# 8 COLLIERY SPOIL WASHING

## Chapter contents

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## 8.1 Introduction

In many of the spoil heaps and tailings lagoons associated with coal mining there exist appreciable quantities of coal, much of which is amenable to recovery. The amount of coal varies widely but patterns can usually be discerned and related to the history of operations. In the UK, for instance, it is rare to find large quantities of coal in the very old or very modern tips, reflecting the total lack of coal preparation or highly efficient removal respectively.

The motivation for coal recovery is primarily financial, but in the context of the reclamation of derelict land it is not essential to operate at an overall profit provided the revenue from coal sales can offset the total cost of an integrated land reclamation scheme.[241] Other motivating factors are those of valuable resource recovery, reduced risk of subsequent combustion, increased stability of the final spoil heap and provision of local employment during the washing operation.

Coal recovery from tips has been practised in the UK, particularly in South Wales, for some thirty years,[194] and in 1992 accounted for around 1 million tonnes of product annually, mainly for power generation. Several schemes have also operated in Belgium, but interest in other parts of the European Community has been lower. Interest in tip recovery is strong in the USA and is increasing in places such as the former USSR, in Poland and in the Czech and Slovak republics.

The coal content of colliery spoil varies from 2-3% for spoil from modern coal washing facilities to, in rare circumstances, greater than 30% coal.

With the development of technology, especially for recovery of fine-grained particles of coal and tailings dewatering, it is now possible to consider coal recovery from large tips containing only about 7% coal, and this means that some of the earlier inefficient operations on relatively rich tips are being assessed for reworking.

Specifications for the coal and discard produced by recovery operations on colliery spoil heaps vary widely depending on the market for the former and end-use of the latter. Coal ash contents from about 15 to 30% might be acceptable for conventional power stations, and possibly double these values acceptable for fluidised bed power generation. It is desirable, on economic grounds, to limit the coal content in the discard, but there may also be other reasons why the level should not be too high. These may include susceptibility to combustion where coal contents are high, and the increased stability of spoil heaps which contain low coal contents. A reasonable target would be a maximum of 2% w/w of material floating at specific gravity (SG) 1.6 in the >250 micron size fraction of the discard, provided that the tip does not contain appreciable quantities of low density non-combustible material such as clinker.

## 8.2 Characterisation of colliery spoil for feasibility of coal recovery

### 8.2.1 Product quality

In order to assess the feasibility of coal recovery from colliery spoil, it is necessary to determine not only the amount but the quality of product which will be produced. The quality will typically be quantified in terms of parameters such as ash, moisture and volatile content (Proximate Analysis - see, for example, BSI 1016[42]), sulphur content, size analysis, calorific value, abrasive and caking properties. The appearance of the product can also be an important consideration for some markets because of the presence of very small amounts of aesthetically undesirable contaminants such as clinker, wood and other low density substances commonly found in tips but not in run-of-mine material.

The investigation of tips and of lagoons will be considered in the following sections.

### 8.2.2 Tip material

Samples for laboratory analyses should be taken during routine site investigations. These can be from trial pits or boreholes. Trial pits provide samples which are probably more typical of what would be fed to a coal preparation plant but suffer from limitations on depth of sampling (see Section 2.5). Shell and auger techniques are better than rotary drilling for borehole investigations, but even this method is limited to a depth of about 60m in the type of material concerned.

Sample size and spacing are important,[4, 131] but even though guidelines exist for conventional site investigations (see Section 2.6), these are not always appropriate to colliery spoil heap examinations. It would be necessary to sample inordinately large amounts of material to perform accurate determinations of the coal content in the coarser size fractions. However, significant quantities of coal are rarely found to exist in the >100mm size fraction, and are uncommon in the >50mm size. For reasons of sample size and statistical accuracy it is convenient to sample approximately 30kg from each location using lined, 150mm diameter shell and auger boreholes at approximately 50m spacings. Sampling frequencies at <50m spacings tend not to significantly enhance the accuracy of investigation. On a large tip the sample would typically be a composite of the material encountered in a depth band of approximately 5m.

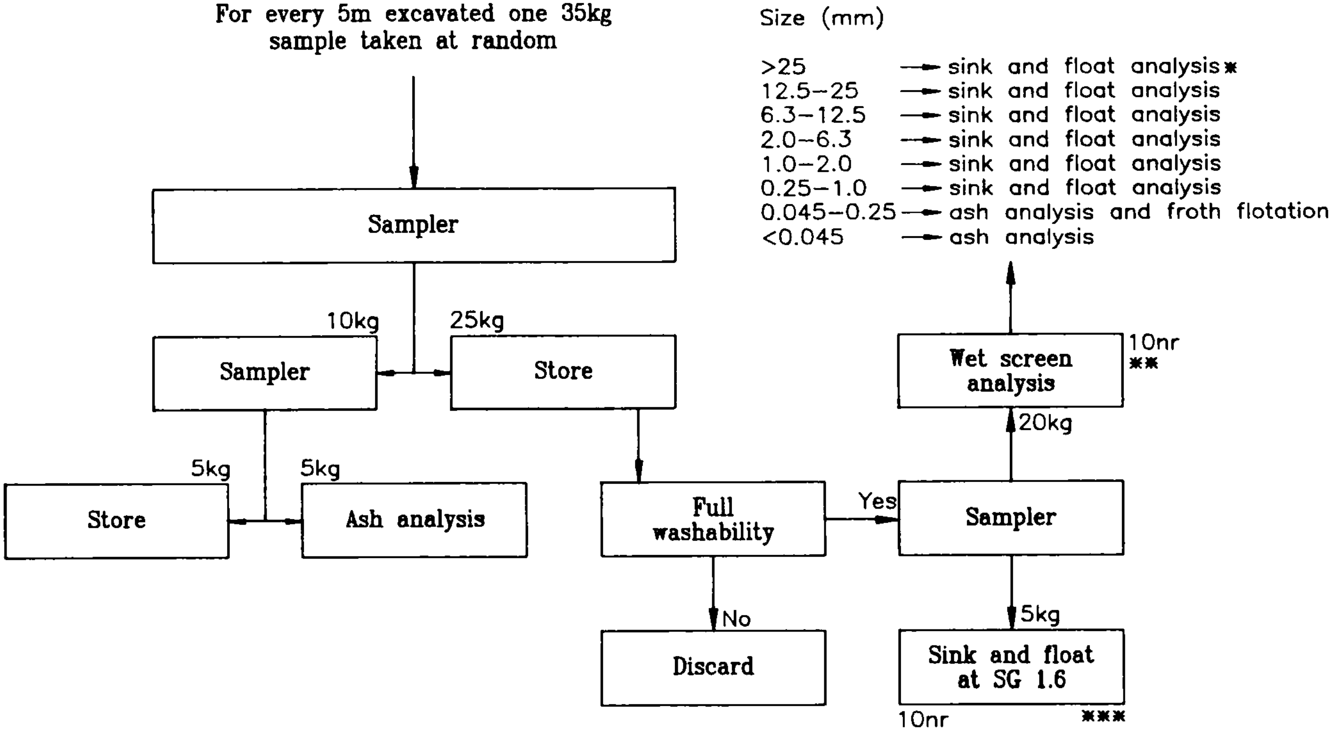
In addition to the traditional drilling methods geophysical techniques exist for the initial assessment of coal contents in colliery spoils. Resistivity methods have been used at several locations, but whilst being useful in locating zones of very low coal content, such as burnt material, they are still not capable of accurate quantitative determination of coal yields. Further developments in this promising field could lead to reduced prospecting costs in the future.

Because coal properties vary both within and between coalfields there is no universally accepted method for determining the data required for the performance of feasibility calculations or plant design. The procedure outlined in Figure 8.1 has been used successfully for several projects. All samples are subjected to ash determinations and a selection of samples are subjected to rigorous size and sink-and-float analyses at a range of specific gravities (SG). Tables 8.1(a) and 8.1(b) show a set of data from one such washability analysis.

It is clearly seen that the amount of low density material increases as particle size decreases, and that the amount of material of intermediate density (middlings, see Box 8.1) also decreases as a proportion of the size fraction with decreasing particle size. This is a very common trend in colliery spoil heaps. For this particular sample it is apparent that a yield of 7.7% of the tip would be obtained with an ash content of 3.5% if efficient separation could be performed at SG 1.4. This yield increases to 12.4% if separation is made at SG 1.6, but the quality of product is diminished as reflected by the increased ash content of 23.6%. This sensitivity of ash content to SG of separation is due to the relatively large amount of middlings in this tip.

In most cases it would be prohibitively expensive to perform such rigorous washability studies on all samples. However, a useful indication of the likely yield of coal is obtained by correlating the yield at a specified SG of separation (commonly 1.6) with the ash content of the raw samples. Linear correlations are usually obtained unless the tip is very heterogeneous or contains large proportions of clinker *i.e.* burnt

> ***Box 8.1:*** Colliery spoil middlings
>
> Middlings represent coal-shale particles with a density somewhere between that of clean coal and shale. Typical densities of middlings may thus be in the order of 1.8 to 2.0t/m$^3$. The material tends to have a high ash content.




* SGs for sink and float study:– 1.4, 1.5, 1.6, 1.7, 1.8, 1.9.
** Samples to be chosen by the engineer after completion of ash analyses.
*** Full proximate analyses, sulphur and calorific value to be determinedon these float products.

***Figure 8.1:*** Typical flowchart for laboratory analyses of samples for assessment of potential for coal recovery

***Table 8.1:*** Washability data for typical colliery spoil material

(a) % WT of sample in given SG range

| size mm | Specific gravity ranges <1.4 | 1.4 -1.5 | 1.5 -1.6 | 1.6 -1.7 | 1.7 -1.8 | 1.8 -1.9 | >1.9 |
|---|---|---|---|---|---|---|---|
| >25 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 | 7.1 |
| 12.5-25 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.3 | 8.6 |
| 6.3-12.5 | 0.5 | 0.3 | 0.5 | 0.3 | 0.3 | 0.4 | 10.1 |
| 2.0-6.3 | 1.7 | 0.8 | 0.8 | 1.0 | 0.6 | 0.9 | 10.6 |
| 1.0-2.0 | 1.5 | 0.4 | 0.3 | 0.4 | 0.3 | 0.4 | 8.0 |
| 0.25-1.0 | 3.8 | 0.7 | 0.5 | 0.4 | 0.3 | 0.5 | 11.6 |

(b) Ash % in given SG range

| size mm | Specific gravity ranges <1.4 | 1.4 -1.5 | 1.5 -1.6 | 1.6 -1.7 | 1.7 -1.8 | 1.8 -1.9 | >1.9 |
|---|---|---|---|---|---|---|---|
| >25 | 0.0 | 0.0 | 30.9 | 0.0 | 0.0 | 49.8 | 88.9 |
| 12.5-25 | 6.1 | 16.3 | 24.8 | 38.8 | 44.1 | 53.1 | 87.9 |
| 6.3-12.5 | 6.2 | 16.3 | 24.0 | 35.3 | 44.7 | 52.2 | 86.4 |
| 2.0-6.3 | 4.3 | 15.1 | 23.8 | 35.9 | 44.6 | 52.2 | 88.8 |
| 1.0-2.0 | 3.6 | 14.2 | 23.3 | 34.6 | 44.6 | 52.0 | 88.1 |
| 0.25-1.0 | 2.7 | 11.2 | 21.2 | 31.9 | 40.5 | 49.0 | 89.2 |

solid residues. Figure 8.2 gives an example of such a correlation. After determination of the ash distribution in the raw samples, it is possible to obtain a weighted average value for the yield of coal. The process can be repeated at other separating densities to relate yield and quality.

Results of laboratory analyses must be treated with care for two reasons. Firstly, the sampling process tends to discriminate against the larger particles; those over 100mm rarely reaching the laboratory. The yields must therefore, be reduced to account for the amount of coarse material in the tips. This is usually estimated by subjecting large samples to screen analysis at coarse sizes. If suitable continuous plant is available then this task is less laborious and more accurate. Secondly, laboratory results should not be used to predict the coal recovery achievable with a full scale operation without consideration of the inefficiencies of the equipment used on the industrial scale.

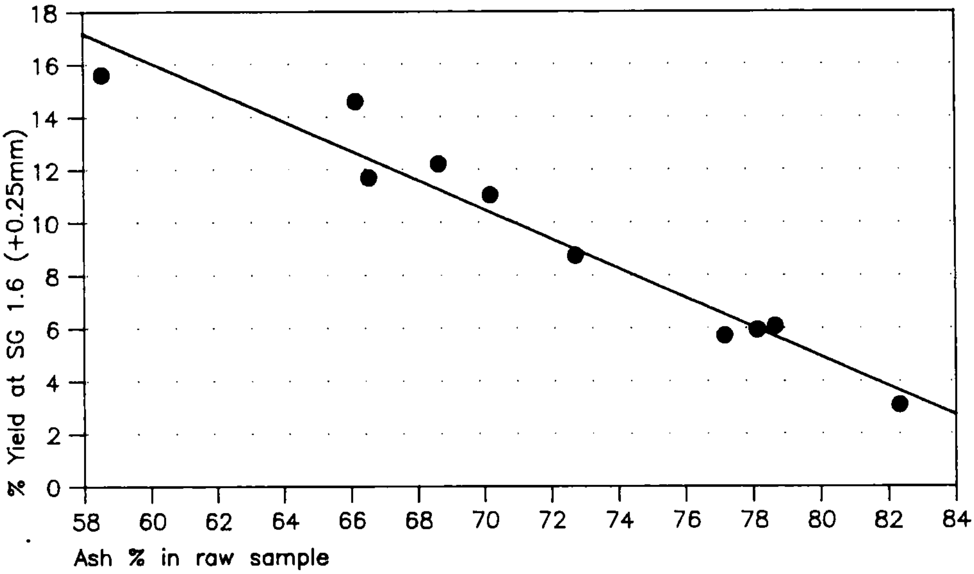



***Figure 8.2:*** Correlation between yield at specific gravity (SG) 1.6 and ash content of the raw sample (site in South Wales, UK)

As an illustration of the trends in coal content with particle size commonly encountered in colliery spoil, washability data for ten UK tips have been combined to produce the data plotted in Figure 8.3.[180] The coal content almost invariably increases with decreasing particle size[47] and the low-density but high-ash clinker material predominates in the coarser size fraction. Coal recovery is rarely practised at particle sizes of less than 0.25mm, but the potential for extra yield from this fraction is high and is therefore receiving attention from plant suppliers and operators. The percentage of material less than 0.25mm in UK tips has been found to vary from 1 to 50%.[198]

### 8.2.3 Tailings lagoons

Characteristics of the materials deposited in lagoons vary widely. It is however rare to find more than about 5% of material of a size >2mm.[169] It is also to be expected that the coal content is highest in the coarsest size fractions, as illustrated by the data of Table 8.2.[260] Coal recovery may simply involve size classification in simple operations using, for example, small hydrocyclones. However, the economics of coal reclamation from such lagoons are critically dependent on the cost of dewatering the resulting slurries.

In certain circumstances the coal content may be high enough to allow blending of the material, as excavated, with clean coal from other sources for use in power stations. Modern fluidised bed combustors may also be able to handle the material directly.

## 8.3 Coal recovery technology

### 8.3.1 Introduction

The unit operations used to recover coal from tips are largely similar to those used for run-of-mine applications (see Section 12.2.1) but adapted to cope with the much higher proportions of high-density materials. The

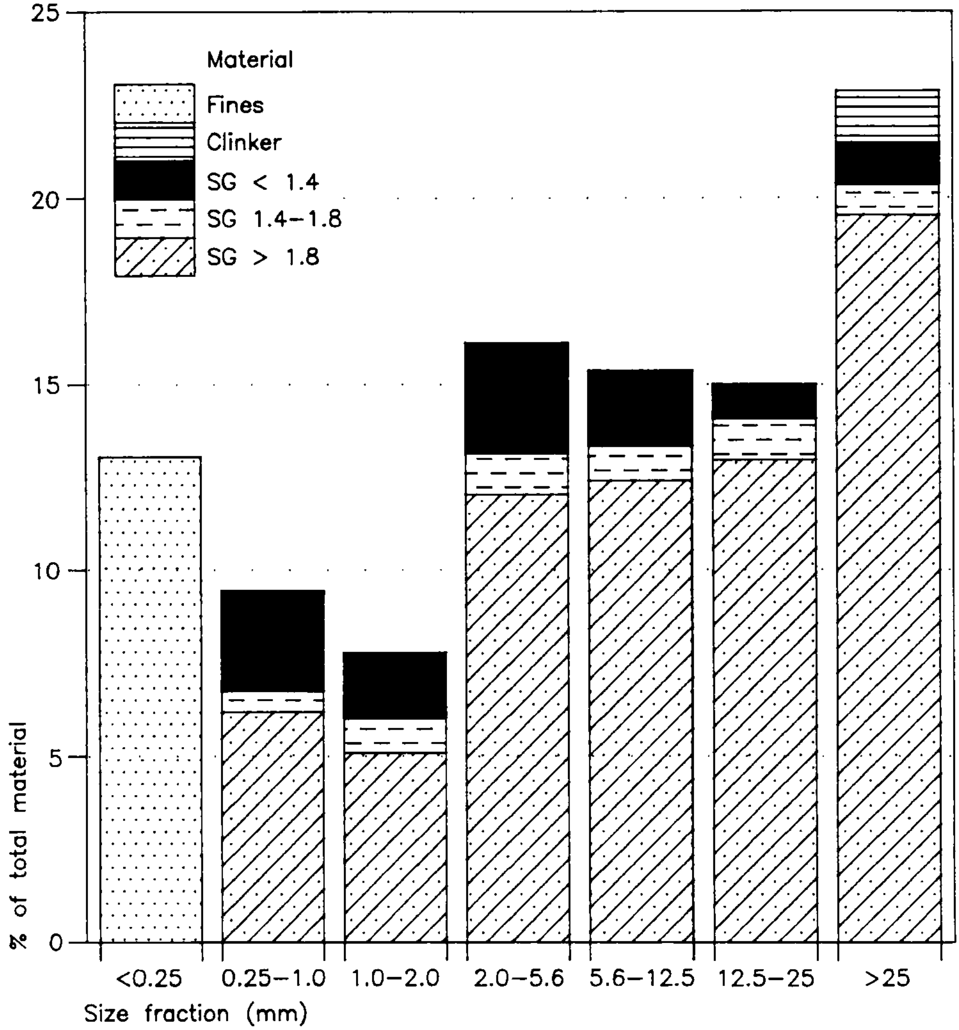



***Figure 8.3:*** Distribution of tip material according to size and specific gravity (SG), data for ten tips in South Wales, UK

***Table 8.2:*** Typical size and ash analyses for a tailings lagoon

| Size micron | % wt | % ash | Cumulative % wt | Cumulative % ash |
|---|---|---|---|---|
| >1000 | 4.4 | 3.3 | 4.4 | 3.3 |
| 500-1000 | 7.0 | 5.9 | 11.4 | 4.9 |
| 106-500 | 17.6 | 26.3 | 29.0 | 17.9 |
| <106 | 71.0 | 66.7 | 100.0 | 52.5 |

processes will involve size reduction, screening and classification, gravity concentration, froth flotation, solid-liquid separation, and drying equipment, which are well described in standard texts.[182]

Figure 8.4 is a schematic flowsheet showing the sequence of operations commonly used for tip processing. The individual operations will be discussed in turn.

### 8.3.2 Feed preparation

It is essential to provide the coal recovery sections of the facility with a constant flow of material of the desired particle size. This is achieved by suitable combinations of stockpile blending, hoppers, feeder, conveyors and screens wherein the coarse, coal-lean fraction is rejected at a size varying from about 30 to 100mm, depending on tip properties. Avoidance of compaction of material, causing blockages in hoppers and chutes, is important at this stage.

For tips with high contents of fine-grained particles which tend to be cohesive, it is often necessary to incorporate devices such as barrel scrubbers into the feed preparation section in order to separate the individual particles. Care must, however, be exercised to avoid production of extra fine-grained particles, particularly of coal. This can occur through excessive abrasion during the washing process, especially where softer shale materials are being reprocessed. If the washing plant

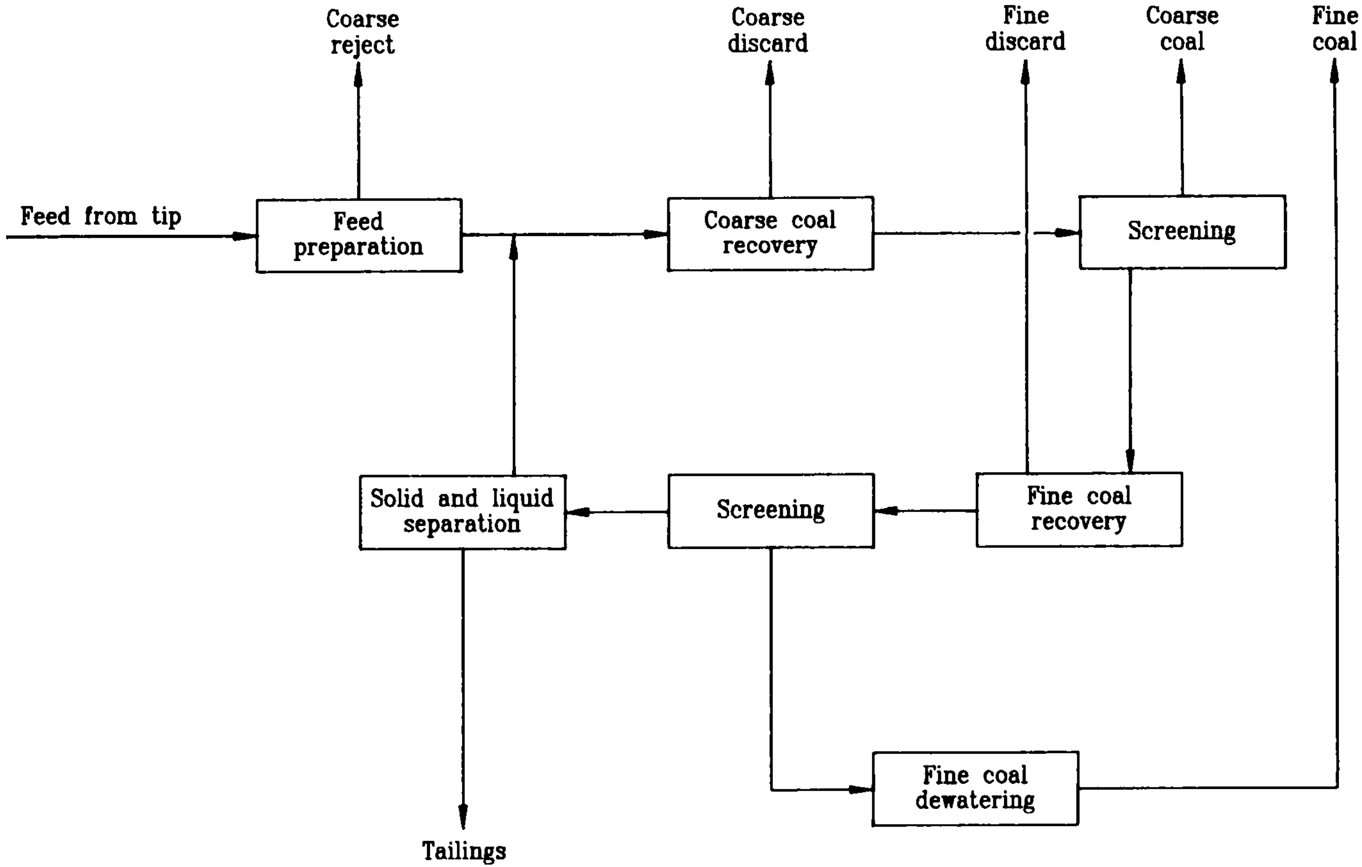



***Figure 8.4:*** Simplified flowchart for coal recovery from colliery spoil

is overloaded with fine material this can severely affect the feasibility of a project.

### 8.3.3 Coarse-grained coal recovery

The size of interest for coarse-grained coal recovery is from about 100mm to 1mm. Coal recovery from material >100mm is considered impractical, and jigs, barrel washers and dense medium methods will only operate effectively above 1mm. No single machine is capable of operating on material of particle sizes from 0-100mm. The unit operations employed are dependent on the quantity and type of materials in the tips, and also on the market for the recovered coal. If the tip contains appreciable amounts of middlings (see Box 8.1) and if it is essential to meet strict limitations on ash content in the coal, dense medium separation, normally in the form of cyclones, might be necessary. Dense medium separation relies on the use of a liquid medium with an SG between that of the coal and discard. This separating medium often consists of the slurry formed by the fine-grained particles in the colliery spoil and water, although slurries of magnetite (a type of iron ore) form lower viscosity suspensions which can be carefully regulated by means of magnetic separators. However, because of the high capital and running costs it is rare to see plant with magnetite suspensions as media, shale mediums being generally preferred, particularly on the smaller sites.

Jigs are cheaper than dense medium systems and have been successfully employed on a large number of colliery reclamation schemes. Modifications to the discard handling mechanisms are required and careful control of discard removal must be exercised to minimise coal losses. Jigging involves the use of pulsating water flows, rather than dense media, and the effective separation density increases as the particle size decreases. This is an important consideration in view of the distribution of coal with particle size discussed earlier.

Barrel washing, normally in combination with shale-medium cyclones for the fraction below 5mm, is probably the most widely used coal recovery system for colliery spoils. It is a low cost option because of its simplicity and ease of operation, and barrels have therefore been found to have application on tips containing as little as 250,000t of spoil. Figure 8.5 illustrates how a barrel washer uses the flow of water to transport coal, leaving the heavier discard to be conveyed against the slope by the scrolls. Provided that the barrel is fed at a constant flow with reasonably consistent material, and that the slurry density is carefully controlled, it can be operated at an efficiency approaching that of a jig.[260] A typical partition curve for a barrel washer is shown in Figure 8.6. The partition curve is the classical method of reporting the efficiency of coal separation achieved by a particular piece of equipment. From it the Epm value (see Box 8.2) and the separating SG, *i.e.* the SG at which 50% of the coal with that SG is recovered in the product, can be calculated.

The Epm value for the barrel washer of Figure 8.6 is slightly higher than would be associated with jigs on similar duties but significantly higher than values found in dense medium processes. Dense medium process Epm values can be as low as 0.06. The separating SG of about 1.5 was found to be insensitive to particle size in the application shown in Figure 8.6, possibly indicating some shielding of fine-grained coal from the flowing stream by overlying discard. Axial lifter bars have been employed in some barrels to alleviate this problem. These data were derived for a barrel of 1.8m diameter handling approximately 100t/hour. Barrel diameters up to 2.9m are now available with throughputs approaching 400t/hour.

### 8.3.4 Fine-grained coal recovery

For the recovery of coal in the size fraction from about 1mm to 0.25mm, it has been common to use Hydrosizers, spiral concentrators and small water-only cyclones.[180] Froth flotation has traditionally been the method employed for separation below 0.25m, but is rarely used because of the high capital and revenue costs, not only of the flotation step but also of

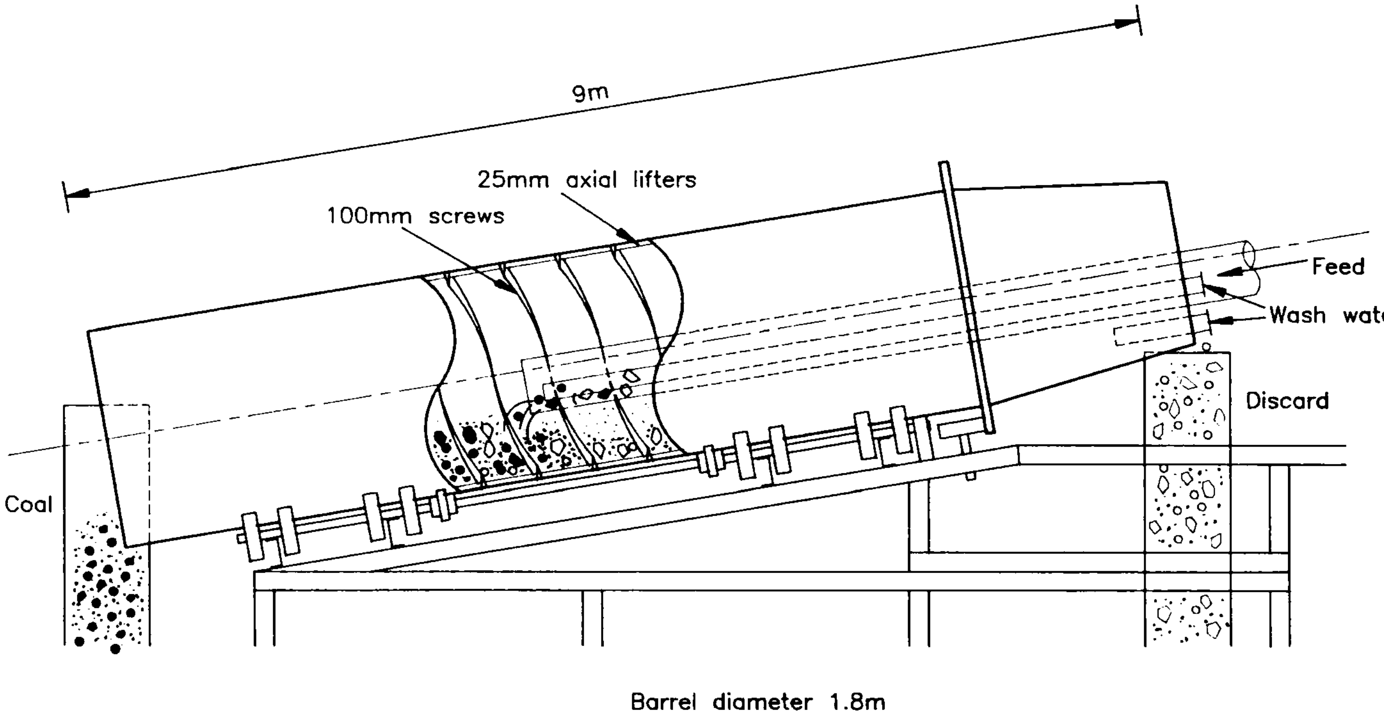



***Figure 8.5:*** Simplified diagram of a barrel washer for coal recovery from colliery spoil

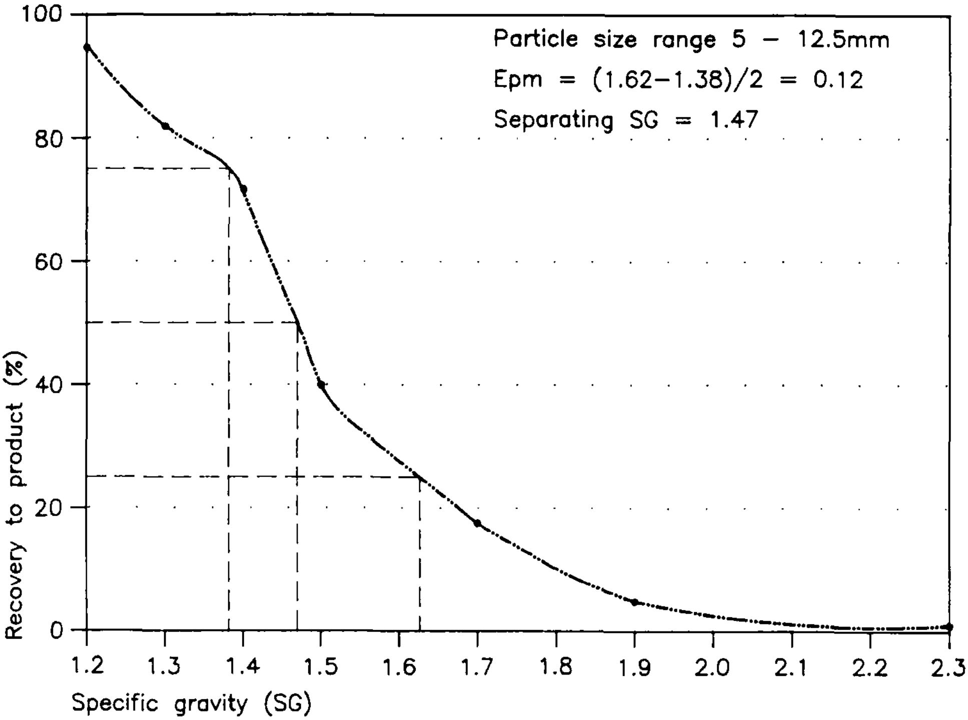



***Figure 8.6:*** Typical partition curve for a barrel washer

***Box 8.2:*** The Epm value

The Ecart Probable Moyen, or Epm value is a measure of the efficiency of a particular piece of equipment used in coal recovery. The Epm value is derived from the partition curve (see Figure 8.6) as follows:

$$\text{Epm} = \frac{\text{SG which will achieve 75\% recovery - SG which will achieve 25\% recovery}}{2}$$

The Epm decreases as the steepness of the partition curve increases, *i.e.* as the separation becomes more efficient.

the associated dewatering facilities. Also, it is often assumed that surface oxidation of the fine-grained particles has occurred to an extent where flotation becomes difficult. However, it is usually possible to achieve good performance with the correct choice of reagents, albeit at slightly higher dosages than those encountered in run-of-mine coal flotation. It may also be necessary to operate at a relatively low slurry concentration, of about 10% w/w solids, to avoid entrainment of slimes.

### 8.3.5 Solid/liquid separation

*Coal product and coarse discard*

Since it has been unusual to recover coal of a size <0.25mm, the coal product has been dewatered using a combination of screening and centrifuging. These operations, together with storage on properly drained pads, result in a product which is acceptable in terms of ease of handling. Further moisture reduction by thermal methods may be used if the economics, in terms of extra revenue for increased calorific value, are favourable.

*Tailings*

In the infancy of colliery spoil washing, use was frequently made of lagoons as a method of storage and dewatering of tailings. Management and engineering constraints on the properties of discard materials often dictate that mechanical means of tailings dewatering are included in modern tip recovery plants. These constraints arise from the high water content and gel-like consistency of lagoon tailings, which limit the after-use of the site due to ground instability, and can produce problems of water seepage and safety risks. Operations such as deep cone thickeners, vacuum filters, filter presses and solid-bowl centrifuges have found application, but are not as common as belt presses (or multi-roll filters) in newer facilities. Newer equipment has the advantages of continuous operation and a greater drop in pressure across the filter *i.e.* they can operate at several atmospheres pressure unlike rotary vacuum separators which can only achieve pressure drops of 1 atmosphere. Flocculant consumption adds a significant operating cost for processes incorporating belt presses, but the tailings moisture content can be reduced to around 30% w/w at rates up to 50t/hour, enabling mixing with the coarse-grained discard prior to formation of the new landforms. If the quantities of tailings are high it may be necessary to consider the addition of cement in order to achieve the required engineering properties.

The use of large open lagoons for the collection and settlement of coal washery tailings is less used in Europe than it was in the past, although where flat land is in abundance it is still an inexpensive option. The need to dewater old lagoon tailings can however prohibit reclamation of these sites due to the high cost of these operations.

## 8.4 Infrastructure

When assessing the feasibility of incorporating coal recovery into a land reclamation project, the availability of land, transport arrangements for supplies and products, availability of utility services such as water and electricity, and environmental issues, must be considered. The equipment generally requires little space but location is important so as to minimise the nuisance to and disturbance of the environment. Transport of coal must be carefully planned and is often an area of contention when permission is being sought for such recovery operations. Rail transport is preferred, and may be feasible for large volumes of material, even if previously abandoned lines have to be reinstated.

Water requirements are also significant, with quantities of the order of $1m^3$ of make-up water needed for every 10t of feed treated. This quantity tends to be higher for tips with a high content of fine-grained particles.

Power requirements for a large reprocessing centre treating about 500 t/hour are approximately 1000kW. The centres are often operated continuously with a weekly stoppage for maintenance. Labour requirements are in the region of 20 people for the larger centres/works, including managerial, supervisory and laboratory personnel.

Construction of new plant requires a minimum period of six months, and relocation of an existing facility approximately half of this time. Modular construction can reduce these times significantly.