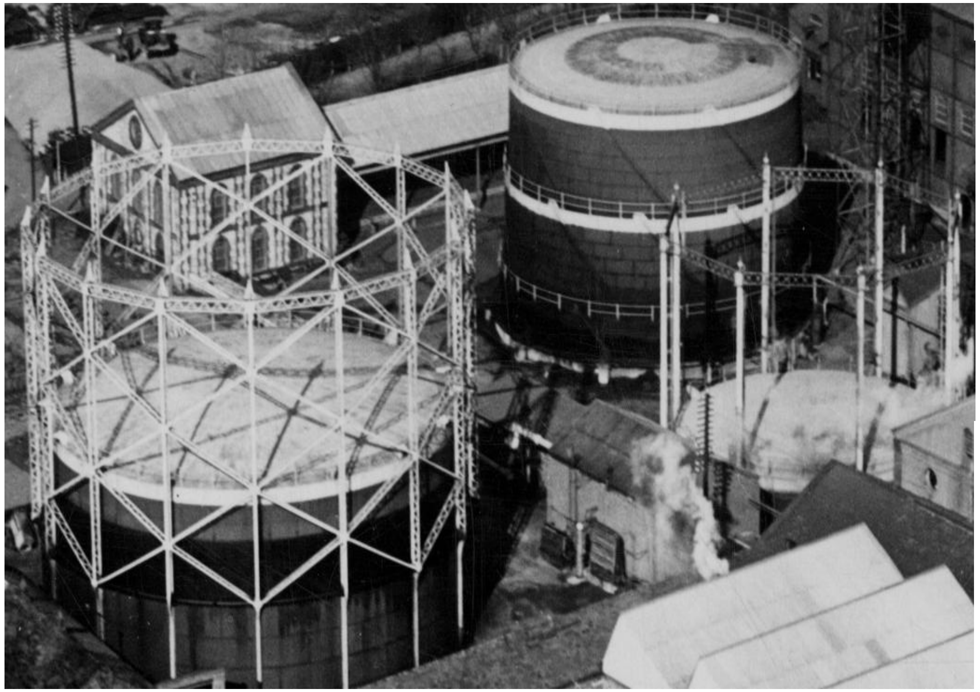
Although gasholders seem simple, the complexity and ingenuity of these structures should not be underestimated; they are the result of complex engineering design which was gradually refined and improved. This profile is limited to a brief description of the different designs of gasholders, their operation and, importantly, their tanks.

Gasholders are the only remaining distinctive feature of a gasworks to still be visible. These structures are characterised by a series of large interconnected (telescopic) cylindrical vessels (lifts) which would rise and fall, depending on the volume of gas stored. The number of operational gasholders has gradually decreased over the past 10 years, and now no gasholders remain in active service within the gas industry. This is because low-pressure gas storage is no longer required, as improved storage capacity has been created elsewhere in the gas network.

A few hundred gasholders still remain today. These are mothballed and awaiting demolition, unless protected by listed status. The gasholder shown in Photograph 1, situated in Fulham, London, is a listed structure and the world's oldest surviving gasholder.

The tanks of former gasholders are often still present on many former gasworks sites, infilled and hidden beneath the ground. During demolition, the tank void formed a ready-made repository for rubble and waste; as such, it can be a potential source of pollution, posing a risk to human health and the water environment.

Photograph 1.
The world's oldest remaining gasholder at Fulham, attributed to Samuel Clegg.



Photograph 2.
Evolution of gasholders on a former gasworks. Bottom right: cast iron column guided. Bottom left: steel guide framed. Top: spiral guided. Source: IGEM PHI

2. Gasholders in a Historical Context

The word ‘gasometer’ is commonly found on historical Ordnance Survey maps dating back to their first editions. The term can even be found on older tithe maps. It was a term used by the lay person, never the gas engineer. It originated from the instrument that Antoine Lavoisier developed to store and supply a uniform stream of oxygen for his experiments and is shown in Figure 1. This had many of the later features of a gasholder for storing coal gas.

In terms of coal gas storage and supply, gasometer was an incorrect term. They were not used to measure gas, as that was the role of the gas meter, although they did give a crude visual indication. They were designed to fulfil the role of a gas storage vessel (gasholder). The term gasometer was used in early gas texts, such as Samuel Clegg Junior’s *A Practical Treatise on the Manufacture and Distribution of Coal Gas*, but not in later gas engineering texts.

Many old structures marked as gasometers on maps were adjacent to mills, factories, hospitals and country houses and were associated with small gasworks (Figure 2). The gasworks themselves were often not specifically marked on maps. Where a gasometer site is shown, it is likely to be a small gasworks, with the production plant located in a nearby building or complex of outbuildings. A detailed review of the history and operation of gasworks can be found in *Gasworks Profile A - The History and Operation of Gasworks (Manufactured Gas Plants) in Britain*.

Many of the factory and mill gasworks date back to 1805-1830 when the gas industry was in its infancy. At this time, William Murdoch, Samuel Clegg and their gas engineer contemporaries were overseeing the construction of small gasworks for factory owners. These followed the success of gas installations at the mills of Phillips and Lee (Salford, by Murdoch) and Henry Lodge (Sowerby Bridge, by Clegg) in 1805.

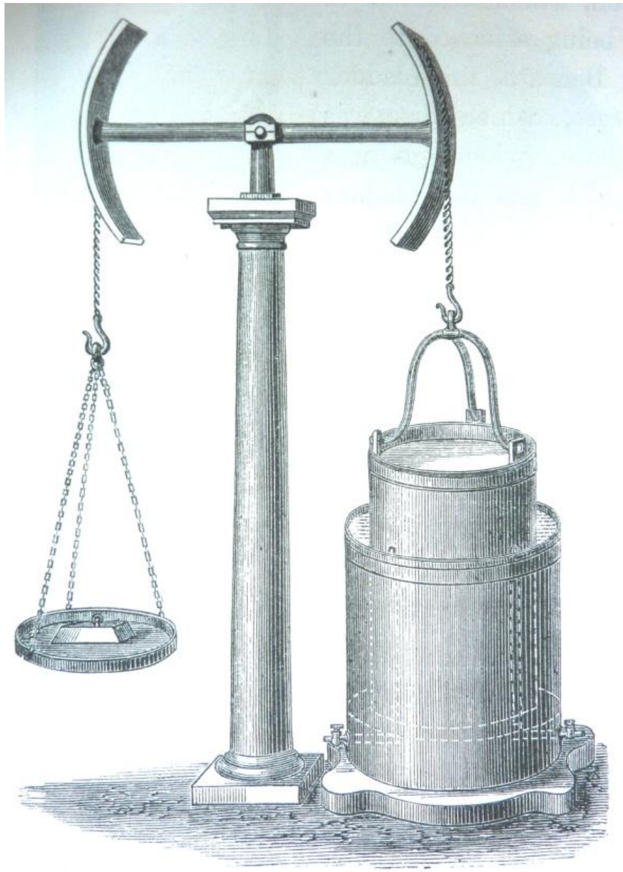


Figure 1. A drawing of the gasholder developed by Antoine Lavoisier, which appeared in his work ‘Opuscules physiques et chimiques’. From King’s Treatise Vol. II, 1879.

The philosophy of building small gasworks for a single establishment was initially successful, but these small gasworks gradually lost favour to the concept of centralised gasworks with distribution mains supplying a larger number of customers. This idea was principally promoted by the German Friedrich Winzer who, to gain acceptance in Britain, anglicised his name to Frederick Winsor. In 1812, Winsor helped establish the first gas company to provide a public supply, the Gas Light and Coke Company.

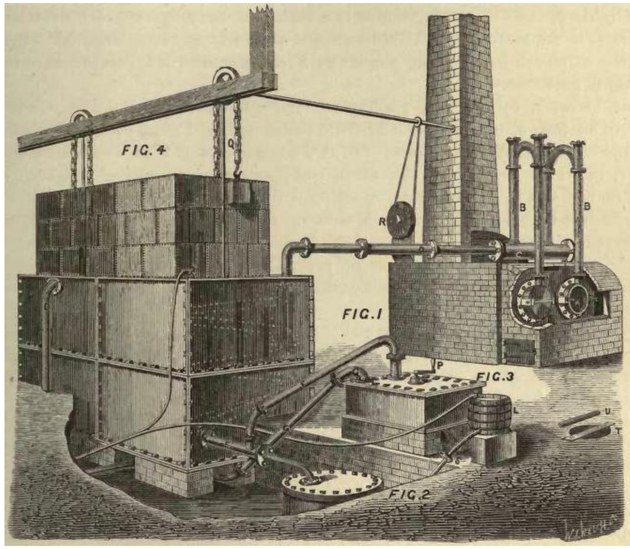


Figure 2. The gasworks built by Clegg for Ackerman, a famous London printer, indicating the retort setting (Fig.1), tar receiver (Fig.2), lime purifier (Fig.3) and gasholder (Fig.4). From the Journal of Gas Lighting.

Whilst many of the factory and mill gasworks appeared small, they often produced more gas than many of the village and town gasworks, given the number of lights they needed to supply. This was because an adequately lit mill using the simple burners available at the time could have required many hundreds of burners throughout the mill and associated properties, compared to a village gasworks with 20-30 street lamps and 30-40 customers.

These mill and factory gasworks disappeared for economic rather than technical reasons. The larger gasworks established in industrial towns could supply many mills at a much lower price than the mill owners could achieve within their own gasworks. The isolated mills, hospitals and country houses (away from a mains supply) kept their gasworks (and gasholders) much longer, but would later transfer to mains gas when it reached them, or move to an alternative form of gas (e.g. acetylene) or electricity. A few mill gasworks did evolve into the main town gasworks for their area, and many others provided a limited public supply through a limited local gas mains, which was often absorbed later by the local gas company.

Gasholders have been a feature of gasworks ever since they were first constructed; examples of such early gasholders can be seen in Figures 2 and 3 and Photographs 1 and 3. The rectangular gasholder design shown in Figure 2 was used by Murdoch and Clegg in early gas installations.

The gasholder consisted primarily of two parts: a tank which contained water, and a vessel or lift which would contain the gas. The purpose of the gasholder was more than just to store the purified gas; it acted as a crude visible ‘meter’, a buffer between production rates and the more erratic consumption rates and, until boosters were introduced, it provided the pressure in the gas mains for the distribution of the gas. The gasholder operated on the basic principle of a gas-filled floating vessel, rising and falling in a seal of water.

The main function of the water was to provide an elastic gas-tight seal in which the vessel could rise or fall. The water also received the whole of the pressure exerted by the weight of the vessel and, in this way, the water formed the necessary resistance to raise the vessel or expel the gas.

It was very important that the weight of the gasholder vessel was correctly calculated so that it would provide sufficient pressure to the gas in the mains with which it was connected.

It was not unusual for weights to be placed on the top of a gasholder to increase pressure. There are even stories of the gas manager and his family sitting on top of the gasholder at a small gasworks in order to provide the extra pressure at times of very high demand.

If the weight of the gasholder was too great, it would put increased back-pressure on the exhauster. If an exhauster was not used, the weight thrown by the gasholder would restrict the flow of the gas leaving the retorts, and the tar released from the coal would be degraded to carbon black in the retort.

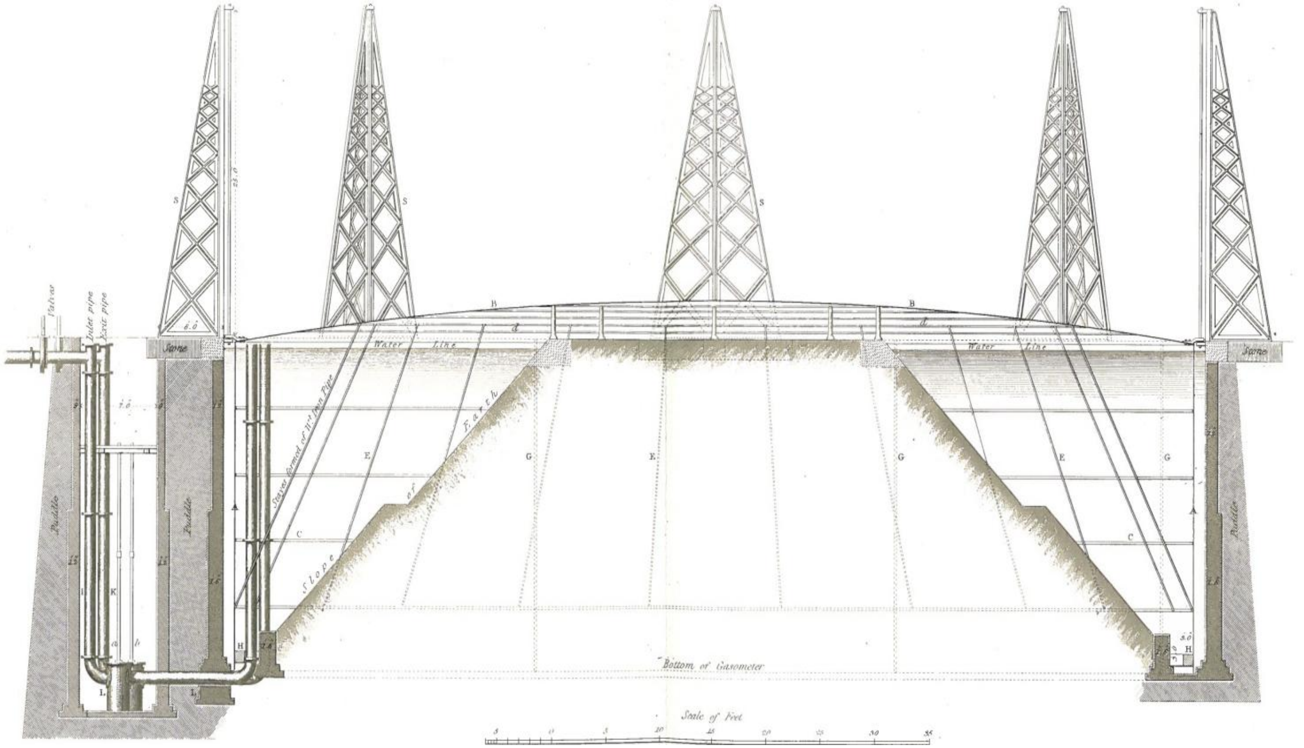


Figure 3. Design of an early gas holder taken from ‘*A Practical Treatise on the Manufacture and Distribution of Coal Gas*’ by Samuel Clegg Junior. This simple design shows many of the features common in later gasholders. Note the basic guiding of the gasholder vessel by metal brackets with eyelets running on cylindrical metal bars; these were later replaced by guided rollers.

Photograph 3. The primitive gasholder at the first small gasworks at the Soho factory of Bolton and Watt.

The first gasholders were rectangular and over-engineered, being constructed of iron with a heavy wooden frame, and holding about 14 m^3 (500 ft^3) of gas. At this time, the gasholder tank was used to condense the tar from the gas, and to purify sulphur from the gas by adding lime to water in the tank. This early use of lime was ineffective due to the settlement of the lime. Rectangular gas holders continued to be built until 1815 when they were replaced by the cylindrical design. These cylindrical gasholders were bigger and had a greater capacity than the rectangular tanks they replaced. The biggest problem with the new gasholders was the building of suitable tanks. At this time, the tanks were usually built above ground and constructed from wood. However, they were not particularly robust and were prone to leaking and collapse. The last of these wooden tanks was removed from the Gas Light and Coke Company's Brick Lane gasworks in 1843. The great gas engineer Samuel Clegg developed some alternative forms of gasholder but none of these were an effective replacement.

By 1819, gasholders had reached capacities of about 566 m^3 (20,000 ft^3) using iron or wooden tanks. John Malam, a gas engineer of the famous Malam gas-engineering dynasty, did much to improve cylindrical gasholder design by reducing the weight of the internal framing and using counterbalance weights and chains. Malam also developed a system where the gasholder was guided by a central rod and tube. This rod and tube system was used extensively on small gasholders, many such examples surviving until at least the 1870s. Brick tanks were introduced in 1818, with stone and concrete tanks coming later.

Their simple design and reliability saw the gasholder concept remain in use for over 200 years. Almost all gasholders worked on the same principle. The vessels or piston would rise and fall depending on the quantity of gas stored. It was the method employed to guide the movement of the vessel or piston that differed as the gasholder technology developed.

Originally, gasholders contained only a single vessel (lift) suspended within the tank; later, multiple-lift (telescopic) gasholders were developed. Telescopic gasholders allowed a much greater volume of gas to be stored in roughly the same footprint of land, making them more cost effective. When Samuel Clegg Junior wrote his treatise in 1841, he commented that telescopic gasholders were an expensive exception to be used only in highly constrained sites. They eventually became commonplace, with many earlier single-lift gasholders being extended to multiple-lift.

Gasholders could generally be classified under four main headings, namely:

- gasholders with vertical columns or guide-framing (Figure 4), which could be single-lift or telescopic, with or without 'flying lifts'
- gasholders guided by wire ropes or cables (rope-based systems appeared *circa* 1885 and were short lived)
- spiral-guided holders (single- or multiple-lift); the guide rails could be left-hand, right-hand or both, and either internal or external and attached to the lifts
- waterless or 'dry' gasholders which stored gas beneath a floating piston

Another later form of gas storage were high-pressure static vessels, which had no tanks or moving parts, and received and stored gas at much higher pressure than those listed above. These bullet-shaped or spherical tanks are shown in Photograph 4. In additon, in more recent years, gas has been stored within high-pressure gas mains, as liquified natural gas (e.g., Dynevor Arms, Wales) and within depleted gas fields (e.g., rough gas storage) or salt caverns (e.g., Holford, Cheshire).

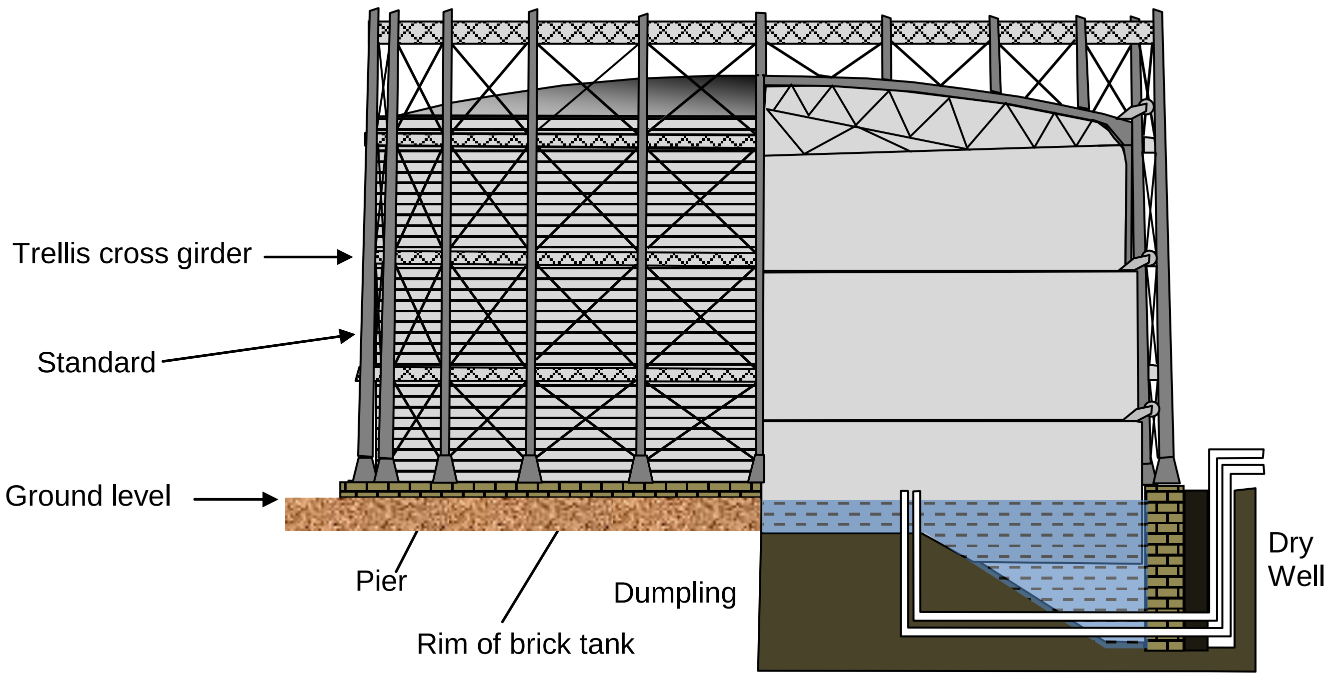
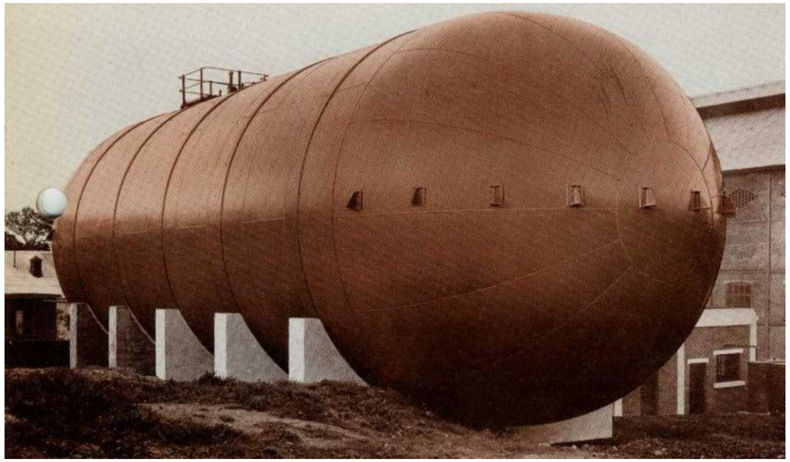
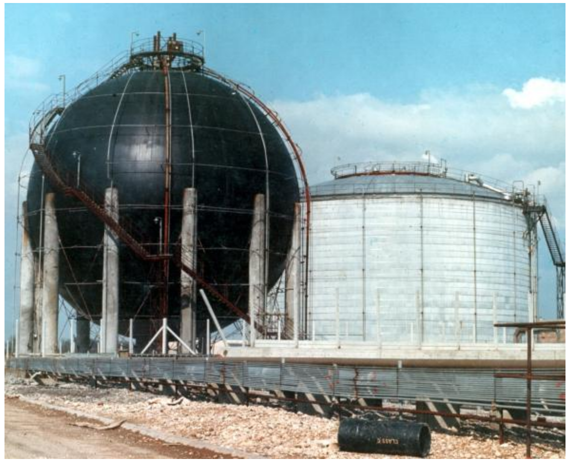


Figure 4. A schematic diagram of a guide-framed gasholder with a below-ground tank. Source: Russell Thomas.





Photograph 4. A high-pressure bullet-type gasholder (left, courtesy of the IGEM PHI) and high pressure sphere gasholder (right), behind which is a small LPG tank.

3. The Housing of Gasholders

Early safety concerns over gasholders expressed by Sir Joseph Banks and members of the Royal Society, led to gasholders being limited in size and constructed in strengthened buildings. Known as a gasometer house, this was a separate superstructure built around the gasholder to protect it from explosions and the weather, especially lightning. The logic behind this was not entirely sound, as gas could leak from the gasholder into the air within the gasometer house, forming a potentially explosive atmosphere. They were phased out in the UK, but in Europe and North America, where cold weather brought the risk of freezing and high snowfall, ornate brick-built gasometer houses (Figure 5) were constructed. Examples in Copenhagen, Leipzig, Vienna and Warsaw are preserved.

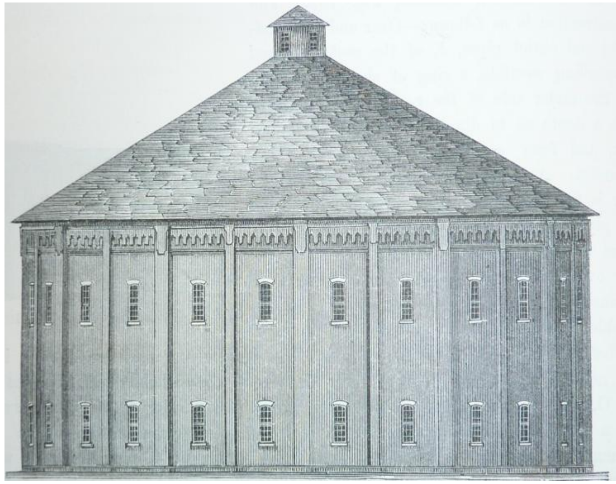


Figure 5. A gasometer house. From King's Treatise Vol. II, 1879.

4. Column-Guided Gasholders

Column-guided gasholders (Figures 6 and 7) were simple and generally reliable systems. As the name suggests, the weight and movement of the vessel lifts were supported by columns attached to the top of the gasholder tank. On the inside of these columns (facing the lift), guide rails were attached to ensure the rigid guiding of the lift. Guide wheels were attached to arms extending from the rim of the top of the lifts. The wheels would run up and down within the guide rail set in the columns.

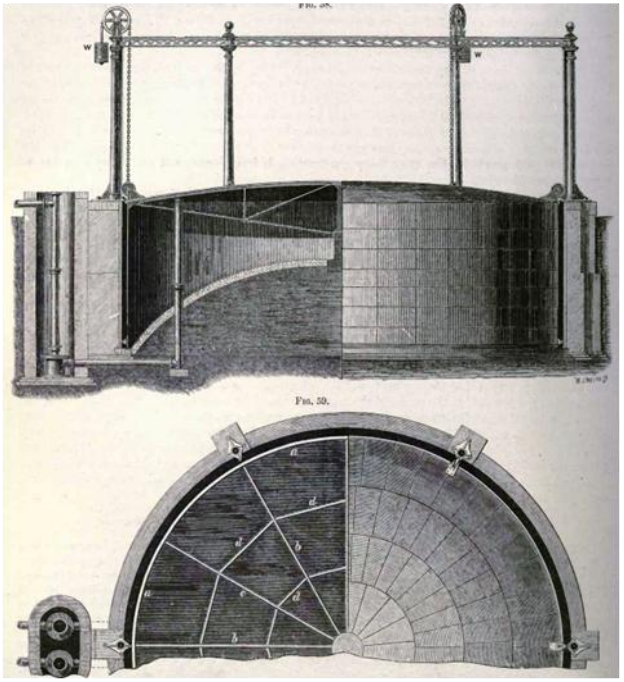


Figure 6. Drawing of an early single-lift gasholder with counterweights and a brick below-ground tank. From '*A Practical Treatise on the Manufacture and Distribution of Coal Gas*' by William Richards, 1877.

The column-guided method proved the most successful, until advancements in the later 19th century.

Some very simple early gasholders were guided by a single central rod and tube as devised by Malam.

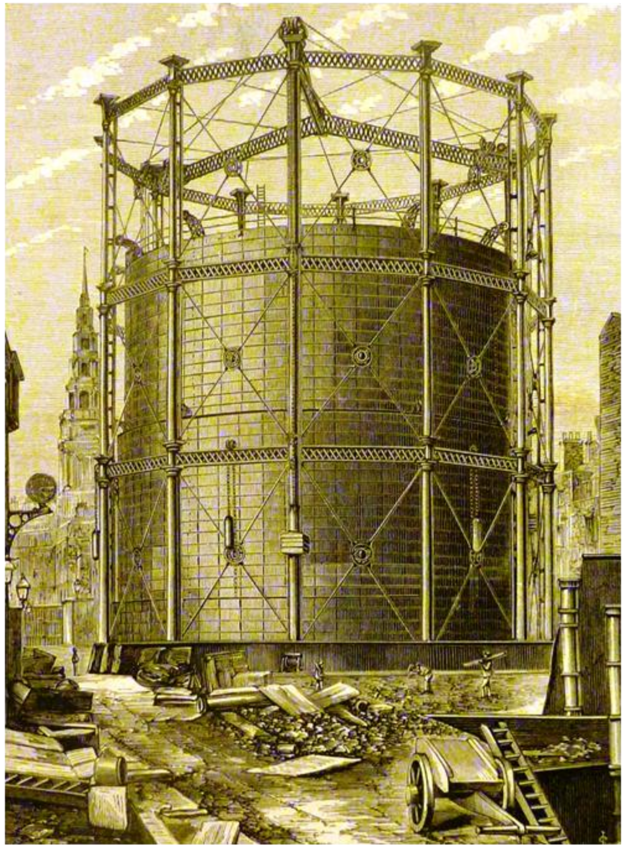


Figure 7. A three-lift column-guided gasholder at the City of London Gas Compan's works at Blackfriars, London. From King's Treatise, Vol II, 1879.

Early examples of guided gasholders used cast-iron tripods as seen in Photograph 1 and Figure 3. These tripods were isolated from each other and used for small holders of 12-15 m

(40-50 ft) diameter by gas engineers such as John Kirkham. When larger gasholders were required, Kirkham connected the tripods using iron girders. The gasholder vessel moved up and down on brackets with a pierced eyelet which ran on cylindrical metal bars (Figure 3).

These columns would be attached to each other with heavy cast-iron or wrought-iron trellis cross girders, and bolted onto the piers of the gasholder tank. Given the considerable weight of the cast-iron columns, they were not suitable for very high gasholder frames (30 m/100 ft) as the piers required were large and costly. These cast-iron constructions were later superseded by structures composed of comparatively light rolled mild steel.

Early gasholders used counterweights (Figures 6 and 7 and Photograph 3) but these were largely phased out (apart from specialist situations). Whilst the counterbalances reduced the resistance to gas entering the gasholder, they also reduced the pressure of gas leaving the gasholder.

5. Guide-Framed Gasholders

Guide-framed gasholders were similar to the column-guided design (the two terms were often interchanged), except that a lighter and more extensive framework was built around the gasholder, forming an outer cylinder of structural steel or ironwork. The guide frame was attached to the outside of the above-ground tank or to the top of a below-ground tank by bolts onto the piers.

Vertical girders (known as standards) were intersected by horizontal girders and braced diagonally for extra strength (Figure 7).

An important development was Cutler's patented guide framing, which consisted of vertical standards braced by diagonal triangulated framing rather than horizontal girders (Photograph 5).

Photograph 5. A two-lift frame-guided gasholder with below-ground tank, using Cutler's patented system, Southern England. Source: IGEM PHI.

In general, the more modern the gasholder, the lighter the material used to construct the guide framing. The gasholders moved up and down the guide rails on wheels in a similar fashion to the column-guided gasholders, with the guide rails on the standards rather than on the columns. Some early examples were known to have been constructed using wooden frames.

6. Cable-Guided Gasholders

Wire-rope or cable-guided gasholders used a complex arrangement of at least three separate cables for a single-lift gasholder which stretched via a series of pulleys from the top of the gasholder tank to the top of the gasholder vessel and back. This kept the cables taut and the floating vessel in position. They were invented in the 1880s by the Darlington engineer, Edward Pease. Figure 8 shows a two-lift example of a cable-guided gasholder.

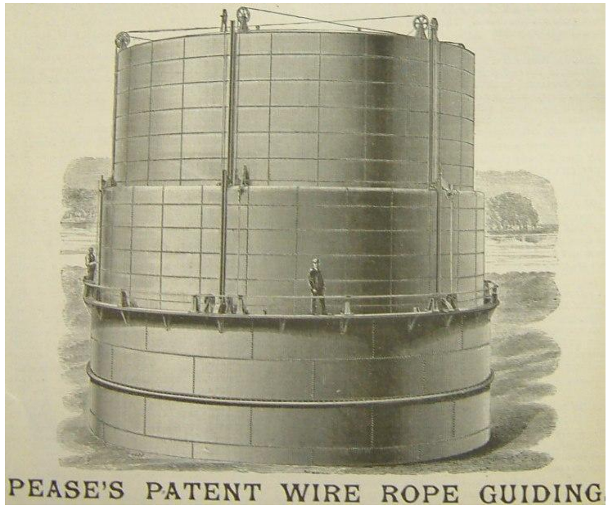


Figure 8. A cable-guided gasholder in an above-ground steel tank. From an old advert *circa* 1880.

Their use was short-lived (*circa* 1890-1910) as alternative designs proved more effective and reliable. They were retrofitted on some column-guided tanks where ground instability had caused the columns and tanks to move, and the gasholder to jam.

7. Flying Lifts

Both column-guided and guide-framed gasholders could be extended by inserting a flying lift, often, but not always (as in the case of Photograph 6) by adding a spiral-guided lift.

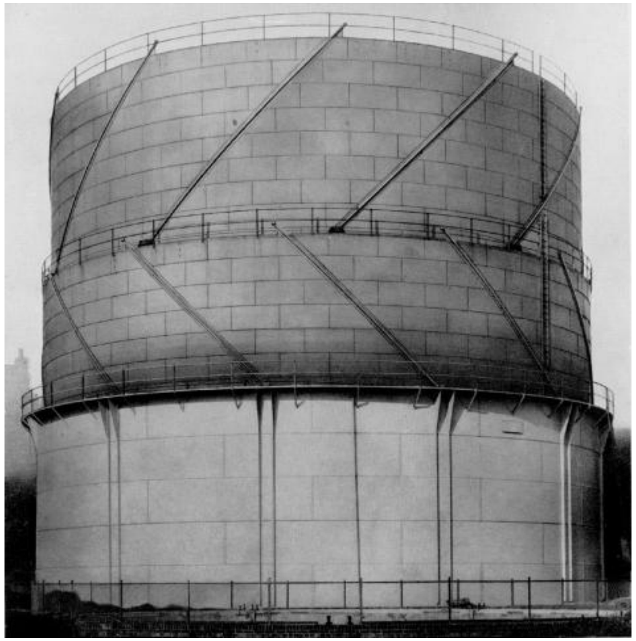
A flying lift was an additional inner lift retrofitted into the gasholder; instead of running within the set columns or rails, the flying lift could extend above the columns or standards without being directly attached to them.

Photograph 6. A gasholder fitted with a flying lift.

This was a common practice for many years to quickly increase capacity on gasworks, but was later phased out. This method benefited from being relatively easy and cheap to retrofit without interfering with the existing guide frame or columns. The gas engineer would need to ensure the gasholder structure could withstand the additional weight and shear forces exerted by strong side winds.

8. Spiral-Guided Gasholders

The spiral-guided gasholder concept was proposed by Mr W. Webber and invented by Mr William Gadd of Manchester. They were introduced into the UK in 1888. The UK's first spiral-guided gasholder was built in 1890 in Northwich, Cheshire, by Clayton, Son and Co Ltd. of Leeds. The spiral-guided gasholder dispensed with the external frame above the tank, with the lifts supported instead by spiral guiding rails fixed to the lifts (Photograph 7 and Figure 9).



Photograph 7. Spiral-guided gasholder with two lifts in a steel above-ground tank. Source: IGEM PHI.

The spiral guide rails engaged with rollers (two above and two below the rail) on the edge of the tank in such a manner that the bell moved up and down in a screw-like fashion (Photograph 8). The guide rails could be all left-handed, all right-handed, or successive combinations of both.

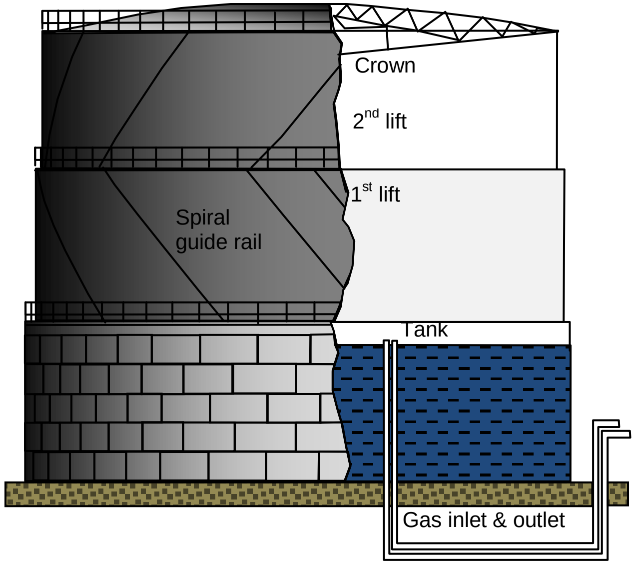
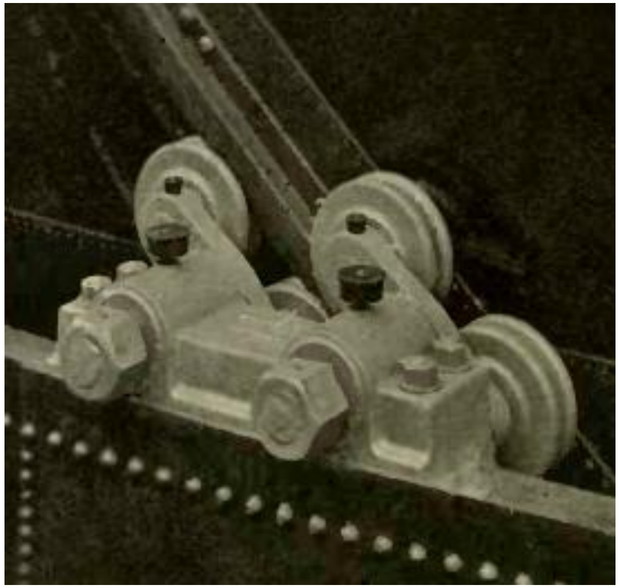


Figure 9. Schematic of a spiral-guided gasholder with an above-ground tank, showing the internal detail and water level. Source: Russell Thomas.

The rails on the outer lift were always fixed to the exterior of the lift, but those on succeeding lifts could be either interior or exterior, although the latter were used in preference.

Spiral-guided gasholders required more precise engineering and, as a result, the rollers were at greater risk of jamming than the other types of gasholders, if damaged. They were particularly at risk from the wheels freezing, which could lead to the catastrophic collapse of the lifts.



Photograph 8. Multiple Roller Carriage which guides the upwards and downwards movement of the spiral gasholder. From *Modern Gasworks Practice* by Alwyn Meade.

9. Waterless or Dry Gasholders

This design allowed for a simplified system, where the major moving part was the piston, dispensing with the need for the water seal and associated water-filled tank. The piston was able to rise and fall via the guide rollers. The outer cylindrical shell was dissimilar in appearance to other gasholders. The outer shell remained static, had the same diameter throughout, and the roof of the structure was permenantly fixed.

The MAN (Maschinenfabrik Augsburg-Nürnberg AG) gasholder (Figure 10) was the first of the dry gasholders and was developed in Germany in 1915. The Klonne was another German dry gasholder design. The MAN and Klonne waterless gasholders had tar and oil/grease seals respectively; only the MAN required recirculation of the seal fluid.

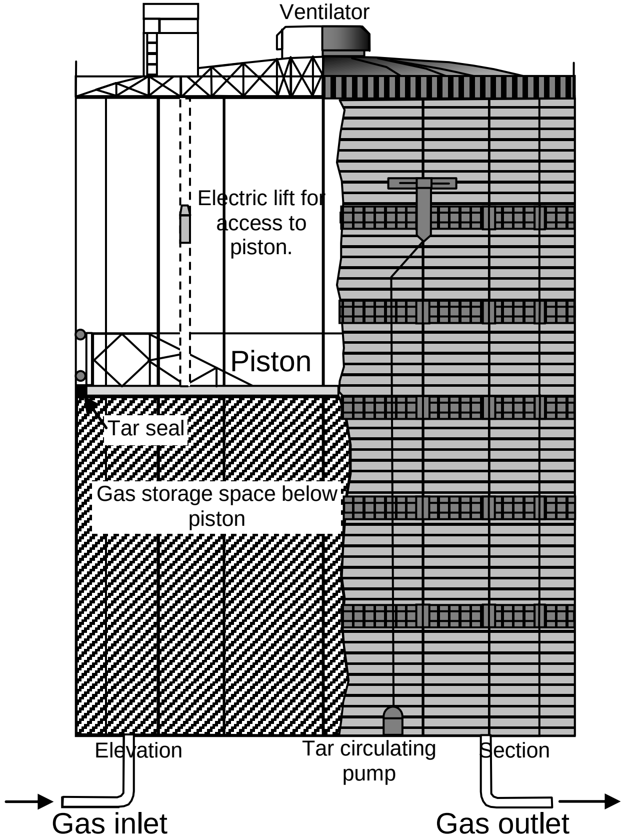


Figure 10. A MAN waterless gas holder. Source: Russell Thomas.

These gasholders allowed the heavy water tanks used on water-sealed gasholders to be dispensed with, requiring less expenditure on foundations. Another benefit was that the gas remained dry. The MAN was polygonal in plan, and the Klonne was circular. There was a third equally important but different design: the Wiggins dry gasholder (Photograph 9). This American design is still popular and is used for gas storage for the steel, iron, and coke-making industries. The largest low pressure gasholders ever built were the Klonne gasholder built in 1938 in Gelsenkirchen (Germany) which was 80 m (262 ft) in diameter and 136 m (446 ft) high and had a capacity of 594,000 m^3 (21,000,000 ft^3) and the MAN gasholder built in 1934 in Chicago (USA) which had a capacity of 566,000 m^3 (20,000,000 ft^3).

Photograph 9. Wiggins type gasholder at Millom, England. Source: Mr Syd Bennet.

10. Crowns, Cups and Dips

Due to the relative weakness of the dome (crown) of the gasholder vessel, support was required to prevent it from buckling when all the lifts were down and there was no gas pressure within the gasholder. In these cases, the crown required either its own internal frame (akin to the supports in an umbrella) to provide strength, or support from underneath to maintain its shape (a crown rest). Where an internal frame was used, this was still supported on a central column or pier. Trussing was generally limited to gasholders with a diameter of 52 m (170 ft) or less, due to the technical limitations of the method.

The crown rest consisted of a series of radiating rafters carried on columns erected in the tank and connected by purlins to form a skeleton framework with the same shape as the crown. Earlier gasholders, especially very large examples, used a fixed timber framework (standing in the water tank) upon which the crown could be seated (Photograph10).

Photograph 10. A gasholder with the sheeting removed from the crown, exposing the crown rest and water-filled tank.

The cups and the dips (otherwise known as grips) were the semi-circular or square features which interlocked to form the seals at the edges of each lift (Figure 11). As the inner lift rose to its maximum, the cups and grips interlocked. The cup was sufficiently deep to form a gas-tight seal when filled with water.

The cups and dips were of similar size and ranged from 20-30 cm (8-12 in) wide and 40-60 cm (16-24 in) deep, depending on the size of the gasholder. They were in use prior to 1833, but it was in 1833 that the cup and dip system was patented by Stephen Hutchinson. Originally they were built of wrought iron but were later replaced by mild steel, when it became available.

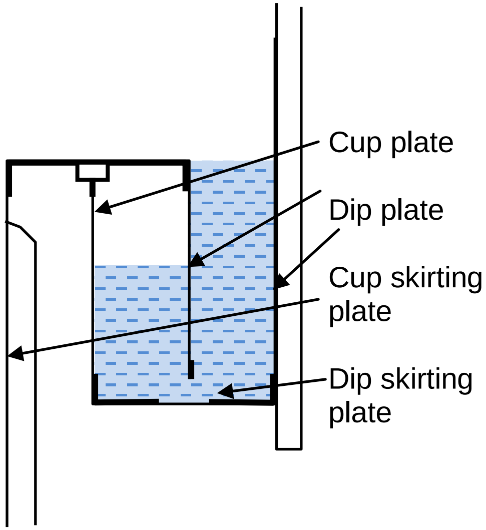


Figure 11. A cups and dips (grips) arrangement. Source: Russell Thomas.

The outer lift of a column or frame-guided gasholder had a different arrangement, having a bottom curb carriage at its base. This was originally referred to as a 'wooden curb', and its role was both simple and clever. It was constructed of Memel timber (pine), measured 30 cm x 30 cm, and extended around the base of the outer lift. Whilst submerged in the gasholder tank, the timber would add buoyancy to the lift. Once partially out of the water, it would act as a weight to stop the lift leaving the water tank and blowing the seal, diverting gas to flow to other gasholders not yet filled with gas. The lifts grounded on rest blocks of stone or concrete set in the annulus of the gasholder tank.

11. Gasholder Tanks

The gasholder tank was the part of the gasholder which would house the lifts when down (empty of gas) and contain the water in which the lifts would rise and fall, depending on gas flow. The water functioned primarily as an elastic gas-tight seal. The tank was waterproofed to prevent water leakage. The gasholder tank could be below ground level (Figure 12), partially below ground level, or entirely above ground level, depending on the type of gasholder employed and the ground conditions.

The material from which a gasholder tank was constructed was dependent on the available local building materials and the ground conditions at the gasworks. Where a local source of good quality building stone was available, then this would have been used to build the tank. The most commonly used material for building below-ground gasholder tanks was brick (preferably low-porosity hard-burnt bricks). The full range of building materials for gasholder tanks comprised:

- stone
- brick
- mass or reinforced concrete
- cast or wrought Iron
- steel
- bedrock
- combination of the above (composite)

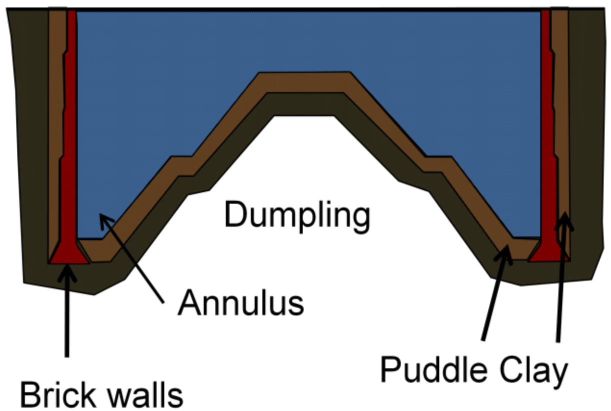
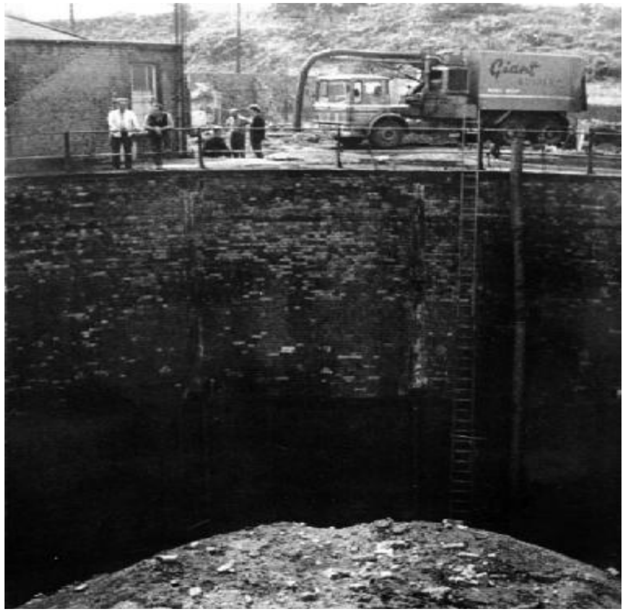


Figure 12. Schematic of a gasholder tank with a dumpling and annulus. Source: Russell Thomas.



Photograph 11. A brick gasholder tank with dumpling visible at the base.

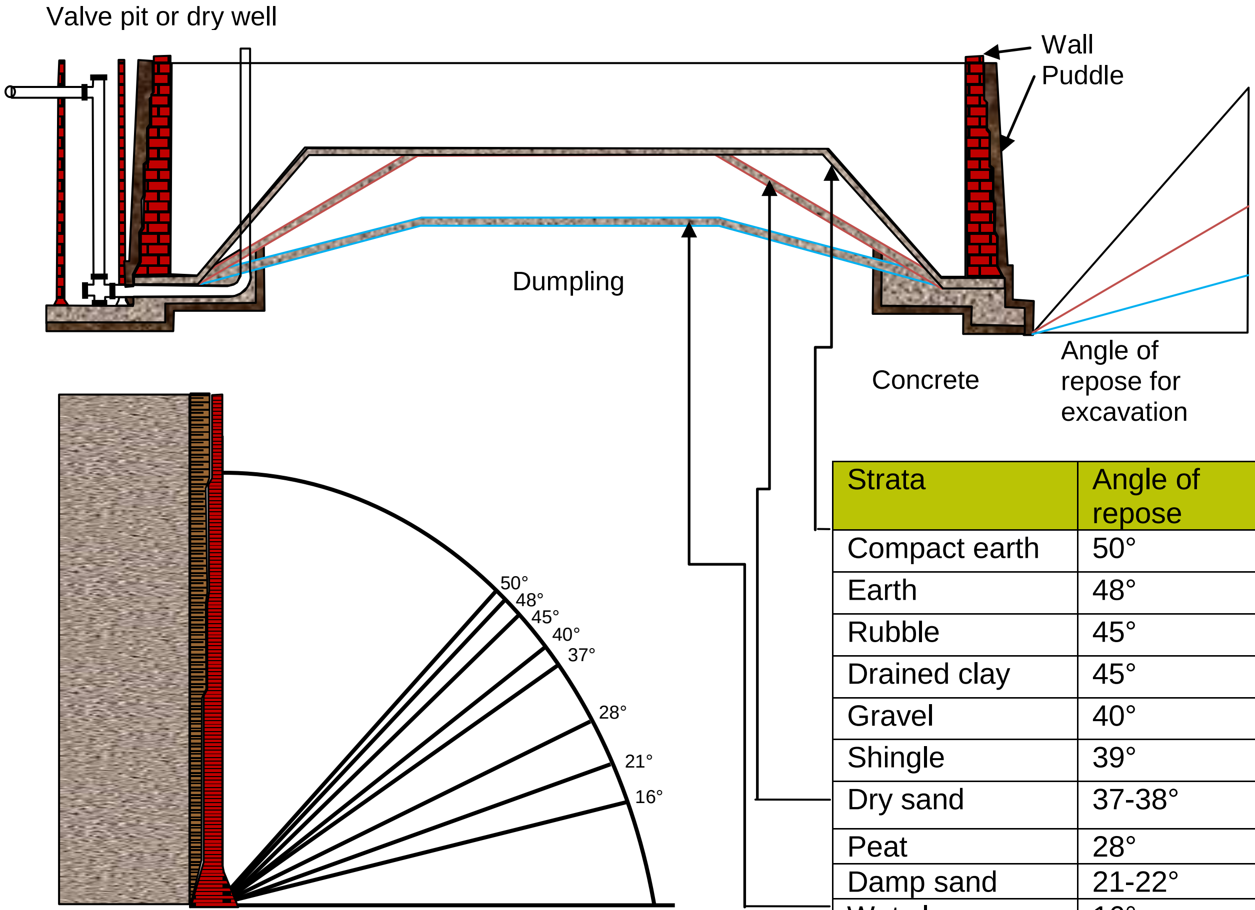
As brick or stone tanks were porous, the outer facing walls and base of the tanks were usually backed with puddle clay. The puddle could be pure clay, but it was thought preferable to mix clay with one-third sand, silt, or soil free from plant matter; this was firmer in texture and less liable to crack when dry. The puddle would be prepared outside of the trench and built up in thin layers as the wall of the tank was built; it was kept moistened, punned well, and backed up with carefully pounded earth.

An alternative method of waterproofing was through the application of 2.5 cm (1 in) render of Portland cement to the internal face of the tank. Applied successfully, this could make the puddle redundant and on such tanks puddle was not always used. The use of 11 cm (4⅓ in) bricks with a cement lining could also serve this purpose. Tanks built from waterproof concrete did not require rendering or puddle.

The excavations required for the construction of a gasholder tank were dependent on ground conditions. As can be seen in Figure 13, the safe angles of repose varied depending on the strata, with compact earth offering the steepest and wet clay the shallowest.

A few examples existed where gasholder tanks were hewn out of bedrock. Gasholder tanks at the Chester gasworks were constructed this way, and still required waterproofing.

Where ground conditions were favourable, it was more economical to leave a conical mound – known as a cone or dumpling (Photograph 11) – within the centre of the gasholder tank. In tanks whose diameters did not exceed *circa* 18 m (59 ft), it would be more economical to remove all the material if it required waterproofing, leaving a flat base, unless it was constructed in rock, stiff clay or chalk.



Strata	Angle of repose
Compact earth	50°
Earth	48°
Rubble	45°
Drained clay	45°
Gravel	40°
Shingle	39°
Dry sand	37-38°
Peat	28°
Damp sand	21-22°
Wet clay	16°

Figure 13. The effect of ground conditions on the angle of repose when constructing an underground gasholder tank, showing angles of repose for different strata. Source: Russell Thomas.

Occasionally, tanks were built by making a circular cutting in the ground and constructing an iron or brick annular channel to contain the water, with the intervening central space also being covered with a shallow layer of water (Figure 14). These were termed annular tanks. Sandstone versions of these tanks, made watertight with pitch of asphalt, have been found in various locations, including Liverpool and Chester which had suitably shallow and solid bedrock.

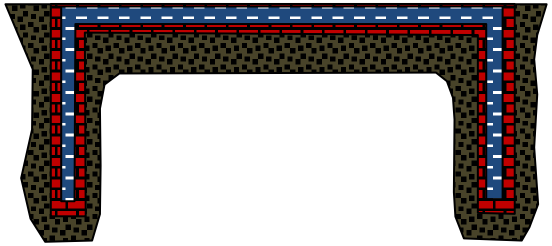


Figure 14. A schematic representation of an annular gasholder tank. Source: Russell Thomas.

The weakest point on a circular masonry tank was always the point at which the gas pipes entered and exited the gasholder. These pipes were used to transfer the gas to and from the gas mains to the gasholder, through the water seal. The gas pipes were generally situated within a recess in the tank walls; however, by passing through the wall, the wall circle was broken and the tank was weakened, making it more likely to fail. A recess was only used on small gasholder tanks in modern times, a dry well being preferred (as shown in Figures 3, 5 and 9). Methods used to minimise stress on the circular tank wall included the installation of iron struts or the use of square pipes built into the wall.

Large gasholder tanks required wall-strengthening methods which included layers of thick Portland cement, at 60-90 cm (2-3 ft) intervals, into which the brick or stone was placed. As an alternative, hooped-iron or flat-iron rings were built at intervals into the wall.

Photograph 12. Concrete foundation slab of an above-ground gasholder.

If ground conditions made it very expensive to construct good foundations to build a tank, or there was a high water table in a porous strata (e.g., sand), then an above-ground tank would be used. Above-ground tanks were generally constructed of flanged cast iron (later, wrought iron or steel plates), bolted or riveted together and built on a reinforced concrete slab (Photograph 12). These tanks could be easily dismantled and reused elsewhere. Buried remains of these tanks are uncommon, except for tank bottoms and the first row of plates. If ground conditions were too unstable even for an above-ground tank, then the concrete slab would require piled foundations. These above-ground tanks placed the gasholder in a more elevated position than an underground tank, putting it at greater risk from wind damage. They were therefore sometimes seen as an option of last resort. After *circa* 1920 it was unusual for below-ground tanks to be chosen; however, all gasholders were built on the most suitable design for the conditions encountered on that specific site.

12. Gasholder Site or Gasworks?

Not all sites containing gasholders were active gasworks. During the expansion and development of the gas industry and its

Photograph 13. The famous Kennington Gasholder, backdrop to the Oval Cricket Ground.

distribution network, some new sites were developed purely for the storage of gas; these were referred to as gasholder stations. These gasholder stations were developed either because there was insufficient room for the construction of new gasholders on the gasworks site, or new areas of supply had been developed and a new remote gasholder was required to store and distribute (via pressure of the gasholder) to this area. In larger cities, the gasworks sometimes expanded to fill the entire footprint of the site, making it necessary for some or all of the associated gasholders to be placed elsewhere. Thus the Nine Elms gasworks had gasholders at Battersea, while Vauxhall gasworks had gasholders at the Kennington Oval (Photograph 13).

These gasholders would have been supplied with gas under a greater pressure (medium or intermediate pressure) than used for local distribution (low pressure) from large centralised gasworks on the distribution network. From the early origins of the gas industry until about 1920, gas would have only existed in the mains at a low pressure of up to 40 mbar. Prior to the introduction of booster pumps, the only pressure to the gas mains was provided by the weight of the gasholder. Descriptions of gas pressure in the gas distribution networks have gradually changed over time as gas networks became more integrated at a local, regional and finally national level (Table 1).

The gasholders were connected to the low-pressure gas mains, which are used for local distribution to domestic properties and businesses. The intermediate-pressure and medium-pressure gas distribution systems are supplied from the high-pressure gas transmission system through Pressure Reduction Stations (PRS). PRSs also reduce the gas pressure from the intermediate- and medium-pressure mains into the low-pressure distribution system. The PRS is designed to ensure that the pressure in a gas main or gas service pipe does not exceed its maximum design pressure.

Table 1: Different types of gas mains and their pressures.

Type of Mains	Pressure
Low	0-75 mbar
Medium	75 mbar - 2 bar
Intermediate	2-7 bar
High	Above 7 bar
National Transmission System	85 bar

In addition to the gas distribution networks, there is a national transmission system (NTS) which operates at 85 bar. This transports gas around

Britain at a speed of approximately 25 miles per hour from North Sea gas fields, continental gas interconnectors, gas storage facilities and Liquefied Natural Gas (LNG) importation sites. The NTS supplies major industrial customers as well as the gas distribution networks.

13. Demolition of Gasholders

As the demand for gas increased, so did the requirements placed on gasholders, whose size and capacity increased over time. Many early gasholders were replaced by larger models. These redundant gasholders would have been decommissioned and filled in, decommissioned, removed and replaced by a larger gasholder, or the gasholder removed and the tank retained and modified for use as a tar tank.

Gas infrastructure developments in Britain meant the gradual disappearance of the requirement for low-pressure gasholders. From the 1950s onwards, many small gasholders (retained on small former gasworks sites to maintain local distribution) became redundant and were decommissioned. The local gas network was instead supplied from a larger centralised gasholder station elsewhere. More recent developments in improving the gas networks across Britain have led to alternative storage capacity being developed in the gas mains, at storage sites such as depleted gas fields, salt caverns and LNG storage facilities. Coupled with the faster transmission of gas across the country, this has made low-pressure gas storage in gasholders redundant, leading to the decommissioning of gasholders across Britain.

Photograph 14. The decommissioning of a gasholder at Croydon in the 1970s. Removal of the guide-frame standards (left) and the partially infilled gasholder tank (right).

In simple terms, decommissioning would include the gas connections to the gasholder being disconnected and blanked off, and the gasholder purged of explosive gases. The outer horizontal trellises and each standard or column would be cut, then demolished individually as shown in Photograph 14.

The lifts would then be removed, with the crown being removed before the columns or standards. The iron or steel work would be taken as scrap for recycling and the money obtained used to offset the cost of the project. If below-ground tanks were present, these were often infilled with demolition rubble and any residual site wastes such as ash or spent oxide, a waste material from the purification of town gas. Gasholder tanks were ready-made landfills given their often watertight bases and side walls and were capable of being capped.

Tanks which contained a dumpling also contained an annular trench or annulus; this was located just inside the tank wall. The annulus would provide a flattened circular trench for the lifts to rest when the gasholder was empty of gas. It varied in size, but reviewing numerous records it appears that it was generally between 0.91 m (3 ft) and 1.82 m (6 ft) wide. Where encountered in infilled gasholders, they are generally found to contain a depth of 200-300 mm (8-12 in) of gasholder sludge as well as the rest blocks.

Recent gasholder demolitions have been undertaken to much higher environmental standards, with the gasholder tanks backfilled with a suitably clean aggregate or site-won materials with the appropriate geotechnical properties.

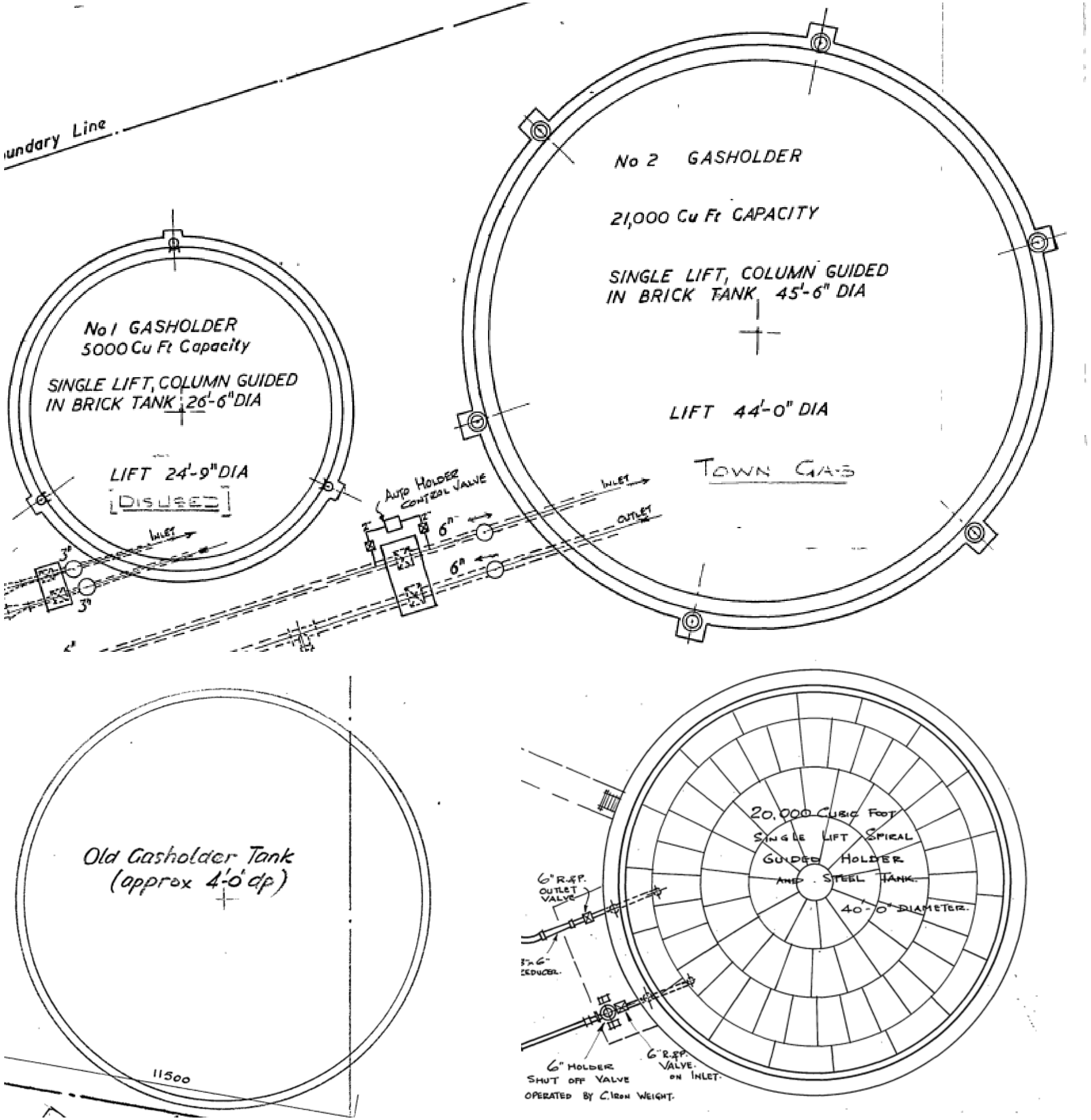


Figure 15. Examples of details of gasholders tanks found on gasholder plans.

14. Calculating the Size of Gasholder Tanks

The first task is to establish whether the gasholder tank was above ground (Photograph 15), partially below ground, or below ground.

This can be worked out from the information available for the gasholder, including plans, photographs and records. Records may show whether the tank was above or below ground and give the depth of the tank, its capacity and the number of lifts. If this information is not available, then the construction material provides an indication. Brick, stone and concrete tanks were normally used to construct tanks which were totally or predominantly below ground. Iron and steel were generally used for tanks which were above or predominantly above ground; however, they were, on occasion, also used for below-ground tanks.

Photographs provide a vital source of information, revealing the type of gasholder and the position of the tank. All types of gasholder (with the exception of waterless types) could have an above-ground (Figures 2, 8, 9, 10 and Photographs 2, 6, 7, 9, 12, 15, 16) or below-ground gasholder tank (Figures 3, 4, 6, 7, 12, 13, 14 and Photographs 1, 2, 3, 5, 11, 14). If a tank is not visible on the photograph, it can be assumed the gasholder had a below-ground tank.

An important point to remember is that even above-ground tanks had concrete slabs which could be buried significantly below ground level (approximately 1-1.5 mbgl) due to ground-raising activities on redeveloped sites. Waterless-type gasholders only had above-ground tanks (Figure 10 and Photograph 9).

Photograph 15. Construction of an above-ground steel tank.

14.1 Methods for Estimating the Depth of the Gasholder Tank with Limited Information

<u>Single-Lift Gasholders</u>

Simple Ratio for Single-Lift Gasholders
For single-lift holders the height of the vessel varied from 0.3 to 0.4 of the diameter of the tank. The height of the vessel was usually about 0.30 m (1 ft) shorter than the depth of the tank.

For example, a 20 m diameter gasholder would have a tank depth of between 6 m and 8 m.

Calculation for Single-Lift Gasholders Based on Diameter and Capacity
If the capacity of the gasholder and the diameter of the tank are known then the approximate depth of the tank can be calculated using the following equation (valid for metric or imperial units).
(Capacity $/(\pi \times (\text{radius})^2)$) = depth of tank (approximately)

This rough estimation for tank depth works better with single-lift tanks, but it can also be applied to multiple-lift tanks. It should be used along with other measures to calculate the potential tank depth. An assumption can also be made based on the graph in Figure 16.

Multiple-Lift Gasholders

Each lift would have been of a similar depth; i.e., the depth of each lift is approximately equal to the total height of the inflated gasholder divided by the proposed number of lifts, due allowance being made for the depth of cups and grips. The depth of the tank would have been roughly equal to the depth of the average lift height.

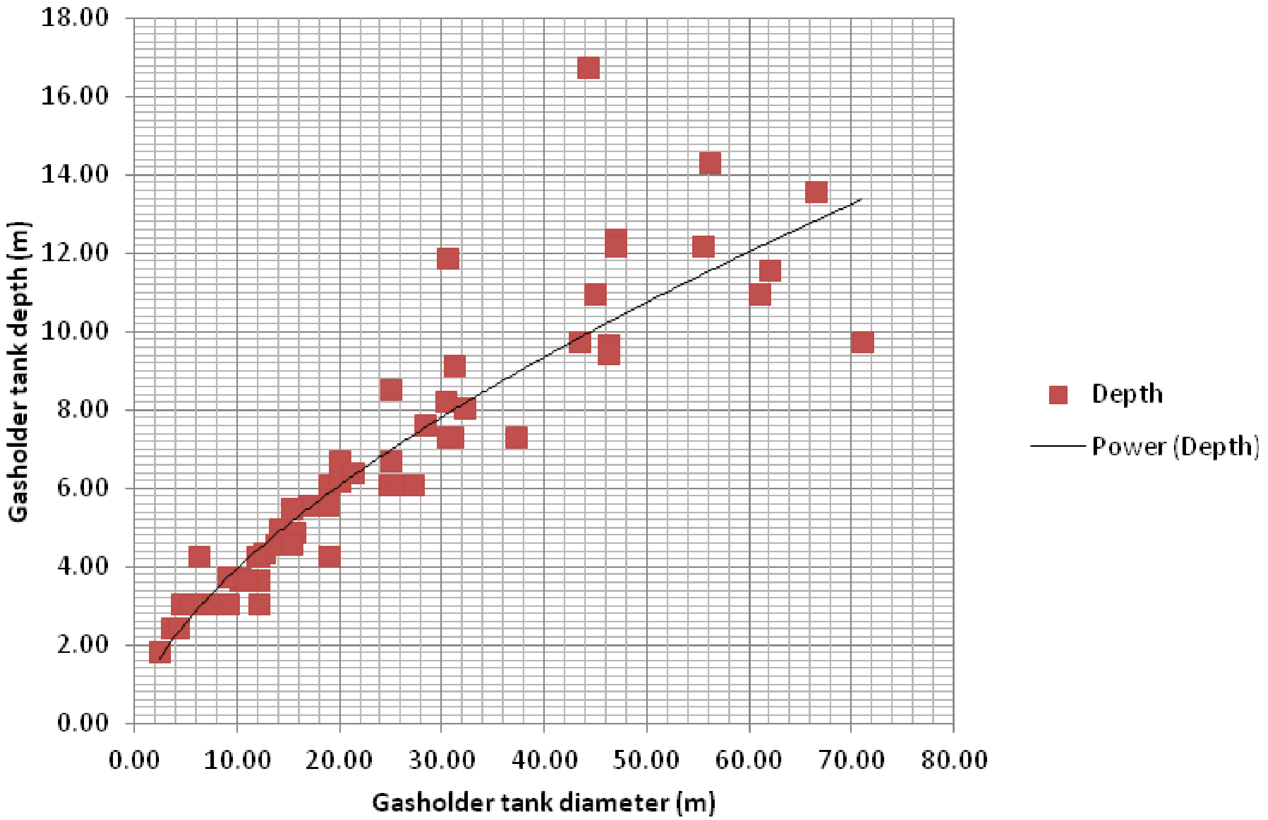


Figure 16. A plot of the gasholder tank diameter against depth for brick, stone, concrete and composite tanks. Source: Russell Thomas.

Simple Ratio for Multiple-Lift Gasholders

For telescopic gasholders, the normal proportion for the depth of the tank varied between 0.5 and 1.0 of the mean diameter. Modern Gasworks Practice suggested that 0.64 could be used as a ratio between total height and diameter of a four-lift gasholder. It also suggested that 0.5 could be used as a ratio between total height and diameter of a three-lift gasholder. On this basis it could be assumed that for a two-lift gasholder the ratio would have been about 0.4. The depth of the tank was usually slightly longer than each of the individual lifts of the gasholder (they were roughly the same length, inner vessels being slightly taller than the outer vessel).

Calculation for Multiple-Lift Gasholders Based on Diameter and Capacity

The same equation could be used as highlighted above, but the number of lifts must be factored in. An assumption could also be made based on the data in the graph in Figure 16.

14.2 Methods for Estimating the Volume of the Gasholder Tank with a Dumpling Present

It should be remembered that while only below-ground tanks had a dumpling, many underground tanks did not have them. Tanks less than 16-18 m in diameter and requiring waterproofing did not generally have dumplings unless built in rock, stiff clay or chalk. Some smaller tanks of brick or stone had floors paved with flagstones.

The dumpling was a mound of earth left within the gasholder tanks for economical reasons (i.e., it was cheaper to leave the material *in situ* than excavate it. It was often covered in a layer of cement, or consisted of puddle covered with stone or brick.

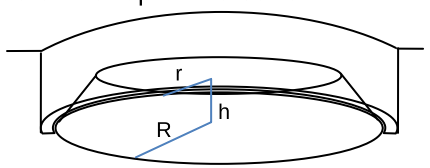
The dumpling was not a uniform structure and its shape as highlighted in Figure 13 would be highly dependent on the strata in which the tank was constructed. An annular channel was built between the edge of the tank wall and the start of the dumpling, measuring roughly 0.91 m (3 ft) and 1.82 m (6 ft) wide.

The dumpling was generally cone shaped with a flat top (e.g., Figure 13) although dumplings which were more dome shaped were also constructed. On this basis, calculating the volume of a dumpling cannot be easily presented here, and it must be made on a case-by-case basis.

The simple calculation for working out the volume of a cone can be used to roughly estimate its size. This calculation is the volume of a cone = ($^1/_3$) x π x Radius^2 x height. This calculation does not take into account that the dumpling was often a wide short cone with a flat top (a frustum of a cone), with the angles dependent on the strata. A more accurate approach would therefore be to work out the volume of a frustum of a cone as below.

$$V = \frac{(\pi \times h)}{3} (R^2+r^2+Rr)$$

v= volume
h = height
R = radius of the base of cone,
r = radius of the top of the cone



Ideally, the height of the dumpling needs to be known. This can be worked out from previous investigations, if boreholes were correctly placed. This information is generally not available from site plans or gasholder records for infilled tanks.

Old gasholder records did provide a lot of detail relating to the gasholders tanks, but these records are rare, as they were generally disposed of when the gasholder was decommissioned. Where this information is not available from records or site investigation details, previous experience of investigating gasholder tanks or reference texts must be brought to bear.

Alternatively, assumptions can be made based on a standard rule of thumb, which is the volume of the dumpling is 30% of the tank. However, this does not take into account the significant variation encountered based on ground conditions. It would be more accurate to calculate the size of the dumpling based on the angle of repose used in the strata in which the tank was built, and use this to guide the size of the upper flat surface of the cone.

Despite these problems, the presence of a dumpling is very important and it should be taken into account when investigating former gasholder tanks. The volume of the dumpling is very important when working out the volume of infilled material present within the tank and remediation volumes. Subtracting the volume of the dumpling from the cylindrical volume of the tank will provide the volume of potentially infilled material within the tank.

15. Selected Bibliography

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

1. Accum, F.C., Practical Treatise on Gas Light, R. Ackerman, London, 1816
2. Clegg Jnr S., A Treatise on Gas Works and the Practice of Manufacturing and Distributing Coal Gas, 1841 (other later editions), John Weale, London
3. Chandler, D. and Lacey, A.D., The rise of the gas industry in Britain, 1949, British Gas Council
4. Cripps, F.S., The Guide-Framing of Gasholders and Strains in Structures Connected with Gas-Works. Walter King, London
5. Francis, A., Stepney Gasworks, Museum of London Archaeology Study Series 22, Museum of London Archaeology, London, 2010
6. Hunt, C., A History of the Introduction of Gas Lighting, 1907, Walter King, London
7. King C. Editor, King's Manual of Gas Manufacture, 1948
8. Meade, A.,, Modern Gas Works Practice, 1916, 1921, 1934, Benn Brothers, London
9. Morgan, J. J., A Textbook of American Gas Practice, 1931, published by the Author
10. Newbigging, T., and Fewtrell, Wm., three volumes published between 1878-1913 King's Treatise on the Science & Practice of the Manufacture & Distribution of Gas, Walter King, London
11. Stewart E.G., Town Gas – Its Manufacture and Distribution, Science Museum/HMSO, 1958
12. Terrace, J., Terrace's Notebook for Gas Engineers & Students, 1948, Ernest Benn Ltd., London
13. The Institution of Gas Engineers and Managers, Variable volume gasholders storing lighter than air gases, 2011, IGEM/SR/4 Edition 3, Communication 1752

Photograph 16. Construction of two above-ground spiral-guided gasholders at a former gasworks in South-West England. Source: IGEM PHI.