7 COLLIERY SPOIL HEAP COMBUSTION

Chapter contents

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7.1 Introduction

Colliery spoil heap combustion is a common occurrence, particularly on older spoil heaps formed by loose tipping over the edge of the heap. At some sites underground fires are known to have been burning continuously for several years.

Little information is available on the current extent of spoil combustion, although in the main coal mining areas of Europe several incidents are reported each year. Historically the problem was much worse. It was estimated in 1967, for example, that of the 2,000 loose tipped spoil heaps then owned by the United Kingdom National Coal Board 15% were classified as burnt out and more than half as burning.[235] Box 7.1 provides some examples of underground combustion, and Box 7.2 gives examples of explosion and landslide.

In recent years civil engineering design has required that spoil is compacted during tip building and this has considerably reduced the risk of combustion.

Spoil composition and consistency varies widely, but loose tipped heaps containing a high proportion of carbonaceous materials are most likely to combust.

Spoil heaps may be ignited accidentally by the lighting of fires or the tipping of hot ashes. Self-heating may also occur, which can lead to spontaneous ignition.

When the supply of oxygen is limited, slow combustion may occur by smouldering, but without the spoil material breaking into flame. Smouldering may proceed underground for long periods with little visible evidence at the surface.

Box 7.1: Examples of underground combustion

1. Lanarkshire Steelworks, Scotland

During redevelopment of a former steelworks site an underground fire was eradicated which was known to have been burning for 45 years[134]. The fire within colliery waste was causing problems with noxious fumes, subsidence of buildings, hardstandings and railway sidings, and disruption of utility services. Early limited attempts to contain the fire were largely unsuccessful, and the fire continued to spread until 4.7ha of the site had at some stage been affected. During the reclamation works the underground fire was treated by excavating the burning material and spreading it out to cool prior to recompacting it in layers.

2. Ramsey Bing, Loanhead, Scotland

Treatment of this burning colliery spoil tip was hampered by the fact that the heap is located in the middle of the town and is surrounded by houses and industrial buildings.[61] A pilot phase of the works was carried out which involved treating part of the tip by excavation, cooling and recompaction. Dust levels were strictly controlled by damping down with water, and dust monitoring was carried out to avoid disruption to a nearby precision engineering works. The pilot phase proved to be successful, and the main phase of the works was then carried out including capping and landscaping of the 11.9 hectare site.

3. Oakthorpe, Leicestershire, England

Combustion can also occur within underground workings. Burning within abandoned shallow workings beneath Oakthorpe occurred over a number of years as a result of spontaneous combustion.[27] This resulted in elevated temperatures beneath buildings, and subsidence damage to buildings and roads. Treatment was carried out by drilling and grouting using pulverised fuel ash and cement grout to extinguish the burning and stabilise the workings.

Box 7.2: Examples of explosion and landslide[79]

The following incidents took place in Pas-de-Calais, France.

1975, Fosse 6 d'Auchel, Calonne-Ricouart.
An accident occurred involving an explosion and avalanche of burning material.

The spoil heap was started in 1913 and tipping continued until 1961. The tip was semi-circular in shape with a radius at the base of 150m. The height was 96m and the slope angle was 32 to 36°. Two villages were located close to the bottom of the spoil heap.

Removal of material from the spoil heap began in 1971, and at the time of the accident material was being worked on four staggered levels.

The incident took place after excessively heavy rain when an explosion occurred followed by a landslide which caused burning material with a temperature of approximately 800°C to flow like larva on to the outskirts of the village below.

The cause of the accident is not known precisely, but at the time was thought to have been triggered by mining subsidence or by a pocket of gas disturbed by the excavation of the heap. It is not known whether the heap had been subject to underground combustion, but this seems likely to have been a contributory factor.

1930, Fosse 5 d'Auchel (conical spoil heap).
An explosion and landslide occurred leading to one person being killed and four seriously burned.

1930, Fosse 5 d'Auchel (conical spoil heap).
A further landslide of hot material occurred causing damage to property.

1962, Bruay-en-Artois (flat spoil heap).
One person dead following a gas explosion.

1968, Blignières (flat spoil heap).
Seven injured in an explosion and landslide of hot material.

1973, Fosse 3 d'Auchel (conical spoil heap).
Explosion and landslide causing two injuries by burning.

1974, Fosse 3 d'Auchel (conical spoil heap).
Major landslide of hot material halted by a dike 100m from housing.

The ignition of materials within a spoil heap, whilst not always being obvious at the surface of the tip, is associated with particular safety and public health risks.

The main hazards from burning spoil heaps are concerned with:

- release of noxious gases;
- subsidence damage;
- damage to buried services.

7.2 Causes of combustion

7.2.1 Factors involved

The following factors determine whether or not a spoil heap is susceptible to combustion:

- the composition of the spoil;
- the grading of the spoil;
- the compaction of the spoil;
- the method by which the spoil heap has been formed;
- the size of the spoil heap;
- whether the spoil heap has steep faces exposed to the wind;
- whether the spoil heap has been capped with dense, non-combustible material.

Spoil can be divided into three main categories on the basis of combustion properties:

- subject to spontaneous ignition;
- combustible but not subject to spontaneous ignition;
- non-combustible.

7.2.2 Spontaneous ignition

Introduction

Colliery spoil materials can spontaneously ignite due to self heating caused by the slow chemical oxidation of carbonaceous material in the spoil. The following sections describe factors which affect spontaneous combustion.[169]

Temperature

The oxidation of carbonaceous material is exothermic, and if the rate at which heat is given out exceeds the rate at which it is dissipated then the effect becomes cumulative and the temperature increases. The temperature rises until smouldering becomes possible if the supply of oxygen is adequate. Spontaneous combustion is thus facilitated by the direct oxidation of coal residues.

Pyrite

Pyrite (FeS_2) is often to be found in colliery spoil (see Section 5.3.2). The oxidation of pyrite is strongly exothermic, and the presence of pyrite in conjunction with the carbonaceous material increases the tendency towards spontaneous ignition.

Coal rank

Lower rank coals are more reactive and more susceptible to self heating than higher rank coals. Low rank coals have a lower carbon content and higher oxygen content than high rank coals.

Moisture

The presence of free moisture is essential for the oxidation of pyrite and can accelerate the heating process. The high moisture content in low rank coals is indicative of a tendency to self heating, and thus to spontaneous ignition.

Void ratio and particle size

The void ratio of the material in the spoil heap affects the ease with which air can pass through the heap and thus supply oxygen to stimulate exothermic reactions. Where heaps consist of large, single-size material, movement of air through the heap can be sufficient to dissipate a build up of heat through a relatively large volume of material. In heaps consisting of well graded or fine-grained material there is likely to be little air movement and the heat generated will tend to be retained. Heating will however stop once available oxygen is consumed.

With heaps of intermediate gradings, conditions for spontaneous heating and ignition are ideal and areas of high temperature may form within the spoil heap which can eventually break into flame. The rate of oxidation and build up of heat increases when there is a high proportion of the smaller particle sizes because of their large surface area to volume ratio.

7.2.3 Accidental ignition

Accidental ignition generally occurs due to a sustained application of heat from the surface. Such heating can be caused by a number of factors including:

- a bonfire;
- a grass fire;
- tipping of hot ashes;
- underground electric cables;
- a boiler house or furnace.

Combustion may continue below ground even after the surface fire has been extinguished.

7.3 Hazards

7.3.1 Noxious gases

Gases produced by burning spoil heaps include the following:

- carbon monoxide;
- carbon dioxide;
- sulphur dioxide;
- hydrogen sulphide.

These gases tend to accumulate in low lying areas where ventilation is poor. This accumulation presents a risk to operatives working nearby, particularly vehicle operators working in poorly ventilated cabs. Such gases are hazardous to health either by direct toxicity or by asphyxiation (see Box 7.3).

The gases produced can travel considerable distances through the ground and may enter and accumulate within nearby buildings thereby putting residents or users of the buildings at risk.

7.3.2 Subsidence

The combustion of spoil heaps leads eventually to localised subsidence of the burnt ground. Hidden cavities are thus formed which may subsequently be subject to sudden collapse. Access by earthmoving equipment and personnel is therefore potentially hazardous.

Underground fires spreading beneath buildings present a threat to the structural stability of the building and may lead to eventual collapse. Incidents have occurred where it has not been possible to bring underground fires under control, and buildings have had to be abandoned and eventually demolished.

Box 7.3: Physiological effects of gases produced by burning spoil heaps

Carbon monoxide

Carbon monoxide is the most dangerous of the noxious gases as it cannot be detected by smell, taste or irritation, even when present in potentially lethal concentrations. Low exposure causes headaches, weakness and nausea. Increased exposure leads to shortness of breath, palpitations and vomiting followed by unconsciousness and in severe cases, death.

Carbon dioxide

Carbon dioxide is an asphyxiant. Low exposure causes increased lung ventilation. Increased exposure causes laboured breathing and headaches with eventual loss of consciousness.

Hydrogen sulphide

Hydrogen sulphide is readily detectable by smell and taste. Low exposure causes irritation to the eyes and throat and eventually headaches. Increased exposure leads to unconsciousness. The ability to detect the odour tends to disappear during prolonged exposure.

Sulphur dioxide

Sulphur dioxide is detected by taste at lower levels and by smell at higher levels. Low exposure causes irritation to the nose and throat and eventual irritation to the eyes. Increased exposure can lead to death.

Combustion does not lead to a loss of stability in all instances, and burning may sometimes lead to an increase in shear strength. At high temperatures fusing of materials within the tip may occur (see Table 5.1).

7.3.3 Combustion damage to underground structures and utility services

Any underground structures and services such as cables and pipework on sites subject to combustion may be affected by heat damage. Underground service ducts or drains may sometimes act as paths along which combustion or combustion products such as gases may spread.

7.3.4 Risk of explosion

When attempting to treat underground fires, the use of excessive water could result in an explosion. The use of water jets on a burning heap will lead to the formation of steam. Hot carbon in contact with steam can form 'water-gas' which is a mixture of carbon monoxide and hydrogen. A mixture of water-gas and air, when ignited, will explode with great violence.

A coal dust and air mixture is also explosive, therefore where there is a significant coal content in the heap there is a risk of explosion if excessive dust is produced (see Section 7.6 regarding safety precautions).

7.3.5 Dust

Dust levels will be affected by the weather conditions. Rainy conditions will help to reduce the spread of dust whereas windy conditions will assist the spread of dust. The emission and spreading of dust from a burning spoil heap can cause nuisance particularly in periods of dry weather. This could affect nearby residents or sensitive local industries, but is unlikely to be a health risk unless dust levels are excessive (see Box 7.4).

7.4 Assessment

7.4.1 Introduction

There are many factors which affect whether or not a spoil material is combustible. Laboratory test results provide a method of assessing potential combustibility, but the assessment of test results is a matter of careful judgement particularly with regard to the risk of spontaneous ignition. The following parameters are of particular relevance to spoil combustibility.

7.4.2 Calorific value (CV)

This is the test most commonly used for assessing combustibility and involves measuring the quantity of heat released from a sample on combustion. It is generally agreed that samples with a CV of 10 MJ/kg or greater are almost certainly combustible, whilst samples with a CV of 2 MJ/kg or less are unlikely to be combustible.[120] Samples with a CV of 7 MJ/kg or greater are considered to be at risk from smouldering, although under laboratory conditions smouldering may occur in samples with a CV of less than 7 MJ/kg.

The calorific value of some spoils in Europe are shown in Table 7.1. Colliery spoils deposited in the nineteenth century and early twentieth century are likely to have higher calorific values than those in Table 7.1 because of their higher coal content.

7.4.3 Loss on ignition

This test is sometimes used for assessing combustibility, and involves measuring the loss in weight of a sample after ignition. Samples with a loss on ignition of 25% or greater are generally considered to be combustible.

Table 7.1: The calorific value of some colliery spoils (after Cañibano and Leininger 1987[47])

Country	Calorific value (MJ/kg)
Germany	2.0 - 6.0
Spain	2.2 - 5.5
UK	5.0 - 8.0
France	1.7 - 5.0

7.4.4 Combustion potential test

This is a test developed in the UK to assess the combustibility of spoil material under conditions similar to those on site. The test involves heating the material in a special container with a controlled air flow and monitoring the rate of temperature increase.[46]

7.4.5 Change in site conditions

Experience has shown that materials which are at risk of spontaneous ignition through self heating will ignite in weeks rather than years.[145] Therefore, providing there is no change in external conditions, older spoil heaps which have not previously been subject to spontaneous combustion are considered unlikely to become so in the future.

7.4.6 Temperature monitoring

The extent and depth of material which is undergoing combustion may be assessed by *in situ* temperature monitoring using steel pipes driven into the heap in a grid pattern. Jointed sealed pipes of 50mm diameter or less can be driven into the heap to a distance of several metres using a pneumatic hammer. Temperature readings may then be taken at varying depths using a thermocouple linked to a digital thermometer. Where deep fires are involved, boreholing may be necessary with the steel pipes being grouted into the boreholes using a pulverised fuel ash/cement grout. Portable infra red temperature indicators may be of use for an initial survey of surface temperatures.

Aerial surveys using thermographic equipment are an appropriate technique for monitoring large spoil heap fires.

Temperatures as high as 1200°C have been recorded within combusting spoil heaps. Ignition is likely to occur at temperatures of 200°C or greater. Temperatures below 200°C but significantly above background temperatures indicate a risk of self ignition.

7.4.7 Surface indications

Indications at the surface that underground combustion is occurring are as follows:

- areas of charred and blackened ground;
- the emission of smoke and noxious gases;
- the emission of steam following rain;
- unfrozen ground during cold weather when adjacent ground is frozen;
- areas of dead or dying vegetation (although initially slightly elevated temperatures could make the vegetation more lush);
- elevated ground temperatures;
- areas of localised subsidence.

7.5 Methods of treatment of spoil heap combustion

7.5.1 Factors determining treatment method

The method of treatment will depend on the following:

- the size and nature of the heap;
- the location of the heap;
- the extent and rate of progress of the fire;
- the proximity of the site to areas of habitation;
- the availability of suitable extinguishing materials.

Expert advice should be sought from experienced consultants as to the best method of treatment to be used in specific circumstances.

Methods to extinguish or control underground fires include:

- excavation;
- trenching;
- blanketing;
- grout injection.

7.5.2 Excavation

Digging out is the most common method of successfully dealing with spoil heap fires. The technique involves excavating the burning material and spreading it out to cool (see Photograph 7.1). After cooling the material can be removed to a suitable tipping area, compacted and covered with a layer of inert material. Two or more cooling areas may be required to allow sequential treatment of the burning material.

Machinery used for digging out usually consists of heavy earthmoving equipment such as large tracked excavators, draglines or drag scrapers. The excavation of burning materials can pose risks to the safety of operatives and plant.

Photograph 7.1: Treatment of a spoil heap fire by excavation (source: Richards, Moorehead and Laing Ltd)

One disadvantage of digging out is that once the heap is disturbed, fresh surfaces are exposed to the air. Further combustion may result and increase the production of fumes and dust. The careful use of water sprays may be employed to damp down excavated material and control dust and fumes.

7.5.3 Trenching

Trenching may be used to isolate and limit the spread of the fire. The trenches should be at least 2m wide and 2m deep, or deeper if the depth of burning material is greater. Trenches may be left open for inspection or, if it is important to contain the fire the trenches should be filled with a slurry of limestone dust and water, or other inert material such as clay or pulverised fuel ash.

7.5.4 Blanketing

Blanketing involves covering the burning area with a layer of inert material such as limestone dust, clay, fine sand, or ground shale. The blanketing layer must be sufficiently thick to prevent air access to the affected area and adjoining slopes, thus starving the combusting material of oxygen. Periodic inspection and maintenance is required to ensure a continuous airtight seal. Blanketing may sometimes be used in conjunction with trenching in order to contain and prevent further spread of the fire.

7.5.5 Grouting

Grouting has been used successfully to control spoil heap fires. The technique involves injecting a slurry of clay, shale or limestone dust directly into the burning material in a controlled manner. Limestone dust is the preferred grouting material because carbon dioxide is produced as the limestone is heated, which starves the fire of oxygen.

Grouting may be more appropriate to limit the spread of fires than to actually extinguish them.

Particular care is required where high temperatures are involved, as there may be a risk of explosion. In these cases grouting may not be a suitable solution to the problem.

7.5.6 Compaction

For shallow underground fires, compaction is a suitable method of treatment in order to limit the access of oxygen to the fire. Treatment has been successfully carried out using dynamic compaction which involves repeatedly dropping a heavy weight on to the material using a crane.[16]

7.5.7 No action

In isolated locations or where the fire is small and the potential spread of the fire is limited the fire may be left to burn out of its own accord.

7.6 Safety precautions

Work on burning spoil heaps is hazardous and has resulted in serious accidents, some of which have been fatal. Recommended safety precautions, in relation to some of the hazardous parameters discussed are summarised in Box 7.4.[169]

7.7 Methods of prevention of combustion

The construction of modern spoil heaps by compacting material in layers, has significantly reduced the risk of combustion, and no spontaneous ignition is thought to have occurred in recently constructed tips.

The recompaction of older spoil heaps to reduce the risk of combustion would be expensive, unless the work to regrade and recompact the material is to be carried out as part of general land reclamation or ground improvement works.

In some cases it may be appropriate to cap existing spoil heaps which are considered to be at risk. A 1m thick layer of inert material is normally considered to be sufficient to prevent accidental ignition of the combustible spoil by an intense fire at the surface. A lesser thickness of capping layer *e.g.* 0.6m, may suffice provided the site will not subsequently be disturbed, although for housing and gardens a depth greater than 1m may be necessary to avoid combustible material becoming exposed during future activities on the site.[120]

Box 7.4: Recommended safety precautions

Noxious gases

- Before commencing treatment consultations should be held with all interested parties such as those dealing with environmental health, health and safety, planning, utilities, and also with local industries, local residents, and adjoining property owners.
- A programme of gas testing should be agreed, including personal gas monitors where appropriate.
- Site staff should be made aware of the symptoms of carbon monoxide poisoning and instructed to leave the area immediately if these or other adverse symptoms develop.
- Safety staff should be present on site, including first aid staff trained in the treatment of gas poisoning.
- Breathing apparatus should be available at all times.
- In the event of equipment breakdowns, operators should be instructed to abandon their machine and leave the area immediately.
- Telephone communication should be provided for use in emergencies.
- The cabs of site machinery should be well ventilated.
- Personnel should be kept under close supervision to ensure operatives do not get into difficulties.

Dust

- Dust levels should be monitored to ensure that they are kept within acceptable limits.
- Dust control measures may vary depending on weather conditions.
- Work programmes may need to be adjusted to take account of prevailing wind conditions.
- Dust levels may be controlled by the careful use of water sprays, including the wetting of haul roads.

Box 7.4 continued

Explosion

- Where the spoil is at red heat the use of excessive water should be avoided as this could lead to the production of water-gas with the subsequent risk of explosion. Grouting should only be carried out in the cooler parts of the heap.
- Where there is a high coal content the production of excessive dust should be avoided as this also presents the risk of explosion.

Collapse of cavities

- Plant and personnel should use access routes which have been investigated and are known to be safe.
- Areas of suspected cavities should be tested by probes or by a crane with a dropping weight.
- Any badly fissured areas should be avoided.
- Personnel on foot should be provided with harnesses and lifelines.

Use of earthmoving equipment

- Draglines should be used rather than conventional excavators in areas where underground voids are suspected.
- In the case of large fires the use of automatic drag scrapers may be appropriate to avoid the need for operatives to come into close contact with the burning material.

Other safety precautions

- Work areas should be cordoned off and warning signs provided in order to prevent accidental access by unauthorised personnel.
- Site operations should be overseen by the safety officer.
- Safety procedures should be agreed in advance with site personnel.

Where spoil is considered to be at risk from spontaneous ignition, capping alone may not be sufficient to prevent the possibility of combustion. Additional measures may therefore be required to compact the material adequately, both to prevent it drying out, and to reduce the ingress of oxygen. Sites at risk from spontaneous ignition are not normally considered suitable for development.

For development sites the capping layer should be designed to provide adequate protection from accidental ignition of the underlying spoil throughout the life of the development. Buildings and hardstandings will also provide protection, apart from boiler houses, plant rooms or electricity sub stations where underground heating could take place.

All underground services placed in colliery spoil should be laid in inert material. This method applies particularly to electrical cables and heating pipes and these may need to be insulated in high risk situations. Public utilities should be consulted regarding any special requirements they may have.

Special design considerations may be necessary in order to allow buildings to be erected on sites containing combustible spoil. For example, at one site strip footings were adopted which were supported on pulverised fuel ash in trenches taken down through the combustible material to natural ground, thus forming an effective barrier against migrating underground fires.[145]

Where sites are known to contain combustible material, the lighting of fires or the tipping of hot ashes or other forms of heating which could lead to ignition of the spoil should be prohibited.