Long-term fate and transport characteristics of manufactured gas plant residuals and wastes

ALLEN W. HATHEWAY[1]

[1] *Consulting Geological Engineer, Rolla, MO, USA. (e-mail: allen@hatheway.net)*

Abstract: The great era of manufactured gas (1805-1970) produced untold quantities of dangerous and non-degradable toxic substances, much of which today remains in the environment and ranks high in its threat potential for damage to human health and the environment. The author herewith classifies the long-term fate and transport of these wastes in a scheme based on two main facts: 1) gas was manufactured from organic feedstocks and 2) toxic residuals were produced along with the gas. The gas also was cleansed (purified) of impurities and all together the residuals formed the basis for recovery of some by-products, leaving the non-selected remainder as wastes.

Gas works not only generated toxic residuals and toxic wastes, but their very presence led to releases of several types: leaks, spills, discharges and dumping. The author has taken a special interest in the observed long-term fate and transport of these substances, mostly appearing as complex mixtures. This paper presents observations based on encounters of nine generic types of gashouse residuals and wastes typically encountered at today's derelict sites and a series of supported generalities (rules of sort) is presented for generic members of both groups of toxic substances.

Once forewarned on the basis of these empirical observations, we can then move forward to predict the general places around the former gas plants at which these toxic substances were released to the environment and also to make informed estimates of their fate and transport, all for the purpose of specifying the parameters for site and waste characterization of these uncontrolled hazardous waste sites (Hatheway protocol, 2002) in designing and constructing actual remedial actions. Without such considerations, derelict gas works and other coal-tar sites are subject to continual release of toxic substances to human receptors and to the environment, sometimes along unanticipated and undiscovered geologic pathways.

Résumé: La grande ère des gaz manufacture (1805-1970) produites quantités incalculables de substances toxiques, dangereuses et non-dégradables, dont beaucoup aujourd'hui reste dans l'environnement et se range haut dans son potentiel de menace pour des dommages à la santé humaine et à l'environnement. L'auteur classifie sous ce pli le destin et le transport à long terme de ces pertes dans un arrangement basé sur deux faits principaux : 1) le gaz était manufacturé des matières de base organiques et 2) des résiduels toxiques ont été produits avec le gaz. Le gaz également a été nettoyé (épuré) des impuretés et tout ensemble les résiduels a formé la base pour le rétablissement de quelques sous-produits, laissant le reste non-choisi en tant que pertes.

Les usines à gaz ont non seulement produit des résiduels toxiques et des pertes toxiques, mais leur présence est le cause de le dégagements de plusieurs types : fuites, flaques, décharges et vider. L'auteur a pris un intérêt spécial pour le destin et le transport à long terme observés de ces substances, apparaissant la plupart du temps en tant que mélanges complexes. Cet article présente des observations basées sur la rencontre de neuf types génériques de résiduels de gashouse et des pertes typiquement produites aux emplacements abandonnés d'aujourd'hui et à des séries de généralités soutenues (règles de sorte) est présentées pour les membres génériques des deux groupes de substances toxiques.

Une fois prévenu sur la base de ces observations empiriques, nous pouvons alors avancer pour prévoir les endroits généraux autour des anciennes usines de gaz auxquelles ces substances toxiques ont été libérées à l'environnement et faire également des évaluations au courant de leur destin et transport, tous afin d'indiquer les paramètres pour l'emplacement et la caractérisation de perte de ces emplacements non contrôlés de perte dangereuse (protocole de Hatheway, 2002) en concevant et en construisant des actions réparatrices réelles. Sans de telles considérations, les usines à gaz abandonnées et d'autres emplacements de goudron de houille sont sujets au dégagement continuel des substances toxiques aux récepteurs humains et à l'environnement, parfois le long des voies géologiques imprévues et non découvertes.

Keywords: contaminated land, groundwater contamination, hazardous waste, pollution, site investigation, waste disposal.

INTRODUCTION

A considerable challenge for geologists involved in site and waste characterization of derelict gas plants and all manner of other coal-tar sites rises in recognizing and defining the nature, position, and extent of toxic residuals and wastes associated with those industrial processes.

In the process of converting organic feedstocks to usable gas, certain benzene-chain PAH (polycyclical aromatic compounds = “tars” and tar oils) organic compounds are generated to an excess degree beyond what are incorporated in the blend of organic compounds making up the gas, for whatever end use; illuminating, cooking, heating, or as fuel. These PAHs and other environmental contaminants, under today’s standards, as excess compounds to the product gas, were removed from that gas, as impurities, and were subject to handling and management on the gas yard footprint.

Each design component of a gas works is the scene of one of the necessary steps of treating the gas (or other primary product, such as coke) to impart necessary characteristics and qualities necessary to prepare the product for sale or recovery and reuse on the gas works property.

An accurate site and waste characterization of each former gas works or other coal-tar site is the absolutely necessary prelude for development of appropriate remedial engineering.

GENERATION OF RESIDUALS, BY-PRODUCTS AND WASTES

Virtually every component of the facility of the facility, save the inter-component piping, surface and subsurface storage vessels, sewers, and areas of discharge or dumping, can be assigned a characteristic manner of generation of residuals, by-products and/or wastes (Figure 1).

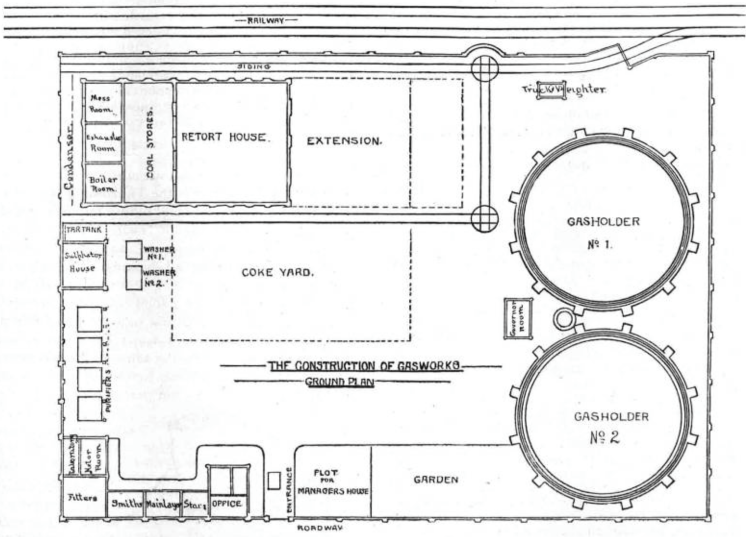

Figure 1 “Typical” gas yard layout for a medium-sized coal gas works, here interpreted to produce about 150,000 cf per day, as based on relative dimensions of the two gas holders, which undoubtedly are of the subsurface-tank variety. Note that the tar tank is shown present and in the subsurface (*Progressive Age*, 1889)

The author’s personal rules regarding these principal components and their generational function are as follows:

Generation

Essentially all gasification processes either liberate moisture or make use of some moisture in the process of gas generation. This moisture becomes the basis for the gas liquors that solubilize and suspend PAHs and other contaminants, which have always been of concern toward creation of nuisances and pollution of yesteryear and the contamination that now is of concern. Some of these liquid wastes escaped plant components especially in consideration of the intimate contact with the foundation soils or from subsurface vessels (Figure 2) in direct contact with the ground.

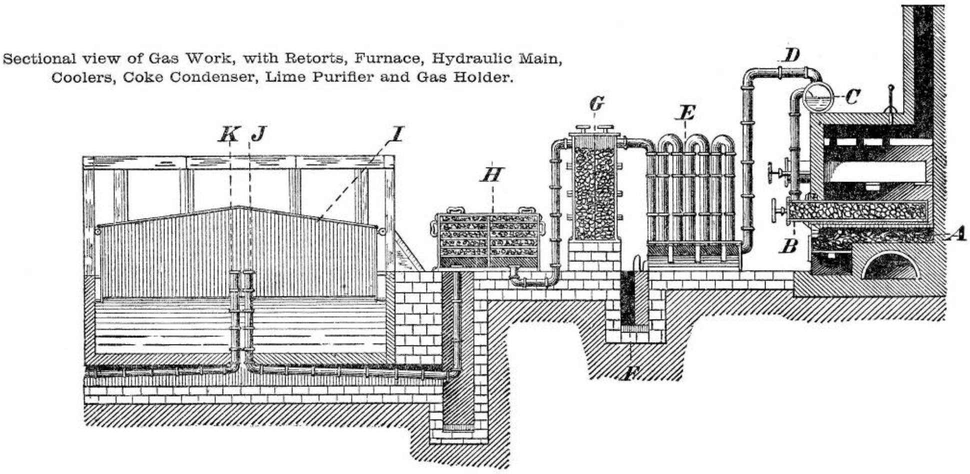

Figure 2. Vertical schematic section of the coal gas plant at Bristol, England (From U.S. Department of State, 1891). Legend: A. Retort Furnace; B. Retorts; C. Hydraulic Main; D. Dip Pipe; E. Condenser; F. Tar Well; G. Washer; H. Lime-Medium Purifier; I. Gas Holder; J. Ascension Pipe through water; K. Supply Pipe to street mains.

Retorts and ovens

Coal carbonization processes liberated water of hydration and some absorbed moisture when coal was stored out of doors, without resort to roofed sheds. This moisture created the fluid waste known as "ammoniacal liquor" and the liquor was always of potential value for recovery of ammonia, certainly after about 1870, due to technologies of the day and the industrial demand for recovered ammonia. Late in the 19th century this ammonia became the basis for an additional by-product, mainly ammonium sulfate, which was becoming, among other uses, a recognized agricultural fertilizer.

Hydraulic main

This component of coal carbonization was utilized to begin the process of capturing impurities (mainly tars and tar oils) that degraded the usefulness of the produced gas. Due to their capacities to collect tar from the gas entering from the retort riser pipes, hydraulic mains typically were drained to some sort of collection point, or to some form of plant discharge, the latter in cases in which the plant management were not interested in recovering the tar.

Generators

This term was reserved for gases that were created for heat and energy, as well as carburetted water gas (CWG) and such oil gases as were made primarily for illumination. CWG in particular, was made for illumination, but the equipment could be used to make non-illuminating fuel gas. The point here is that water is either essential to these process or is yet present. The main residual that has been of concern is the "gas liquor," which had essentially no value in terms of recoverable by-products.

Clarification

This is a collective term, which has been introduced by the author, to serve in the traditional lapse for an overall term for process treatments designed to remove mainly tars and ammonia, before the gas reached the stage of "purification." The various clarification component devices were on many dimensions and operational design variations, but generally (not always) appeared in the process pathway in the order shown below.

Some clarification devices employed rather less (to nil) gas liquors, but many were dependent upon passing the "foul" gas through a water-based cleansing fluid (the gas liquor) or employed water (in some instances, light oil ("straw oil) for absorption or dissolution-removal of impurities. Essentially all of the clarification devices had some sort of tar sludge collection sump, generally requiring removal (usually by hand) on a frequent (say, weekly or more frequent) basis, and subsequent management of the tar.

Wash boxes

This stage served to isolate the created gas from passing backward in the system and into the retort or generator, where such could cause and explosion. In addition to the water-seal function, the gas liquor present in the wash box served to begin the removal process for impurities.

Condensers

As the wash box primarily serves as a safety-related feature, the condenser(s) serves as the first step in gross removal of impurities. It is helpful to determine if and when non-contact condensation may have been employed in lieu of the older and more traditional contact devices, as concerns the potential for generating additional gas liquors which required management and may have been discharged to the ground on or around the site. The main function of condensation was to lower the temperature of the gas as a means of precipitating tars.

Some condensers, especially the Pelouze & Adouin variety, manufactured in France, also delivered strong concentrations of ammonia, when installed at coal-gas plants.

Scrubbers

As a rule, scrubbers all employed liquid in some form, and their main characteristic was a packing of some sort of removable sorption medium, which would eventually become saturated ("spent") and then generally required removal and management as a solid waste. Scrubbers, in addition to collecting tars, also were specially designed for removal of other undesirable gas impurities such as ammonia.

Washer-scrubbers

These devices combined the use of a washing fluid and a sorption medium. Again, the impurities were captured and then required additional management.

Tar extractors

These were dominated by the always-successful Pelouze & Adouin device brought out commercially in the 1850s and served throughout the manufactured gas era. The extractors were floor-mounted and operated in indoor locations.

Tar separators

Coal carbonization processes liberated water of hydration and some absorbed moisture when coal was stored out of doors, without resort to roofed sheds. These units generally appeared after 1900 and were designed to deal with the tar-water emulsions of carburetted water gas plants, and most were installed underground and operated on gravity through-flow with a baffle-extended flow path operating on sedimentation of suspended tar particles. Again, the captured tars needed removal and the separated gas liquors faced further management as plant effluent wastes. Many of the boxes were constructed of wood and were more susceptible to outward leakage of gas liquors and light tar oils, into the geologic host medium, than were the alternative construction material, reinforced concrete (Figure 3), with wood baffles.

Figure 3. Concrete tar separator box discovered during site remediation at Dover, New Hampshire. The box measures about 2 x 3 m in plan (Courtesy of New Hampshire Department of Health Services, Concord, N.H., 2002)

Purification

The clarification process was custom designed for each plant and changes were made for various reasons, with time, to include specific attempts at removal of certain impurities that entered the system from the feedstocks employed. The major objective of clarification was the removal of tar, while the last step in the manufacturing process, purification, was to remove sulfur, as well as (when present) carbon dioxide, cyanide, and particulate trace elements known to be unsatisfactory to the quality of the gas, for whatever purpose it was manufactured.

Purifier boxes

Purification went on in “boxes,” though by no means were all purifiers of a standard geometric shape, cube, parallelepiped, or cylindrical. The boxes generally were employed in series, as pairs, and, as backup to cleaning and malfunction, most plants had a parallel system. The interiors of some boxes were shelved and some were bulk-filled, the latter generally not applying to slaked lime as the purifying agent, in recognition for its tendency to clog and therefore better used in shelved layers. It is not generally recognized that purifiers gathered significant amounts of precipitated gas liquors, containing tars and liquid PAH fractions, which usually drained by gravity to the bottoms of the boxes, which were typically valved for off-drainage of such liquors.

By-product recovery (not essential; when employed)

Recovery of residuals for conversion to valuable by-products (bye-products) often is claimed to be routine. For some larger gas works, especially after about 1875, this was so, but at earlier dates and for many smaller plants the option of recovery and reuse or resale was not adopted, thus transferring most residuals directly to the waste category.

Ammonia still

Discharge of ammoniacal liquors from gas works was perhaps the earliest of the damaging waste discharge practices to reach the courts in terms of litigation over damages or nuisances. These complaints were particularly rife in the United States by the 1850s and 1860s and by the 1870s some gas companies (notably the San Francisco Gas Light Company) had taken measures to run at least part of their ammonia cal liquor through recover stills, and were marketing the residual as a by-product to home makers and to industry as well.

Ammonium sulfate recovery plants

Beginning with the Belgian emphasis on recovery of residuals at coke oven plants, a new trend developed in the gas-making industries of the industrialized nations, by which both ammonia and sulfur were recovered for industrial and agricultural purposes, especially ammonium sulfate for agricultural fertilizer.

Tar still

Larger gas works sometimes (but not to be considered routinely) made constructive use of their gas tars by sending them through stills and separating each distinct tar-oil fraction for off-plant shipment in wooded kegs or barrels. Tar stills locations remain today as typically contaminated ground, from leakage and spillage of their external feed and discharge piping.

Light-oil stills and benzol recovery plants

Thanks to the overall contribution of Belgian gas and chemical engineers, 1890 emerged as the general availability of technologies designed to recover by-product light oils and solvents (from what was termed "benzol"). When selected for employment, the nuisance and damage potential for those involved plants was lowered considerably.

Gas liquor dehydrator

In North America, at least, about 1905 there developed a situation that has led to much specific gas-plant contamination being faced today. This came about through the highly successful promotion of T.S.C. Lowe's carburetted water gas discoveries of 1873-1875, by the United Gas Improvement Company (UGI), of Philadelphia, Pennsylvania. UGI bought Professor Lowe's patents and pushed the process strongly against its 17-year patent life, both in North America and in Britain. Around 1905, the success of the motor car, however, had created a strong market for light oils as vehicle fuels and the price of carburettion oil began to rise. At the same time, enhanced industrial consumption of coke, the ideal CWG generator fuel, was rising, and, during WWI became not only costly, but scarce. Under these pressures, CWG plant operators frequently made us of bituminous coal feedstocks and heavy oils for carburetting. The net result of this choice was creation of gas liquors made up largely of tar-water emulsions that contained up to a recorded 92 percent water, excessively higher in all cases than the tar distillers would tolerate for purchase at reasonable prices.

As a result of this situation, widespread dumping of tar-water emulsions was selected as the management option and tar ponds became even more common, along with direct discharge into adjacent swamp (today's wetlands) areas.

Some relief could be had by a number of options by which the tar-water emulsion was stripped of its bound water content. The most common of these treatments were low-cost steam-activated dehydrators (Figure 4).

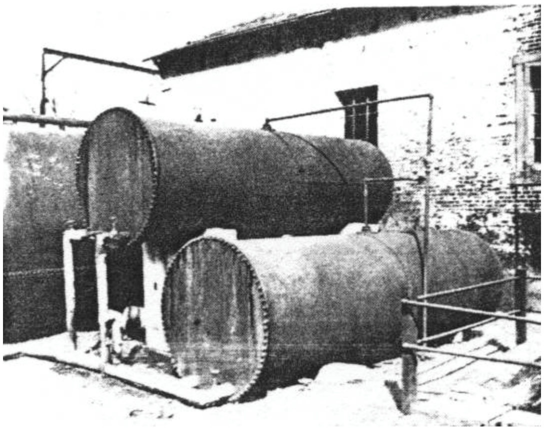

Figure 4. Tar-water emulsion dehydrator fabricated at the Pottstown, Pennsylvania Gas Company (*Proceedings,* American Gas Association, 1929)

Yard and line drips

Gas sent into subsurface piping was subjected to further cooling and also separation of PAH light oils from the gas. These fluids were heavier than water and gas engineers learned to place collection sumps, called "drips" at points of depressed elevation along the gas yard lines, and certainly at artificially-created low points along the distribution points. These drips were pumped out periodically, into tank wagons or, later, tank trucks. The drip fluids normally were rich in light oils, such as naphthalene. In some cases the light oils were turned into recyclable feedstocks for enrichment of coal gas or for carburetion of water gas, or for sale as solvents. Other cases of discharge to the ground as utility company herbicides or as discharge into the interstices of gas works dumps.

Storage

At those plants at which some further use or recovery of liquid residuals was embraced, there was a natural need for interim storage, even as a basic collection device. These storage vessels generally were of the subsurface variety and they typically received the flow of tar and/or gas liquor by gravity drainage. Once in the cistern or well (equally equivalent terms), some degree of gravitational separation of oils from water-based liquor was carried on, including a hand or steam-operated recovery pump to raise the lower-elevation tars for follow-up treatment or use. Other plants, not interested in recovering tars or light oils, employed vessel designs equipped for automatic overflow of the gas liquor as it separated and made up the upper layer of fluid.

At least until about 1900, most of the subsurface vessels were constructed of stone or brick masonry, less frequently and later, of concrete, unreinforced or reinforced, and virtually all of these leaked substantially, through fractures and mortar joints, transferring light oils into the surrounding earth media.

Tar cisterns and tar wells

These are terms of the gas maker's art and to date, the author has not found evidence of definitive design or construction details that might suit either term universally (Figure 5). These vessels generally are of masonry, with or without formal masonry bottoms, and in the typical range of three to five meters in diameter and 4 to 6 meters of depth, as retained generally by a single course of masonry. Of course, each of the vessels should be considered to have naturally leaked gas liquors and light oils of the contained tars, into the surrounding geologic media, to the extent of their physical-chemical character and that of the soils to which the outflow was incident. In this connection, it always is wise to explore ground around each such vessel, particularly on that portion of the wall that appears to represent the most likely overall lateral down-gradient groundwater flow vector.

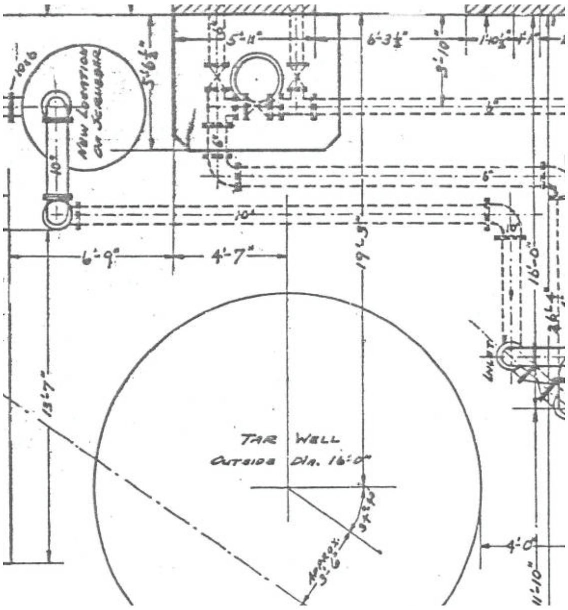

Figure 5. One of twin 4.8 m-diam. tar wells at the Olwein, Iowa gas works, 1928 utility plant drawings (Courtesy Iowa Department of Natural Resources, Des Moines, Iowa).

Discharge or disposal

Gas liquors were the ultimate gas works effluent and not matter the degree of attention given to removing captured impurities, their ultimate discharge was subject to a number of environmental consideration; not the least of which were cooling and PAH precipitation on entering surface waters. Then discharged to inward-draining pits, depressions or ponds, the liquors were subject to gravitational infiltration into the geologic subsurface.

Tar filter

These boxes generally were filled with sorptive coke breeze or some straw-like sorptive medium. Most were placed at the last point of plant gas liquor sewer, just before discharge. The State of Pennsylvania was a leader in requiring such treatment, to reduce the content of solubilized PAHs in the discharged gas liquors, mainly after 1928.

Gas liquor pond

Even in those situations where efforts were made to recover tars and/or tar oils from all manner of gas liquors, the fact remains that the "purged" liquor yet likely would have retained PAH compounds to such a degree that some environmental damage or nuisance might occur with its off-plant discharge. For this reason it is well to keep in mind the possible interpretation of hot spots of TPAH concentrations, along with slightly to grandly stained surrounding soils, yet without relatively large concentrations of tar sludge within the confines of the hot spot or of excessive tar blebs occurring in the natural ground around and below the hot spot.

Tar pond

At various times and places, plant economic conditions were such that there was essentially no effort to recover tars and tar oils for any reason. It is a well-established fact that direct discharge of tars has been known as a damage-producing nuisance in the British Isles and in North America (the main geographic fields of study of the author) since the very beginning of the manufactured gas industry. In consequence of whatever situations led the gas works management to eschew tar recovery and conversion to useful or salable residuals, a tar pond often was employed, on or at the fringe of the gas yard, as a dumping ground. Tar relegated to these ponds, depending on its character, the pond configuration and local geological conditions, often led to a self-draining situation in which the lighter fractions were transferred, out of sight, into the subsurface. Such a situation should be kept in mind in planning and executing gas works site and waste characterization efforts, as an item to investigate and confirm presence or to verify and absence of such a choice of waste management options.

Subsurface tanks of gas holders (gasometers)

Gasometer design, from the earliest days of the manufactured gas industry, typically included a subsurface water-seal tank and these tanks typically were constructed of three-rings of brick masonry, and known, from the earliest days, to be susceptible of outward leakage of their water seal.

With time, the seal water became highly contaminated with PAHs and the tank itself accumulated tars and tar sludges. Gas holder design did not advance from subsurface to surface water seal tanks until about 1900, and this advance was known worldwide as an improvement that was almost universally adopted. Therefore, in terms of gas plant site and waste characterization, every subsurface water-seal tank should be investigated for having experienced outward leakage both through the walls and, sometimes, through the bottom, which was not always equipped with a formal floor.

The potential for contribution of gas holder tank leakage rises incrementally for those holders employed as “relief holders” for carburetted water gas plants, in which the raw gas often was delivered directly to the holder, without efforts toward clarification. The gas was then withdrawn for further treatment, leaving an enhanced opportunity for contamination of the water seal fluid.

ESTABLISHING A BASIS FOR FATE AND TRANSPORT ASSESSMENT

In order to assess fate and transport of gas works contaminants, it is necessary to develop a hierarchical understanding of what forms, quantities and times of generation are relative for the processes or processes known or suspected to have been used at the site.

The preliminary step in site and waste characterization is to assess how the plant, works or facility is known or suspected to have operated. Here is the author’s concept of working up this information:

- Establish the nature of the operation;
- Define the likely process(es) present;
- Establish the nature and presence of each component of the gas works, from retort (or generator), through clarification, to purification, then gas and residual storage, and the presence and routing of subsurface piping between the components;
- Identify the most likely points or areas of discharge of such residuals as were not converted to by-products, therefore having become likely wastes;
- To the extent possible (considering gas yard solid debris in the subsurface, as obstacles), use various soil gas or push probes to track typed contamination between component-points-of-origin and the down-gradient edge of concern for particular contaminants (Contaminants of Concern; COC’s)
- Consider that some liquid-born contamination may have leaked into the ground from subsurface piping compromised by rust, soil or process-waste chemical corrosion, or from electrolytic corrosion;
- There is a possibility that “hot spots” of contamination, bearing no demonstrated spatial connection with known generating components or compromised subsurface piping, may well represent a plant dump, and;
- Plant dumps often are made up of a matrix of inert gas works solids wastes such as fragments of spent retorts, generator bricks, damaged metallic tools and plant equipment, into which gas liquors or other toxic gas plant liquid wastes were discharged.

AUTHOR’S OBSERVED FATE AND TRANSPORT “RULES”

It is of prime importance to work toward a logical historic operational assessment for the condition(s) of origin of each distinct occurrence of gas-works site contamination. It is obvious that each occurrence of these residuals or wastes represents a chain of events spanning 1) creation (generation), 2) release, and 3) possible transport. At some point, the contamination can be said to have come to a position of relative positional stability, from which it either remains in essentially its concentration-upon-arrival, or it will be reduced, if in the presence of passing groundwater of a chemistry favorable to its dissolution and with further transport of its chemical substance, as borne in solution by the passing ground water.

Table 1 provides a sense of some general gas-house “fate and transport” rules as observed by the author, based on analysis of reported concentrations of types of contamination reported to environmental regulatory authorities in the course of gas-works site remediation.

Table 1. Typical Observed Fate & Transport "Rules" for Gashouse Residuals & Wastes

Residual or Waste	Typical Condition	Implications
PAHs in General (1 or more benzene rings)	Relative time of discharge may be established by careful observation and recording of exhumed field operations	When not established, there will be virtually no support for later claims as to timing and responsibility for release of the PAHs, whether during operational times, or as sometimes claimed, after termination of gas-making operations
"Light Oils" (VOC PAHs; AKA MAHs and DAHs; monocyclic aromatic hydrocarbons [BTEX] and duocyclic aromatic hydrocarbons, of one and two benzene rings)	o Typically found miscibly or dissolution-associated with heavier PAHs o Generally about 10 percent of associated heavier-oil tars o Often originated as gas liquors (process effluent) o Generated in far larger quantities than heavier tar oils; say tens to a hundred times more quantity o The only PAHs that travel extensively o May carry dissolved heavier PAH compounds outward to point of subsurface deposition	o When encountered below the vadose zone, generally associated in the mix of heavier tars o May reach several km in surface- water distribution in the most porous of soils, then precipitate the carried heavier fractions of PAHs o When leaked as fractions of heavier PAH tar associations, reach radial, stratigraphic down-gradient fans at up to several meters from point of leak, spill or discharge o Often drop heavier fractions as isolated tar 'blebs' without visible connection to other PAH contamination in the host stratigraphic position
Medium Oils (Tar) (3 and 4 benzene rings)	Generally found within 3 m laterally/radially of the original discharge point	Where found without direct association with a gas works component, then to be considered as transported manually for dumping
Heavy Oils (Tar) (5 and 6 benzene rings and greater numbers not reported under USEPA protocols	Typically immobile from point of discharge, except for lighter contamination and soil staining from light oils caught up in the original tar body	Where found without direct association with a gas works component, then to be considered as transported manually for dumping
Sludges & Pitch (No inference as to benzene ring numbers; rather having lost volatiles and/or heavy percentage of non-refractory geologic minerals present)	Strictly immobile; required at least weekly cleansing of gas works components at points of generation	Typically found as dumped at some distance from the most logical point of generation at the gas works.
Free Carbon Retort and Shell Scurf Lampblack	Not intrinsically toxic but highly adsorbent of PAHs after generation and at disposal sites	Lampblack was a major waste of oil-gas generation; scurf accumulated in retorts and in carburetted water gas shells before innovation of backrun
Spent Lime Box Wastes	Dense and foul with sulfur, expect to see iridescent sheens of Prussian blue	Only infrequently found in direct association with wood chips or forms of iron oxide; may have some tars as stringers and blebs
Spent Wood Chip Box Wastes	Most often found without associated lime or oxide	Expect to find small (few cm diam) accumulations of tars; may blossom into Prussian blue stains only after exposure to the atmosphere for hours upon exhumation
Spent Oxide Box Wastes	Come in many forms, including iron-rich acids originally sprayed to enhance capture of cyanide and sulphur	Contents range all the way from solution-impregnated wood chips to low-grade iron ore; the latter generally caked and dense; expect blebs of tar
Plant Dump	Typically solid waste made up of spent retort and shell bricks and miscellaneous plant trash	Inherently non-toxic, but often the site of discharge of toxic gas liquors and off-specification gashouse tars.

RELATIVE MAGNITUDES OF GAS-WORKS TPAH CONTAMINATION

As the results of laboratory analyses of waste characterization sampling begin to arrive for analysis in terms of site-specific contamination, it often is helpful to consider the relative magnitudes of total PAH concentrations (TPAH) reported at specific sampling locations. These concentrations, when studied in the context of surrounding values, site geologic characteristics and relative position in the gas yard layout, can lead to a refined understanding of the entire contamination situation, both for continued site and waste characterization, and also in the development of the site remediation and closure plan. Table 2 represents the author's framework for assessment of the ultimate meaning of contamination magnitude, for these purposes.

SUMMARY

It is clear that much definition of site contamination can be gained from simple comparisons of the relative nature, position, and concentration magnitudes of not only species of gas-house contamination, but of their relative magnitudes. The overriding rule of consideration, however, is the evaluation of contamination in terms of individual "hot spots" of contamination and how they relate, on the one hand, to likely points of generation in the gas-manufacturing process, how they came to be in their respective locations, and how that presence may lead to continued contaminant transport or release to the environment or to potential human receptors. These considerations are developed to a full extent in the author's forthcoming technical book (Hatheway, in press, 2006).

One most important factor to keep in mind, concerning the generation of gas-works wastes is that the entire effort toward clarification and purification was conducted to remove impurities from the gas produced for sale by the works. This, of course, means that the residues of clarification and purification all were intrinsically toxic at the time of their creation and this situation means that plant residuals and wastes were always representative of concentrated toxic substances.

Table 2. Typical FMGP Residual and Waste TPAH Contamination Magnitudes

Relative Concentration	Typical Reference Condition
< 100 ppm	Operational leaks, spills and ordinary gas yard transfer of gas-production residuals; PAHs, sulfur, ammonia, cyanide
100 – 1,000 ppm	Small leaks and incidental discharge of gas liquors Typical of sorptive-stabilized wastes encountered and left in place by post-operational plant demolition activities (typically 1960-1976 in the U.S.) 1,000 ppm here established as an arbitrary threshold of convenience in designating accumulations such as may indicate a hot spot or evidence of a larger subsurface body of toxic gas-manufacturing residuals

Author's Presumptive Threshold
Between FMGP Minor and Major Waste Concentrations

1,000 – 100,000 ppm	Taken here as representative of long-term, operational-era leakage of PAHs as toxic gas-manufacturing residuals Should be considered as possible evidence of the outer radius of gas pit-holder discharge of PAH-based gas liquors
> 100,000 ppm	Taken here as representative of typical bodies of subsurface storage; Possibly indicative of one or more of the following conditions: 1) Chronic (long-term) operational leakage as the condition which brought about the detected subsurface toxic gas-manufacturing residual source volumes 2) Major operational-era spillage and/or major dumping 3) Long-term operational discharge of gas liquors 4) Long-term, operational subsurface transport of light to medium oils and oil-water emulsions 5) Operational-era gas-liquor discharge into the voids of previously-dumped gas-yard solid wastes

Corresponding author: Dr Allen W. Hatheway, Consulting Geological Engineer, 10256 Stoltz Drive, Rolla, Missouri, 65401, United States of America. Tel: +1 573 364 0818. Email: allen@hatheway.net.

REFERENCES

HATHEWAY, A.W. 2002. Geoenvironmental protocol for site and waste characterization of former manufactured gas plants; worldwide remediation challenge in semi-volatile organic wastes: Inaugural Paper in *Principles of Engineering Geology*; The George A. Kiersch Series, Engineering Geology, Amsterdam, **64**, 4, 317-338.

HATHEWAY, A.W. 2006. (in press), Remediation of Former Manufactured Gas Plants & Other Coal-Tar Sites: Taylor & Francis Ltd./CRC Press.

U.S. DEPARTMENT of STATE. 1891. Gas in Foreign Countries. Reports from the Consuls of the United States; In Answer to a Circular from the Department of State. Washington; Government Printing Office. iii + 256p.