10 COAL CARBONISATION

Chapter contents

10 COAL CARBONISATION

10.1 Introduction

10.1.1 Coke, coal gas and smokeless fuel

The process of coal carbonisation is intimately associated with both the coal and steel industries. Coke, a primary product of the coal carbonisation process, is produced from coal for use in the manufacture of iron and steel, where it provides a fuel and a reductant for the smelting of iron ore. Coke replaced charcoal in the iron-making process in the early eighteenth century (see Section 9.1.3).

In addition to the manufacture of coke, coal carbonisation is used for the production of coal gas ('town gas') and of smokeless fuels for the domestic market. Smokeless solid fuel is produced by low-temperature carbonisation (<700°C), whilst coal gasification relies on the high-temperature process (>900°C). Coke may be regarded as a by-product of the coal gas industry.

The European coal gas industry has now almost disappeared in favour of natural gas and other, cleaner, alternative sources of energy.

Coal gasification, coke making and smokeless fuel manufacture are all coal carbonisation processes. In these processes coal is heated under oxygen deficient conditions, usually in large batteries of silica-lined ovens, with the subsequent liberation of gaseous combustion products and volatile components, including both aliphatic and aromatic hydrocarbons, oxides of sulphur and nitrogen and other coal impurities.[30] Although coal gas produced from the gasification itself acts as a fuel to fire the ovens, large quantities of gaseous and particulate emissions from the coking and smokeless fuel processes were, in the past, freely liberated into the atmosphere. In many areas this has led to a significant rise in the background concentrations of toxic organic compounds in surface soils.[116, 130]

Coke is thus a purified carbon product. It has a large particle size not dissimilar to that of the coal feedstock, but exists in a highly reduced form, and has robust structural qualities. In the blast furnace coke provides heat, reducing power (in the form of carbon monoxide) and structural support. The long history of the coking and coal carbonisation process has been parallelled by the development of a variety of different designs of carbonisation plant, with significant contributions arising from Germany, the United Kingdom and the Netherlands.[30, 262]

Although the best coking coals are of a low-volatile bituminous nature, other highly volatile and highly sulphurous coals have traditionally been blended with more suitable coal feedstocks for the production of coke. Whilst good coking coals produce significant quantities of by-products, those of a lower quality led to greater emissions to the atmosphere, greater deposition in local areas and larger quantities of by-products and wastes.

10.1.2 The carbonisation process

Coal carbonisation involves the destructive distillation of coal, and during this process as much as 50% of the weight of the coal feedstock is driven off as gaseous and volatile components. These are regarded as by-products of the coking process, and include combustible gases *e.g.* methane and hydrogen, and the lower boiling point components of coal tar *e.g.* benzene and naphthalene.

Older coal carbonisation works burnt coal in horizontal, silica-lined retorts. These were often long pipes with a semi-circular cross section, arranged in two vertical rows of four or more, on either side of a primary combustion chamber where the ‘producer gas’ was burnt. Gas passes from the retort along a hydraulic main, and here some ammonia, coal tars and phenols are recovered in condensate as by-product liquor.

Larger volumes of tarry condensate are recovered in condenser plant, consisting of vertical water- or air-cooled pipes over which the crude gas is passed. This removes further ammonia and tar in the gas stream.

At town gas works and coking plants gas passes through scrubbing systems, which use dilute acid solutions to remove the remaining ammonia, giving rise to ammoniacal liquor. The liquors associated with gas cleaning are often the source of significant contamination of coal carbonisation sites.

The partially-cleaned gas then passes through purifier beds containing hydrated ferric oxide (or 'bog iron'), where hydrogen sulphide gas was removed.

10.1.3 By-products and environmental considerations

In the past the by-products from coke manufacture often formed the feedstocks for other chemical manufacturing industries, although much of the material was regarded as waste, with little or no intrinsic value. The hazardous nature of these wastes was not fully realised, and consequently the waste disposal practices of the manufacturers were basic, with little or no consideration being given to either the environment or the health and safety of workers at the site. Therefore many sites on which coal processing facilities once stood still contain significant quantities of toxic waste products from their former activities, often indiscriminately deposited in unlined landfills or poorly maintained underground repositories.

The locations and nature of such underground deposits of waste are often identified only after a thorough site investigation. Measures can then be taken to minimise environmental and health risks in the area during the course of a reclamation scheme. Often, however, land reclamation schemes that were undertaken in the past have paid little attention to the adequate removal, containment or treatment of these wastes, and they remain in subterranean deposits beneath newly developed sites. In many

European countries, the presence of an operating gas works in a central location in most towns and cities prior to the use of natural gas, has resulted in a large number of former coal carbonisation sites being redeveloped as part of urban regeneration and development schemes. Although some of these sites remain derelict and/or untreated, there are many that have been reclaimed, and of these a number retain underground deposits of wastes that have been merely covered over in the course of development. The ill-founded philosophy of 'out of sight is out of mind' has been all too commonly adopted in the redevelopment of chemically polluted sites. Coal carbonisation sites are no exception.

Improvements in the 1970s to the design and operation of coal carbonisation facilities have been prompted by the requirement for cleaner, pollution-controlled operations. Previous unwillingness by the operators of coal carbonisation facilities to incorporate new technologies for the purpose of pollution control has been overcome by legislatory pressure to meet increasingly stringent emission standards. What was therefore once viewed as capital expenditure with no foreseeable financial benefits has become a necessary expense to avoid both ongoing pollution and potentially large remedial action costs prior to the sale or redevelopment of redundant sites. Various technologies and equipment are now used in operating coking plants to improve the environmental and output performance of the coking process.[160]

Coking and coal gas production are industries which originated in the nineteenth century, and, like coal and steel production themselves, they have left behind a legacy of industrial dereliction and environmental damage. Derelict land from the closure of coal carbonisation facilities continues to be created throughout Europe, as the requirements for coal products and by-products decline in the face of new technologies and other changes to industry.

The fundamental environmental consequence of the coal carbonisation process is that it involves the separation and concentration of various chemical fractions, from their relatively low concentration within the coal-carbon matrix to several by-product chemical streams of highly elevated concentrations. In addition, some of these by-product chemicals are of relatively high mammalian toxicity, and therefore pose a risk to human and animal health, and to the environment in general.

10.2 Nature of by-products and wastes

10.2.1 Introduction

There are a number of categories of by-products that arise from the various coal carbonisation processes.

The major by-product streams from carbonisation can be placed into five categories:

- liquid effluents;
- high boiling point tars;
- spent oxide;
- acidic sludges;
- benzole still bottoms.

The chemical nature of all of these waste streams is dependent on the nature of the coal used to feed the plant and on the type of process employed. The following gives a broad account of the composition of these by-product streams.

10.2.2 Liquid effluent

Ammonia, a simple though potentially toxic chemical combination of nitrogen and hydrogen, is a major constituent of the reducing process of coal carbonisation. Ammonia was removed principally as a waste product by condensation and scrubbing liquors, which were often produced in large volumes during coking and gasification. Such liquors often contained in the region of 1 to 2% ammonia.

Box 10.1 lists the compounds found in a typical ammoniacal liquor. Ammoniacal liquors are usually alkaline, and in addition to the substances shown in Box 10.1, they may contain significant quantities of other potentially toxic chemical species, including pyridine and other heterocyclic nitrogen compounds. Generally they contain high concentrations of inorganic and organic compounds, and therefore have high biological and chemical oxygen demands (see Box 10.2). Ammoniacal liquors are therefore of great significance as potential polluters.

In addition to the scrubbing and condensation processes described in Section 10.1.1, ammoniacal liquors amended with ammonium sulphate and sulphur, or alternatively, alkaline ferrous sulphate liquors, have been used to remove further cyanide from the coal gas. Significant quantities of ferrocyanide and ammonium thiocyanate are produced at this stage.

The waste disposal practices of former carbonisation plants are likely to have included indiscriminate discharge into local watercourses, and even to groundwater. Later effluent management practices may have involved the storage of liquors in holding tanks prior to collection and disposal off site. Where a coal processing plant was closed, undisposed liquors may

Box 10.1: Chemical components of a typical ammoniacal liquor from coal carbonisation

Phenols	e.g. phenol, cresol, dimethylphenol
Cyanide	as HCN
Thiocyanate	as SCN^-
Sulphide	e.g. H_2S in solution
Thiosulphate	as $H_2S_2O_3$
Ammonia	e.g. NH_4^+ in solution or fixed ammonia
Carbon dioxide	as CO_2
Light aromatics	e.g. Naphthalene, methylnaphthalene, benzene
Chloride	as HCl

Box 10.2: Definition of biological oxygen demand and chemical oxygen demand

Organic molecules can be oxidised, *i.e.* combine with oxygen and donate electrons, either through biological processes (mediated by enzymes) or by chemical oxidation (facilitated by oxidising agents). Oxidation can give rise to the mineralisation of an organic molecule, producing carbon dioxide and water.

Biological Oxygen Demand (BOD) provides an estimate of the amenability of organic materials in solution to biological oxidation. Thus, the BOD test involves the dilution of a liquid sample with aerated, distilled water, and the measurement of dissolved oxygen in each of two identical sub samples; one immediately after dilution and the other after seeding with aerobic bacteria followed by a period of incubation at 20°C. This incubation is typically for five days, in which case the notation BOD_5 is used. The BOD test, by quantifying oxygen consumption, measures oxidisable organic matter, oxidisable nitrogen compounds and some reducing compounds e.g. sulphides. The latter is due to chemical rather than biological reactions.

Chemical Oxygen Demand (COD) measures the chemical oxidation of organic material in a solution. The method uses boiling acidified potassium dichromate to oxidise the material, and the excess dichromate remaining after the reaction is measured by titration. Some chemical species, notably chloride and ammonia, can give anomalously high COD values, however, and in addition some organic molecules e.g. benzene and toluene, are incompletely oxidised.

Results for BOD and COD are expressed in mg/litre.

Although both tests have limitations, as outlined, they provide useful indications of the general nature of organic contamination in a liquid sample. The testing of BOD and COD on the same sample can, in addition, provide a useful estimation of the proportion of organic contamination that is amenable to biodegradation. This can be expressed as the COD:BOD ratio.

have been left on site, and these may remain in underground tanks and pipes for many years. Leakage of liquor from both above- and below-ground structures would have invariably led to local contamination and possibly the accumulation of residual chemicals in spatially distinct soil and groundwater. Changes in the local soil and groundwater conditions, during, for instance, a reclamation operation, structural development or site investigation, may result in the spread or redistribution of contamination (see Section 4.5).

10.2.3 Tars

Tar was often a valuable by-product at coking works and associated facilities. Tar was removed by either condensation or gravity separation from the liquors or by tar extractors used for purifying the gas stream.

In all but some of the more recent coal carbonisation plants, tars were generally stored in structures below ground, and were often transported from one part of a site to another via large underground pipes. Tar pipes, wells, pits and slumps are common features of former coal processing facilities, and are often a cause for concern during reclamation works due to the problems associated with the handling and disposal of the residues contained within them.

More recent coal carbonisation facilities were designed with above-ground tar storage tanks, from where crude tar could be collected and transported off site for use elsewhere.

Tars are a complex and diverse mixture of organic compounds. Amongst the more toxic and harmful to the environment are the PAHs (polyaromatic hydrocarbons). A great number of this diverse group of hydrocarbons are present at high concentrations in coal tars. Box 10.3 gives details of some of these compounds.

Coal tars are an important product of coal carbonisation. Tars are distilled and refined to produce a variety of products, such as

Box 10.3: Major chemical components of coal tar

Polyaromatic hydrocarbons (PAHs) are large organic compounds, usually of low aqueous solubility. Many are known to be carcinogens. PAHs have a basic structure of two or more benzene rings. Analysis of coal tar for PAHs is likely to focus on the following members of this group:

Compound	Number of rings in structure	Typical composition (% of coal tar)
Naphthalene	2	5 - 15
Acenaphthene	2	
Fluorene	3	5
Anthracene	3	10 - 20
Phenanthrene	3	
Fluoranthene	4	
Pyrene	4	
Chrysene	4	
Benzofluoranthene	5	25 - 40
Benzopyrene	5	
Perylene	5	
Benzoperylene	6	
Coronene	7	

Other components of coal tar, besides PAHs, include phenols (monohydric and polyhydric), benzene, toluene, xylene, tar acids, tar bases and a variety of compounds that comprise pitch. Pitch is the high boiling point fraction of coal tar.

weatherproofing and road building materials. The sites of these tar distilleries are also important sources of wastes and potential contamination of ground. Similar precautions to those at coal carbonisation facilities should be adopted at tar distilleries.

Low quality tars and tar residues were traditionally tipped in discrete areas of a given coal products site, often with little regard to the future use of these areas. In many instances these tar dumps or low-technology landfills now present significant constraints on future development due to their large size, high toxicity and low potential for on-site decontamination of the waste material.

10.2.4 Spent oxide

During the process of town gas production and coke making the gas produced was often fed over a series of purifier beds in order to remove toxic and foul smelling hydrogen sulphide prior to sale and use as a fuel. Hydrogen sulphide was often present in very high concentrations, and had to be reduced to a concentration below 1mg/l in the gas distributed to domestic users. These purifiers contained moist iron oxide which reacted with the hydrogen sulphide to form iron sulphide.

Although the resulting iron sulphide material could be reoxygenated by exposure to air, eventually the material was discarded as spent oxide. In addition to the iron sulphide the oxide also accumulated contaminants such as cyanides and elemental sulphur.

Spent oxide produces the distinct ‘gassy’ odour typical of coal carbonisation sites, and was often tipped on site with little regard to safe disposal practices. Its excavation and disposal during the course of reclamation of a site can be therefore be problematic, not only because of its chemical nature, but also due to its odorous properties.

Spent oxide, present to a greater or lesser extent at old carbonisation sites, is often mixed in with other wastes and fill materials. The appearance of spent oxide varies, but often resembles clinker and slag material, though it has a characteristic blue-grey colour, due to the presence of complex cyanides. Box 10.4 gives the chemical composition of a typical spent oxide.

10.2.5 Acidic sludges

Acid tars and sludges are derived from the acid washing of crude tar oils resulting from the coking process. Acid washing results in the extraction of a variety of impurities including aromatics, hydrocarbons, and sulphur and nitrogenous compounds.

Mineral acids, particularly sulphuric acid, were widely used as washing and scrubbing liquors at coal carbonisation facilities. Sulphuric acid was particularly popular for the chemical washing of benzole, and for the conversion of ammonia in by-product liquors to ammonium sulphate.

Acid sludges are often of very viscous, which causes handling difficulties. This viscosity, combined with their complex and toxic chemical nature, and their low pH, makes acid sludges a waste product of considerable potential environmental impact, requiring special treatment or disposal to reduce the risk of contamination of surrounding ground.

Box 10.4: Typical chemical composition of spent oxide (adapted from Environmental Resources Limited, 1987[86])

Compound/Chemical	Concentration range
Free sulphur	35-60 %
Sulphate (SO_4^{2-})	1-3 %
Cyanide (total)	2-5 %
Thiocyanate	0.1-0.5 %
Iron	2-10 %
pH	2-6
Metals e.g. Cd, Pb, Cr	2-100 mg/kg

Treatment of these acidic residues during operation of a carbonisation plant was not often practised, and they were simply tipped into pits on or near the plant. Any treatment of the wastes was invariably limited to either the burning of the residues in the ovens on site, or hydrolysing them with hot water. The latter included neutralising the acidic water phase with lime. This process resulted in two waste streams (neutral effluent and dilute tar), which remained a problem for disposal. The high cost of hot water hydrolysis and neutralisation tended to dissuade operators from practising this method. Acid tar lagoons are thus still a feature of some industrial sites, and treatment remains as inefficient and costly as ever. Such treatment methods, which may include excavation and incineration, are discussed in detail in Chapter 11.

10.2.6 Benzole

Benzole was a valuable crude product of coke manufacture, produced in countercurrent scrubber towers, where a mineral wash oil was used to absorb the benzole hydrocarbons. The benzole hydrocarbons were then recovered in a benzole distillation plant.

As with other by-products of the coal carbonisation process, the chemical composition of benzole differs with coal feedstock and separation and distillation processes, but essentially the main components are benzene, toluene, xylene and related compounds (often referred to as BTEX). Impurities include phenols, carbon disulphide, naphthalene, oils and paraffins.

The liquid and readily water-miscible nature of these compounds, combined with their toxicity, makes them significant contaminants of former coal carbonisation sites.

10.2.7 Coal and coke

Coal and coke are also found in the vicinity of coal carbonisation plants. Whilst these materials are not of great significance in terms of their toxicity, they do constitute a combustion risk at such sites, particularly in areas of former coal and coke stocking. Site investigations into the nature of ground conditions must therefore take into account the calorific value of soil containing quantities of potentially combustible material. However, if the quantities of coal and coke materials at a given site are not sufficient to warrant economically viable recovery (see Section 8.2), there may still be a strong case for removal prior to site development if by doing so the area will be brought into a state of low combustibility.

10.3 Background levels of contamination

Coal carbonisation facilities are usually situated in areas of either high urban density or dense industrialisation, where soil concentrations of coal-related contaminants are already elevated. Coal carbonisation will further increase the concentrations of these soil contaminants over an area far wider than that of the former carbonisation facility alone because of atmospheric discharges and deposition.

The elevated soil concentrations of coal-related contaminants common in urban areas can result in misinterpretation of data from a site investigation if concentrations are being compared with those found in rural locations (see Section 2.6.5). Background concentrations of coal-derived contamination in the locality of a carbonisation facility should therefore be taken into account when setting reclamation standards (see Section 11.9). Elevated concentrations of PAHs in urban areas may derive from the burning of coal and other fossil fuels for domestic and transport purposes, as well as industrial uses.

During the active life of a coal carbonisation plant, and especially those that operated with little or no regard for the release of emissions to air, potentially toxic compounds including sulphur dioxide and PAHs were almost continuously pumped into the atmosphere. The soluble and particulate nature of such contaminants meant that they were destined to become deposited on the land in due course.[130]

Such deposition of airborne pollution is prevalent in areas where highly sulphurous or bituminous coal was utilised, and where the situation of the site is such that high annual rainfall and/or low levels of prevailing winds have optimised the potential for fallout in the vicinity. The soils around the brown coalfields and associated coal processing areas of eastern Germany, such as those in the Leipzig-Halle region, are, for instance, highly acidic because of the deposition of sulphuric acid from the airborne sulphur dioxide of coal processing origin (see Section 17.7). The effects of the resulting acidity on the mobilisation of toxic metals *e.g.* aluminium from soils, is well documented,[81] and has resulted in widespread deterioration in soil, surface and groundwater quality, and in the corresponding depletion of vegetation and wildlife.

Metals too were deposited from the atmosphere in the form of fly ash. Some of these metals are toxic, and occur as both background contaminants, as well as components of bulk wastes, such as spent oxide. Such metalliferous contaminants include chromium, lead, mercury, cadmium, copper and arsenic.

10.4 Structures and materials on site

Coke works and associated industrial coal processing facilities were often composed of large structures in which the various processes were carried out. Coke ovens, distillation towers, gas purifier beds and venting chimneys are structures which are all closely associated with the generation of contaminated materials, and as such require special regard during the decommissioning and demolition of these facilities. These matters are discussed in Chapter 4 in more detail. The handling of contaminated building materials is as important an issue as the handling of toxic wastes, and care must be exercised in the disposal, retention or reuse of such materials during redevelopment work. Analysis of brick from the chimneys which once vented emissions from the Siemens-Martin steel furnaces of the Riesa steelworks in Germany, showed high concentrations of some potentially toxic metals up to 60mm into the brickwork lining the chimneys (see Section 17.7).

Therefore, demolition of the structures present at a cokery is not limited to problems of scale and the resilience of building materials. Preliminary assessments of contaminated structures should be made prior to demolition (see Box 4.5). This can be done by a visual assessment, or preferably, in addition, by the collection of samples for appropriate chemical analysis. Visible contamination may include the blue staining of materials by ferrocyanides (sometimes called 'Berliner Blue' or 'Blue Billy'), the retention of spent oxide in old purifier boxes, or bright yellow deposits of elemental sulphur. These materials need to be accounted for in terms of both risk and cost in the overall plans for remediation of a given site.

10.5 Environmental contamination

10.5.1 Introduction

The complex chemical nature of coal gives rise to the array of compounds produced during the carbonisation process. It is this mixture of chemical elements and compounds that produces the unique circumstances to be found at coal carbonisation sites, and gives cause for the special measures that are required in order to restore the site to a safe and appropriate after-use.

Most nationally adopted standards and guidelines for contaminated land in Europe take into account the contaminants typical of coking, gas and smokeless fuel works. In the United Kingdom, for example, the frequently used ICRCL (Interdepartmental Committee for the Reclamation of Contaminated Land) guidelines for contaminated soils, are based on common coal carbonisation contaminants. Such guidelines, whilst forming a nationally accepted standard for the reclamation of contaminated soils of all types, may not cover all the contaminants present at former coal carbonisation sites. Chemical guidelines for the decontamination of polluted soils are published in many European countries, although nationally adopted guidelines are less common than regional standards. In many cases soil chemical standards are still set on a case by case basis, even where local guidelines exist.

The wastes generated and frequently present at these sites may have the following effects:

- lowering of groundwater quality;
- direct toxicity;
- degradation of building materials;
- difficult ground conditions.

At some coking works large volumes of effluents were pumped to settling tanks or lagoons, where particulate and heavy materials were allowed to settle out under gravity, and the clarified effluent released either directly to the sewers or further treated prior to disposal. At coke works in some mining regions this practice has led to the leakage of effluent waters into underground mine workings.

Settled materials in primary treatment lagoons build up during the course of operations, and the residues are likely to be of a contaminated nature, requiring treatment or disposal at a later date. Such residues must be carefully considered as potentially hazardous material during a reclamation scheme, and should be treated accordingly *i.e.* by sampling, analysis and, where necessary, remedial treatment.

10.5.2 Groundwater quality

Introduction

In general those chemicals of high to medium aqueous solubility such as soluble components of former liquid effluents, including ammoniacal liquors, are of greatest concern to ground and surface water quality at coal carbonisation sites, particularly where water is extracted to supply potable water or water for other industries.

The solubility and mobility of contaminants in bodies of water is, however, only one part of a much more complicated equation, as aqueous solubility is often strongly related to other factors such as pH, microbial action and soil disturbance.[246]

Inorganic contaminants

Coal, the parent material of the coke making industry, contains a variety of chemical elements (Table 5.4). Amongst these elements are many toxic heavy metals, and other hazardous components such as arsenic, which are associated with the pyritic materials present in coals.

Heavy metals such as lead and mercury tend to be far more soluble under acidic (low pH) than alkaline conditions. At coal carbonisation sites, where acids were regularly used and disposed of, soil and groundwater pHs are often low. In such conditions metal solubilities are high, giving rise to a high potential for metal leaching and dispersion over a wide area. Where the concentrations of soluble metals are high, little or no vegetation may exist. In this way sparse or limited vegetation in an area can indicate the possible presence of phytotoxic (plant toxic) metals or other chemicals in soil water. Plant communities tolerant of metals may also develop. An experienced botanist will be able to identify such metal tolerant plant communities, and therefore highlight areas of potential contamination.

Inorganic contaminants of ground and surface waters in the region of coking works and associated facilities are not limited to metals. Sulphates and other anions, including chloride associated with coal ash residues, are often present, derived from the metal salts in waste materials.

Chemical attack of building materials

Sulphate solubility is enhanced by low pH, and increasing concentrations tend to have correspondingly deleterious effects on concrete building materials. Sulphate reacts with cement-based materials causing structural decline and associated risk, and as such can be a significant contaminant at coal carbonisation sites[177] (see Section 2.6.5). Similarly, phenols, as significant organic contaminants of soil and groundwater at many coal carbonisation sites, can produce adverse effects upon both concrete and plastic building materials in contact with contaminated materials.[224] Excessive acidity in contaminated ground may also cause structural problems if the ground is not decontaminated or target building materials protected.[112]

Organic contaminants

Organic contaminants in water present a different type of problem from those posed by metals and other inorganic substances. Many organic wastes from coal processing are only of limited solubility in water. The constituents of coal tars are, for instance, of varying aqueous solubilities, from the simple aromatic compounds of phenols, benzene and xylene, which are all relatively soluble, to the polyaromatics (PAHs), many of which are practically insoluble. Insolubility does not however exclude them from causing contamination, and organic liquids which are less dense than water can form immiscible surface layers on groundwater. The organic liquid will then flow under its own hydrostatic head in the same direction as the groundwater. Tar oils and other mineral oils can cause such phenomena to occur, and lead to severe contamination of subsurface water.

The differing aqueous solubilities of the organic compounds of coal carbonisation wastes, is perhaps one of the most significant barriers to their successful remedial treatment, and the reason why such materials are often dealt with by containment. Cyanide, for example, a common contaminant at former coal carbonisation sites, exists in many different chemical forms, from the extremely toxic hydrogen cyanide gas, through free cyanide in solution, to the commonplace metal-cyanide complexes which are relatively insoluble and of lower toxicity. The latter forms of cyanide are therefore resistant to leaching, which gives them a lower potential to cause more widespread pollution, but also makes their removal from the soil matrix difficult.[97]

In addition to the chemistry of the soil and groundwater, the underlying hydrogeology has important consequences for the spread of a groundwater contamination plume. The containment and treatment of such groundwater contamination arising from coal carbonisation sites is discussed in Chapters 11 and 12.

10.5.3 Direct toxicity

There are many chemicals that produce toxic effects in animals and plants when they are presented directly to the target organism in unnaturally high concentrations. At sites of current or former coal carbonisation activity, high concentrations of the most ubiquitous of chemical species, such as sulphates, ammonium and sulphur, can produce toxic effects. Table 10.1 summarises general information on the toxic effects of some coal carbonisation by-products and includes the nature of the chemical, its likely form at coal carbonisation sites, and its mammalian toxicity.

The assessment of the risk of toxic substances causing harm is not a simple matter; not least because harmful effects may often only be seen many years after exposure, following a period or periods of continuous or intermittent exposure. The exposure of an organism to carcinogenic compounds, such as coal tar PAHs, may consequently not reveal the symptoms of toxicity *i.e.* tumour growth, until some years after a single period of exposure. A similar scenario exists for teratogenic and mutagenic effects.

Table 10.1: Summary of the toxicity of major coal carbonisation by-products

By-product and potential contaminant	Appearance at former coal carbonisation sites	Toxicity and hazards
Coal tars	Black, viscous with typical tarry, phenolic odour. Often in buried deposits or tanks.	Lighter fractions may be absorbed through skin. Immediate toxic effects unlikely, but many components are carcinogenic. Tar has a high calorific value and may combust.
Spent oxide	Often mixed with other wastes and soils. Typical 'gassy' odour. Some may have a clinker-like appearance, with brown, yellow and blue coloration.	Direct skin contact may cause irritation and burning. Dusts may result in inhalation and eye contact, which may cause irritation and/or allergic reaction. Toxic components include sulphur compounds and cyanide.
Light tar oils and phenols	Typically present as liquors with an oily sheen and oily or phenolic odour e.g. in groundwater. More concentrated liquids are viscous and tend to coat soil and stone particles.	Skin contact can cause irritation, and vapour inhalation may produce headaches and drowsiness. Liquids can be corrosive to plastics and concrete. Long-term exposure can cause damage to central nervous system.
Ammoniacal liquors	May be present in underground tanks and voids, or mixed with soils and groundwaters. Phenolic and ammoniacal odours.	Irritation and burning following skin and eye contact. Vapours can produce nausea and asphyxiation in confined spaces. Liquors may attack concrete and plastics underground.
Cyanide residues	Cyanide exists in various forms at coal carbonisation sites e.g. as the residues on stonework and in spent oxide, or as hydrogen cyanide gas, or in liquids.	Free cyanide causes respiratory failure. However, hydrogen cyanide gas, the most toxic form, is only likely to occur in confined spaces. Complex cyanides are less toxic but can cause skin irritation.
Sulphide residues	Associated with various coal carbonisation wastes as solid metal sulphides (principally brown iron sulphide) and gaseous hydrogen sulphide, typified by an aroma like rotten eggs.	Solid sulphide residues may be corrosive and cause skin irritation. Hydrogen sulphide gas is highly toxic at low concentrations.

For those involved in the remediation of contaminated sites therefore, there are two major considerations concerning direct toxicity:

- human contact with toxic materials;
- plant and animal contact with toxic materials following reclamation.

The first of these considerations is critical before, during and after reclamation. Contact may include the inhalation of contaminated dusts, skin contact and direct ingestion. The second must take into account the continued presence of contaminated materials on site after reclamation, for example contaminants within a containment cell, or as residual concentrations of contaminants remaining in the soil after decontamination treatment.

10.6 Reclamation of coal carbonisation facilities

The information provided in this chapter highlights the complexity of factors affecting the reclamation of coal carbonisation sites. In many ways they are amongst the most challenging sites to the developer because of:

- the large structures present at the sites;
- the indiscriminate handling and disposal of toxic wastes at older sites, and the complex mixtures of contaminants that are likely to occur in soil and groundwater;
- the location of many gas works sites in areas of high population density.

The last point here draws attention to the often valuable development potential of these sites, despite their constraints. Thus, although the costs of redevelopment of coal carbonisation sites will often be increased due to the assessment and treatment of contamination in addition to the demolition, site preparation and construction costs, these extra costs may be offset by the value of the land.

The options for clean-up of contaminated coal products sites are limited by:

- nature of the contamination;
- characteristics of the geology and hydrogeology of the site;
- topography of and access to the site;
- proximity of treatment or disposal facilities for hazardous wastes;
- cost.

These factors, and the methods suitable for the treatment of contaminated materials, are fully discussed in Chapter 11. An appreciation of the risk of contamination should however be gained at the outset of site works. This will include the potential for encountering contaminated building materials, as well as contaminated ground and groundwater. These possibilities are best assessed at an early stage in the reclamation and redevelopment works, by the undertaking of carefully planned and executed investigations (see Chapter 2).

In many cases the environmental liability attached to coal carbonisation sites is significant, and national and regional legislation may be unclear about who is responsible for any pollution arising from a site. In this respect, however, the EC directives on groundwater quality and protection (see Section 12.6.2 and Boxes 12.4 and 12.5) are applicable throughout the Community, and it is the duty of a developer to ensure that the quality of groundwater is not adversely affected by:

- the undisturbed site;
- the site during ground engineering or remedial works.

The varied nature of toxic contaminants at coal carbonisation sites makes them a challenge to land reclaimers. In this way these sites require special regard to the reduction of on-site health and safety risks to ensure the future well-being of those who use them, and the protection of the quality of local ground and surface waters.