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COAL PREPARATION

S U M M A R Y

Coal preparation technology covers a wide range of processes that can be applied to improve the quality of coal to meet market requirements. These can include raw coal pre-treatment, crushing and sizing, and coal cleaning or beneficitation. The traditional role of coal preparation has been to produce a saleable product from and add economic value to run-of-mine (ROM) coal. More recently, it has been recognised that coal preparation can also bring considerable environmental benefits, including reduced emissions of sulphur dioxide (SO_2), carbon dioxide (CO_2), and particulates, through the supply of clean coal of consistent quality to downstream coal utilisation processes.

During the last decade, continuing process development and R&D effort has led to significant changes in coal preparation practice and this trend appears likely to continue in the foreseeable future. Amongst the major coal producers, however, there still remain significant variations in coal preparation practice.

For the coarser grades of coal, two coal-cleaning processes predominate: dense medium (DM) separation and jig washing. Both processes have gained wide application throughout the world and the choice between the two is not always straightforward. Regional preferences can be influential and, in some countries, DM separation is preferred while, in others, jig washing is preferred. It is generally recognised, however, that DM separation has the potential to achieve more accurate separation than jig washing. This technology has benefited from the recent introduction of larger-diameter DM cyclones, allowing the treatment of larger tonnages and a much wider size range of coal in a single unit. This has helped to simplify DM plant design and reduce capital and operating costs. Nevertheless, jig washing is still widely perceived as a simpler, lower-cost option than DM separation and a range of improved jigs has continued to find wide application in Germany, India and China.

For fine-coal cleaning (coal below ~0.5mm), the past decade has seen the increased application of density-separation techniques, such as spiral concentrators and test-tube separators. For coal below ~0.15mm, however, froth flotation is still the most widely used process and, particularly for ultrafine coal (e.g. minus 0.250mm), recent practice has favoured the use of selective flotation technologies such as column flotation. It is now common to find fine-coal cleaning circuits that combine density separation for the coarser fractions with selective flotation for the ultrafines.

Dewatering of fine coal continues to be the subject of considerable R&D effort. For coal below ~0.5mm, vacuum filtration is still widely used in a range of disc, drum or horizontal belt configurations. There is also increasing application of high-speed scroll centrifuges for fine coal dewatering. Often used in combination with conventional vibrating-basket centrifuges for coarser coal dewatering and vacuum filtration for finer coal, scroll centrifuges have allowed greater flexibility in process design to suit a wide range of dewatering applications.

Tailings treatment and water clarification remain the most difficult and costly areas of coal preparation. Current practice now favours the use of modern, high-rate thickener/clarifier designs, enhanced by the use of advanced chemical reagent systems. For applications where further dewatering of thickened tailings is necessary, the traditional method has been the recessed-plate filter press. However, for some applications, the multi-roll filter (MRF) can offer acceptable dewatering performance in a continuous process at lower capital cost, and is now challenging the predominance of the filter press.

The level of automation and control in coal preparation throughout the world varies considerably. Although sophisticated technology is now available for on-line process monitoring, coal preparation plant, even of recent construction, still employ a mixture of conventional manual and automated monitoring and control. One of the major R&D issues currently facing plant automation is the need for improved sensors for the monitoring of process stream qualities. Recent attention has also focused on the development of advanced control systems using fuzzy logic and neural networks. However, commercial application of these advanced systems in coal preparation is unlikely in the near future.

The design of coal preparation plant can be influenced by a number of factors including coal characteristics, market requirements, local infrastructures and regional preferences. Accordingly, there is considerable regional variation among the major coal producers in design philosophy. However, two major categories of plant can be identified. In applications where a range of premium products is required, total washing is normally carried out using a number of technologies in a relatively complex flowsheet. Where the main product is power station fuel (PSF), dry fines are often extracted from the ROM coal by screening and a relatively simple partial-washing process is applied. The cleaned coal from the washery is then blended with the untreated fines to achieve the required PSF specification.
In coal preparation plant design, there is now a clear trend towards simpler process flow sheets employing larger equipment in single-unit processes. This trend has been driven by the need to reduce the costs of coal preparation whilst maintaining acceptable process performance. There is also a trend towards modular preparation plant designs, which allow greater flexibility in operation and can be readily dismantled and re-located.

**Benefits of the Technology**

Coal preparation can offer a number of commercial and environmental benefits. These include:

- increased quality and commercial value of saleable coal
- potential to exploit coals that would otherwise be classified as unrecoverable because of commercial or environmental constraints
- increased efficiency and availability and reduced maintenance of coal utilisation plant through the supply of lower ash coal of consistent quality
- improved environmental performance of coal utilisation plant (this could include reduced SO₂, CO₂, and particulate emissions, depending on each application)
- reduced transportation requirement of clean coals compared with raw coals
- reduced quantities of combustion ash for disposal.

**Department of Trade and Industry Support**

Since 1990, the Department of Trade and Industry (DTI) has supported 12 projects associated with coal preparation, contributing £577.718 to a total project value of £2.4M.

**Introduction**

ROM coal, whether produced from underground or surface mines, is rarely produced in a form suitable for use without further processing. Coal preparation, to some degree, is practised by all the major coal-producing nations of the world. The technologies employed range from sophisticated plant, employing advanced equipment and process designs to meet tight quality specifications, to more rudimentary plant involving merely the crushing and screening of raw coal to a uniform size to facilitate handling.

The aim of this review was to investigate the global status of coal preparation technologies, to determine technology needs and to identify key areas where future R&D should be focused.

As part of the review, a questionnaire was designed and submitted to major coal producers worldwide. Substantive responses on coal preparation practice in specific plant were received relating to operations in Australia, the Republic of South Africa (RSA), the UK and the USA. Information from other major coal producers has been obtained primarily from recently published sources and from manufacturers and suppliers.

Coal preparation, in its earliest forms, dates back to mediaeval times. Coal preparation can offer a number of commercial and environmental benefits. These include:

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- improved environmental performance of coal utilisation plant (this could include reduced SO₂, CO₂, and particulate emissions, depending on each application)
- reduced transportation requirement of clean coals compared with raw coals
- reduced quantities of combustion ash for disposal.

**Raw Coal Pre-treatment**

Raw coal, characteristically, is of variable size, moisture and ash content, with differing amounts and types of other contamination from the mining operation. Much of the recent development in raw coal pre-treatment has focused on ROM screening for dry fines extraction and application of improved crushing technology.

The basic equipment in general use worldwide for the dry screening of ROM coal is the vibrating screen, in its various forms. Multi-angle deck screens (also known as banana screens) were first conceived in an attempt to achieve high throughput, high screening efficiency and low power consumption. This technology shown in Figure 2, has proved a popular and reliable method of unsorted fines extraction and banana screens are now found in the majority of modern high-technology coal preparation plants throughout the world.

**PRINCIPAL PROCESSES**

Coal preparation conventionally involves the cleaning of coal by the separation of coal-rich from mineral-matter-rich particles in different size ranges. Typically, the processes employed include:

- raw coal pre-treatment
- coal cleaning
- coal sizing and classification
- coal dewatering
- tailings treatment and water clarification.

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Figure 2, Banana screen for ROM coal screening (Courtesy of Don Valley Engineering Ltd)

An interesting departure from this trend is in the RSA, where roller screens have been used for some applications in preference to banana screens. In this screening technology, the screen bed is kept alive by the use of elliptical rolls, which rotate to prevent pegging and blinding. For dry-coal screening, roller screens have been reported to achieve high efficiency down to 6mm.

For pre-crushing of raw coal, the use of standard jaw crushers has now declined because these can be unselective, can generate a large amount of fines and are frequently constrained by throughput capacity. During the last decade, there has been a corresponding move towards the use of twin-scrolls for this purpose and many of the major coal producers are using this technology throughout the world.

The twin-scroll, shown in Figure 3, allows the selection of a wide range of capacity, up to 5000t/h, and a wide range of product sizes.

Twin-scrolls also generate less fine material than crushers and the trend towards their use appears likely to continue and increase.
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(ii) separation based on differences in surface properties between coal and associated mineral matter, coal is hydrophobic, whilst associated mineral matter is generally hydrophilic.

Other separation methods, which include magnetic, electrostatic, chemical or biological coal-cleaning processes, have also attracted considerable interest but, in general, these have yet to achieve commercial viability.

The processes employed in coal cleaning are determined, to a large extent, by the variability in size of the coal feed and the size range desired in the final products. RD processes, of one type or another, are normally restricted in application to particle sizes above ~0.1mm although recent developments are extending this lower size limit further towards ‘zero size’. Processes based on surface properties, such as froth flotation, can normally be applied to particle sizes below ~0.6mm.

Coal cleaning methods are often categorised by the coal size range for which they are designed, ie coarse coal, small coal, fine coal, and ultrafine coal. These terms can cause confusion because many of the principal methods and much of the equipment used for cleaning coal have significant overlap in the particle size ranges they can treat. Commonly accepted nominal size definitions, as used in this report, are as follows:

- coarse coal (>25mm)
- small coal (25-3mm)
- fine coal (<3mm)
- ultrafine coal (<0.15mm).

Coarse coal
Coarse coal has always been in demand for burning or less sophisticated grate and combustion systems and for domestic use. Although the traditional use of large coal leg for railway and householder use has virtually disappeared as a significant market in many economies, there remains a small but important demand for larger coal for industrial applications. For these applications, a significant price premium is often payable. For coarse coal cleaning, two main processes are used:

(ii) Jig washing, which is a water-based process that relies on the pulsation of water through the particle bed to stratify particles of different density. The higher-RD shale particles, forming the lower layers, are separated from the clean coal using a shale discharge system.

Both processes have found wide application throughout the world. The choice is often made according to regional preferences for particular processes, which only in part reflect the washability characteristics of the coal. Jig washers, such as the Baum jig, have been developed to accept a wide range of sizes up to a top size of 150mm in a single process. The jig is a relatively low-cost, simple washing system generally considered efficient only for coals that are relatively easy to clean. However, Jig washing technology has been subject to continuous improvement since the 1970s and a number of improved jigs (eg the Batac jig and the PCB jig) have found wide application, particularly in Germany, India and China. Much of the present R&D effort in this area is aimed at the development of improved jig control systems. An example is the JESCAN on-line control system developed by the Julius Kruttschnitt Mineral Research Centre (JKMRC), which uses nucleonic density gauges to monitor jig bed density. The signal is then used to control the jig density cut-point.

Another recent entry into the market has been the ROW jig, developed in Germany for the de-shaling of lump coal. The ROW jig, shown in Figure 4, was originally developed at the instigation of the Indo-German Coal Group and has attracted considerable interest for this application in India.

Since the 1950s, DM separation processes have become increasingly popular because of their potential for high efficiency and accuracy of separation. As quality requirements for coarse coal have become more rigorous, the DM static bath has become the predominant technology for cleaning larger coal, ie up to 250mm. A wide range of DM baths is available, the main differences being the method of introduction of the separation products.

DM cyclones, which employ high centrifugal forces, are commonly used for the finer size ranges of coarse coal cleaning. Until recently, the application of DM cyclones had been restricted to particle sizes <35-40mm. However, the introduction of larger-diameter DM cyclones has now allowed the treatment of a much wider feed size range, and larger cyclone units are now capable of accepting topsizes up to 80mm, depending on feed inlet configuration (ie tangential, involute or cycloidal).

The largest DM cyclones now in commercial operation are of 1.25m diameter, with feed capacities of 300-350tph per unit. There are, however, technical issues still to be resolved concerning the performance of the large-diameter cyclones in the finer sizes, where some misplacement of low-density material to reject has been reported.

Another DM system worthy of mention is the JARCODEMS (Large Coal Dense Medium Separator) which was developed in the UK as a replacement for the Baum jig. The JARCODEMS, shown in Figure 5, is a cyclonic DM separator capable of accepting raw coal up to 120mm. It has been used widely in the UK and, more recently, has also been applied in the RSA.
One of the earliest coarse coal separators, the barrel washer, has also re-emerged as an option for upgrading coals for applications where it is less important to achieve high accuracy of separation. Traditionally, the barrel washer has been used as a semi-continuous method for the recovery of coal from waste tips but in recent years it has also found some application as a simple, cost-effective method of de-dusting ROM coal. An example is the recent Lodna washery in India, which incorporates barrel washers and cyclones to produce coal for the cement market.

Small coal
Jig washing systems are capable of treating both large and small coal in a single unit. Over the years, jigs have undergone considerable development to improve performance, particularly in cleaning small coal. One of the most notable developments in this area has been the Batar Jig, which, in some forms, is claimed to be capable of washing coal down to 2mm. However, the DM cyclone is probably the most widely used system for processing coal in the 0.5-0.085mm size range. As mentioned above, the most notable recent development has been the introduction of large-diameter DM cyclones, capable of accepting particles up to 75mm size and allowing both small and large coal to be treated in a single unit.

Fine coal
Coal producers throughout the world have long debated the pros and cons of fine coal treatment and recovery. In the past, arguments for discard of fines direct to lagoons have been based on the cost of fines recovery and the increased difficulty this causes with product handling. Current coal preparation practice now tends to place primary importance on maximum recovery of coal, which favours fines treatment. The requirement to maximise coal yield, together with a growing emphasis on improving product quality, has redefined the scope of fine coal cleaning and, nowadays, a wide range of process design is available.

Froth flotation is almost certainly still the most commonly used process for the preparation of coal below ~0.6mm in size. Mechanical flotation cells, which inquirers are employed to disperse air bubbles within the fine coal slurry, are used in all of the coal-producing countries and can be highly effective in terms of recovery and selectivity. Flotation cells are now available with volumetric capacities up to ~120m³. For coal applications, however, where much of the flotation feed is removed as froth concentrate, the maximum practical size is thought to be closer to ~40m³ per cell. Figure 6 shows a typical bank of mechanical flotation cells.

Although mechanical flotation cells are still widely used, in the past decade a range of selective flotation technologies, such as column flotation, have become increasingly popular. Mechanical agitation is not used in these systems and selectivity is increased for the smallest sizes of particles by producing much smaller bubbles than are possible with mechanical flotation cells. In addition, water sprays are often used to rinse entrained mineral matter from the froth concentrate. There are now many types of column flotation cells commercially available. The most recent installation in the UK is at the Gascoigne Wood mine complex, where a 100t/h Pyramid column flotation plant, shown in Figure 7, was installed in 1997.

In Australia, the preference for column flotation over mechanical systems has focused particularly on janssen cells, in which coal particles and bubbles collide and attach in a downcomer feed and air tube. Another notable development in fine coal treatment is the widespread application of fine-coal density separation techniques, such as spiral concentrators (shown in Figure 8) and teeter-bed separators to clean the ~3.0-0.15mm size range.

Figure 3. LARCODEMS installation (Courtesy of Don Valley Engineering Ltd)

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Figure 7. Pyramid column flotation plant at Gascoigne Wood coal preparation plant, UK (Courtesy of RJB Mining Consultancy Ltd)
Water is scarce, although the throughput can be considered currently small number of units in operation, particularly in some areas of China where table- or jig-based designs, the latter being more common. There remain a performance. During that period, the main processes used were pneumatic and throughput and moisture presented a major inhibiting factor on separation was not accurate, available technology severely restricted feed size during the period 1930-1965 but were later abandoned, largely because of their potential to remove fine pyrite from coal. However, these processes are expensive and, in general, separation results have been inconsistent. Nevertheless, although there are no known commercial installations in current operation, these processes remain of considerable interest in R&D circles.

**Coal Sizing and Classification**

Classification by size is one of the fundamental operations of coal preparation. Screens can classify a broad range of sizes and are used for various applications throughout the coal preparation plant, including raw coal pre-treatment and dry fines extraction, size classification of feeds to separation processes, recovery and dewatering of products after separation processes and sizing of washed coal to meet market requirements. The main screen types currently in use are static screens and vibrating screens. The most common application of a static screen is the sieve bend, constructed as an arc or bend, with the sieve surfaces offering a steep to progressively lower angles to the flow of material. The most common application of sieves is to remove large volumes of water prior to material passing to a vibrating dewatering screen.

Vibrating screens are widely used to size and dewater coal in the range 200-0.25mm. A wide range of screen sizes and designs are available to meet the specific requirements of each application. One of the most significant developments in screening technology in recent years has been the introduction of new materials for screen decks to reduce wear, increase screening performance and reduce noise at coal preparation plant.

Vibrating screens become less effective as particle size decreases and accurate size classification of fine and ultrafine coal remains a problem. These sizes tend to be classified using the principle of differential settling velocity. In the past, a range of classifiers operating on this principle have been applied, including hydrocyclones, spiral classifiers and settling towers. Settling towers are still in common use for the classification of process water or jigmatare plant. However, a major feature in recent years has been the increasing use of hydrocyclones in coal preparation. Hydrocyclones are used for many applications including control of fine solids recirculating in process water, classification of fine from ultrafine coal prior to further cleaning and pre-concentration of fine coal before dewatering.

Over the years, there has been considerable R&D into means of improving the accuracy of separation in hydrocyclones and, currently, a number of high-efficiency units are available. However, the hydrocyclone has the inherent problem that some ultimates or slimes always report to the coarse product. Efforts to minimise this displacement of slimes have included
optimization of hydrocyclone design to minimise water flow, and hence the entrainment of slimes, to the underflow and injection of clean water close to the cyclone underflow spigot. A recent approach of interest has been the use of multiple-stage hydrocyclone circuits to increase overall accuracy of separation. In Australia, a three-stage hydrocyclone system has been tested recently and found to produce a much sharper separation, both improving the recovery of coarse coal and minimising the misplacement of slimes. However, despite the improved performance, multiple-stage hydrocyclone systems are relatively expensive to install and operate and their use will be limited to applications where the additional cost can be justified.

**Coal Dewatering**

Effective dewatering of coal has become increasingly important to meet product specifications and to improve handleability. The most common items of equipment used are vibrating screens and vibrating basket centrifuges for coarse coal dewatering, scroll centrifuges for fine coal and vacuum filters for froth flotation concentrates.

While dewatering of sizes above ~0.5mm has generally presented few problems, the dewatering of finer coal, particularly by vacuum filtration, has always been more difficult. Traditionally, rotary vacuum filters, either disc or drum, have been used. A more recent addition to filtration technology has been the horizontal belt filter (HBF, shown in Figure 11) and this is now finding increasing popularity.

In general, compared with disc and drum filters, the HBF has demonstrated improved dewatering performance and ease of operation and maintenance. During the 1990s, the HBF was the main type of vacuum filter installed in the Australian coal industry, totalling more than 15 units. One possible disadvantage of the HBF is its requirement for a large floor area to accommodate the horizontal belt.

For some applications, high-pressure filters have also been considered for fine coal dewatering to increase filter throughput and produce low-moisture filter cakes. A number of variants have been investigated, including tube presses, air-blown filter presses and hyperbaric filters, where a vacuum drum or disc filter is installed inside a pressure vessel. However, although these devices can demonstrate much improved dewatering performance compared with conventional vacuum filtration, they are expensive and commercial application is restricted to special cases where the additional costs can be justified.

For fine coal dewatering, various designs of scroll centrifuge have also been introduced in the last decade and these are finding increasing application in coal preparation. Generally, these centrifuges operate at higher speed and can generate greater dewatering forces than the more traditional vibrating centrifuges used for coarser coal. In this type of centrifuge, shown in Figure 12, the inner scroll rotates at a slightly slower speed than the centrifuge basket, to discharge the dewatered coal.

Typically, scroll centrifuges dewater coal up to a topsize of 1-1.5mm. Overall, reduced product moisture is achieved not only through improved dewatering of this finer fraction but also through the decreased solids loading on the coarse coal centrifuges. Screenbowl centrifuges operate at even higher speeds than scroll centrifuges and are capable of dewatering coal down to ultrafine sizes. This type of centrifuge has found application, in particular, for the dewatering of froth concentrates. Again, although dewatering performance can be excellent, screenbowl centrifuges are expensive and their use is limited to applications where their cost-effectiveness can be demonstrated.

R&D is continuing into the development of centrifuges for the dewatering of ultrafine particle sizes. Much of this R&D has focused on the development of high-speed centrifuges with fine-aperture dewatering baskets. One such system is the Fletcher Smith centrifuge currently under test in the UK. The centrifuge, shown in Figure 13, has achieved good dewatering performance and attention is now turning towards the use of improved materials to reduce maintenance costs associated with basket wear.

**Tailings Treatment and Water Clarification**

Tailings treatment continues to be the most difficult and expensive area of coal preparation. Consequently optimizing thickener performance and reducing operating costs have been areas of considerable ongoing development. In recent years, this has led to the introduction of a range of modern, ‘high-rate’ thickener designs. An example is the Delkor Hi-Rate thickener which introduces the feed into a flocculated and fluidized bed of settled solids. The feed is filtered by the solids within the bed, leading to
higher moisture content can be acceptable. Capital cost and ease of operation have made multi-roll filter (MRF) presses viable. Although flocculant consumption is higher, advantages of low MRFs are continuous in operation and are lower in capital cost than filter presses. A typical example is shown in Figure 16.

Filter pressing is a batch process and one of the oldest established mechanical techniques for solid/liquid separation. This process has, however, been subject to continuing R&D to optimise performance and one important development has been the introduction of the membrane or variable-volume filter plate. The use of membrane plates can produce a filter cake with lower total moisture and/or can achieve a higher solids throughput than conventional recessed plate presses. Modern filter press installations are highly automated and offer excellent dewatering performance, producing filter cakes with very low moisture contents. However, filter pressing is still a costly operation and recent years have also seen the introduction and increasing application of multi-roll filters (MRFs). A typical example is shown in Figure 16.

MRFs are continuous in operation and are lower in capital cost than filter presses. Although flocculant consumption is higher, advantages of low capital cost and ease of operation have made multi-roll filters (MRFs) a viable alternative to filter presses for many applications where filter cakes of higher moisture content can be acceptable.

PLANT MONITORING AND CONTROL

Effective monitoring and control systems are recognised as being essential for the efficient performance of coal preparation plants. A wide range of techniques are now available for on-line process monitoring, including neutronic density gauges, magnetic flowmeters, ultrasound level detectors and mechanical belt weighers. However, it is still common, particularly in older plant, for at least some of the processes to be monitored and controlled by operators relying on manual measurement of process parameters.

For on-line quality monitoring, a number of techniques are used, including measurement of response to electromagnetic radiation, measurement of the emission of natural gamma radiation and variation of capacitance recorded between two charged plates.

In both types of monitoring system, the measurement technique produces an electronic signal that can be used for control purposes. Conventional control systems use either traditional hard-wired technology or computer-based programmable logic controller (PLC) systems for stop-start sequencing and control of equipment speed and feed rates. PLC control supports individual control loops to allow constant monitoring and adjustment of processes. However, PLC control is limited by the rule-based logic that is applied and by the inconsistencies of applying this logic to processes in which the dynamics are, as yet, ill-defined.

Recent R&D in this area has included investigations into the application of advanced control systems using fuzzy logic and neural networks. However, although both systems have been employed in grinding and froth flotation circuits for base metals and industrial minerals, there is, as yet, no known commercial application in coal preparation. Yet further in the future is the application of intelligent systems for control of a whole coal preparation plant.

The plant survey associated with this review highlighted the very variable extent to which monitoring and process control systems are currently applied in coal preparation plants. In the western industrialised economies, automatic weighing systems are used in only 90% of plant surveyed, whilst only ~40% use ash monitors and ~35% use automatic samplers. For process control, only 80% of plant have PLC systems installed. The survey had a lower response from plant operators in the developing coal economies but, from the information received, <20% of plant use PLC systems.

The majority of coal preparation plant constructed in the last decade still employ a mixture of manual and automated monitoring and control, with an increasing trend towards the latter. Further automation is constrained by the need for improved sensors for the characterisation of process stream qualities and also the need for improved logic-based systems for plant control. The survey identified monitoring and control as an important focal area for further development.

PLANT DESIGN AND CONSTRUCTION

Process Design

There is no consistent layout for new coal preparation plant currently being installed, nor is there any universally accepted design that covers all operations. As discussed earlier, particular technologies are favoured for a number of reasons. These include the physical or chemical properties of the coal to be treated, the product specification, the range of products...
required, the supporting infrastructure, the perceived cost, the complexity of operation and, not least, local preference for familiar or indigenous technologies. Consequently, coal preparation plant designs are many and varied. However, two major categories of plant have emerged: total-washing systems and partial-washing systems. Figure 17 compares flowsheet examples of both types of washing system.

Total-washing systems meet the markets for high-quality premium products (eg metallurgical coal), requiring a relatively complex flowsheet design. These systems are common in Australia, the RSA and the USA.

Partial-washing systems are aimed at the preparation of PSF, using a less complex flowsheet design, where unretreated fines are extracted by dry screening before the washery and then blended back with the washed coal to meet the PSF specification. These systems are common in the UK and the RSA and are also considered suitable for the preparation of PSF in India. The example shown in Figure 17 is for a simple de-stoning flowsheet without the benefit of fine coal.

Coal preparation plant can also be classified according to the main separating process employed, either jig washing or DM separation. Coal washability can vary considerably throughout the world and this variation is reflected in the common choice of process technologies in each region. Figure 18 shows the densimetric profiles of a number of coals.

In general, because of the potential for higher accuracy of separation than jig washing, a coal preparation plant using DM technology is a more common choice for difficult-to-wash coals. For coals that are easier to wash, the benefits of increased accuracy of separation are less clear and the preferred choice may be either DM separation or jig washing.

Table 1 shows the distribution of the main processes used in the various regions of the world.

A significant proportion of the world's coal production, eg coals found in the RSA, are Gondwana in origin and are typified by high levels of ash, finely disseminated throughout the coal matrix. These coals are difficult to wash and DM systems are favoured for separation of the plus 0.5mm fractions. One exception is India, another Gondwana coal region, where jig washing has been favoured in the past, possibly because the relatively poor yield of clean coal for metallurgical use produced by jig washing has been compensated for by the use of jig discard as a saleable PSF.

For the easier-to-clean coals, typically found in the Northern hemisphere, jig-washing processes can often achieve efficient separations, depending on the quality of the product required. However, even for these coals, there is now a general trend towards the increased use of DM systems due to significant tightening of product specifications and increased price penalties for variations from these specifications. This trend has also been aided by the change in relative economics of the two competing processes. Traditionally, it has been perceived that the capital and operating costs of DM plant are higher than those of jig washing. This perception has changed gradually over the past decade, largely through the introduction of large-diameter DM cyclones. This has allowed the use of a single DM cyclone process instead of the traditional use of DM static baths and cyclones in combination. This has greatly simplified circuit design and reduced the capital and operating costs of DM plant.

Table 1. Distribution of major coal preparation processes employed by region
tailing dewatering remains a high-cost activity and is still avoided where possible, with thickened tailings being discharged to lagoons for further settlement and dewatering.

**Plant Construction**

Traditionally, coal preparation plant have been tall structures with multiple levels to maximise the use of gravity flow. The supporting steelwork and building cover has also tended to be an integral structure. More recently, particularly in the western industrialised countries, there has been a trend towards construction of plant with single-level operating floors, with much of the material transfer being pumped between processes. Despite the larger footprint of low-level structures, there are advantages in costs of construction and accessibility for maintenance. A single-level structure also allows much more flexibility in terms of modification of plant equipment and the introduction of new systems.

Another well-established trend is towards modular plant designs. These allow the flexibility to incorporate new processes within the flowsheet or to increase throughput by the addition of new modules in parallel. Modular plant can also be readily dismantled for transfer to another site. Characteristically, modular plant are constructed in relatively simple, single-level, steel box structures for fast construction and portability.

**International Practices in Coal Preparation**

The potential market place for coal preparation technologies has been seen to fall into two distinct categories:

(i) Industrialised nations, which are able to draw on a wide range of coal preparation technologies and in which significant research and innovation are developed through both research institutions and coal preparation equipment manufacturers. These nations include Australia, Germany, the RSA, the UK and the USA.

(ii) Nations in transition or development, in which the choice of technology is often constrained by lack of capital funding and by a low revenue stream. In general, the technology employed must be low in capital and operating costs, and characterised by minimal processing or maximum use of indigenous technology and equipment. These nations include China, India, Kazakhstan, Russia and the Ukraine.

Influences on the degree of coal preparation and on the technology employed vary considerably from region to region. The following sections discuss these influences and their effects for some of the major coal producers.

**Australia**

Although Gondwana in origin, Australian coals are formed in somewhat different sedimentary environments from other Gondwana coals. As a result, Australian coals are typified by high vitrinite content, giving rise to high-quality coking coal.

Most of Australia's coal production is for export and the saleable products are categorised as either metallurgical or thermal coal, largely depending upon coking properties. Over 80% of Australia's ROM coal is processed by coal preparation and, in 1998, some 64 plant were operating, the majority with a feed capacity >4000t/h.

In Australia, DM separation technology predominates, treating 50-60% of all washed coal. Typically, DM static baths are used for large coal cleaning, with Teska or Daniels baths currently being popular. However, the DM cyclone remains the workhorse of the Australian coal preparation industry, with large-diameter cyclones of up to 2200t/h capacity becoming common over the last few years. In Australia, the drive towards even larger DM cyclones continues, with a 1.25m unit installed recently by Burton Coal.

For fine coal cleaning, spiral concentrators are in common use, often in combination with conventional or column flotation for fine coal. However, with the continuing drive to improve clean coal quality, there has also been recent interest in the use of froth-bed separators because of their ability to achieve low RD cut-points. The first froth-bed unit was installed in Australia in 1987 to re-treat spiral product in order to enhance the yield of low-ash coking coal.

Over the last two decades, new plant typically have been of large (5000-20000t/h) capacity but there is now a clear trend towards smaller-capacity (500-10000t/h) plant of modular construction. Modular construction is seen to provide a means of standardisation and to contribute to lower construction and operational costs. The recent developments in large-diameter DM cyclones, together with more frequent use of multi-stage (or banana) screens, have also allowed single-stream designs to be adopted in Australia, with corresponding cost benefits.

**China**

In China, the current ‘Tenth Five-year Plan’ has recognised the need to achieve major improvements in emissions from coal combustion, and has allocated significant funds for investment in coal preparation technology. This has been driven largely by the need to improve air quality in heavily-industrialised areas, the emphasis being on reducing smoke pollution and SO₂ emissions. Coal preparation has been identified as a cost-effective route to achieve these improvements. In particular, coal preparation is attracting considerable interest as a means of reducing sulphur in coal. China’s coals are generally low in sulphur by world standards but the distribution of sulphur is uneven and it has been estimated that ~10% (or ~100Mt/a) of the country’s production is high-sulphur (>0.6%) coal. In many cases, this is due largely to the presence of pyritic sulphur, much of which can be reduced by coal preparation.

There are reported to be over 1570 small coal preparation plant in China. These plant are generally of <30,000t/a capacity, with jigg washing the predominant technology. In the larger, state-owned coal mines, the great majority of preparation plant are >60,000t/a capacity, with some 73 plant having feed capacity >1,500t/a. However, only ~50% of all China’s coal production is currently processed and there is considerable scope for increasing the washing rate. Figure 19 shows a modern Chinese coal preparation plant under construction.

It is expected that the continuing drive to increase coal exports, together with the national objective to reduce SO₂ emissions, will lead to an increased emphasis on large coal preparation plant using western technology, including the greater use of DM systems.

**India**

India is now the third-largest coal producer in the world, relying to an overwhelming extent on the use of coal for power generation, with ~70% of total coal production used for this purpose. In general, this coal is burnt untreated, often with an ash content of >40% and often delivered by rail over distances of >1000km. Coal preparation is used widely only for coking coal, comprising some 20% of national production. Of the 24 coal preparation plant currently operating in India, 13 were commissioned before 1970. Figure 20 shows a more recent plant, the 500t/h West Balangir No.3 coal preparation plant, commissioned in 1994 to produce high-grade coking coal for the Tata Iron and Steel Company (TISCO). The plant, designed under supervision from Kawasaki & Co Ltd, consists of four 125t/h modules, each comprising a two-stage DM cyclone system for the coarse coal and froth flotation for the fine coal.

The coals of India are Gondwana in origin and are characterised by finely disseminated mineral matter throughout the coal matrix, giving rise to relatively high-sulphur, low calorific value (CV) coals. In general, these coals present particularly difficult washing characteristics. However, for reasons explained earlier, jigg washing systems predominate in India at present, with only limited application of DM systems.
1970s and 1980s as a result of the oil crisis. However, coal preparation technologies dating back beyond the middle of the 19th Century. This has led to renewed interest in the application of alternative fine coal cleaning processes such as fine coal DMS cyclones and enhanced density separation.

In the past, it was believed that most of the RSA’s coal was unsuitable for froth flotation. However, work carried out over the last decade has shown that this coal can be froth floated, provided that the feed is <0.1mm and that it has been pre-treated adequately. In particular, turbo-flotation has shown that this coal can be froth floated, provided that the feed is <0.1mm and that it has been pre-treated adequately. In particular, turbo-flotation plant recently constructed by the CLI Corporation of the USA, to supply washed coal to power stations in the Mumbai area.

The USA has a long tradition in the development of coal preparation technologies dating back beyond the middle of the 19th Century. This development continued throughout the 20th Century and, in the latter part of that century, considerable R&D effort was focused on coal desulphurisation. Along with the application of conventional coal preparation technologies, this R&D included investigations into the use of more novel technologies including magnetic, electrostatic and chemical desulphurisation techniques.

The number of coal preparation plant in the USA increased during the 1970s and 1980s as a result of the oil crisis. However, coal preparation then decreased again as oil prices started to stabilise and decrease and, over the last 20 years, there has been a dramatic reduction in the number of plant in operation.

There has also been a change in the mix of equipment found in US coal preparation plant, with a trend away from jig washers and DMS static bath plant and towards large-diameter DMS cyclones. More than 50% of US coal preparation plant now operate some form of DMS cyclone system. Fine coal processing has also increased significantly in the last two decades with the installation of froth flotation plant, spiral concentrator circuits and, more recently, column flotation for recovery and cleaning of ultrafine coal.

In recent years, coal production has remained more or less static in the traditional coal-producing regions of the USA. However, there has been consistent growth in the western region and, with an output of 443.3Mt, this region became the leading US producer in 1998. In particular, there has been increasing production of low-cost, low-sulphur (<0.6%) coal from the Powder River Basin. With increasing concerns about SO2 emissions from coal, this has had an important effect on the cost structure of coal supply throughout the USA. As a consequence, other US coal producers are having to reduce their mining, coal preparation and transport costs to compete. It is anticipated that these competing coal producers will need to benefit from economies of scale and there is likely to be an increasing trend towards the construction of coal preparation plant of 2000t/h capacity or over.

In contrast to the top five coal producers in the world, coal production in the UK has been in long-term decline. Nevertheless, competition with imported coal and other energy sources has provided the driving force for the UK to become one of the most efficient of the traditional coal producers. The UK industry is, by a wide margin, the most cost-efficient and productive coal industry in Europe: according to International Energy Agency (IEA) figures for 1998, the UK produced 1.15t per man-year in contrast, for example, to the 600t per man-year produced by the German coal industry. Currently, the power generation market consumes ~60% of UK coal production. However, industrial and domestic markets still command a premium price and, where the coal quality is appropriate, coal preparation is also geared towards achieving the size and quality targets for these markets.

Traditionally, the strategy adopted for the power generation market in the UK has been partial cleaning, in which raw coal is initially screened to remove the finer fractions, and these untreated fines are later added to the coarser fractions which have been cleaned. This strategy continues to be used in the majority of plant. A variety of plant designs are employed and virtually all the principal processing techniques are represented.

As a reflection of a contracting coal industry, few new coal preparation plant were built in the UK in the 1990s of these, currently operating plant include Mal捂t and Glasgow and Wood, both commissioned in 1994, and Orkney, commissioned in 1998 and shown in Figure 22. However, for existing plant, new processes are constantly under review and, as with other coal producers, the design philosophy is tending towards single-stream process flow.
R&D AND FUTURE TECHNOLOGY DEVELOPMENT

For many western industrialised countries, and former Comecon economies that have undergone restructuring, there was a significant change in the 1990s in the structure and funding of R&D institutions working in coal preparation. With the privatisation of nationalised coal industries, large government-funded central R&D institutions have either been closed or transferred to the private sector. In contrast, China and India still support large government-funded research centres.

Coal preparation research is now largely undertaken in universities and technical institutes, drawing support both from government research grants and commercial contracts from industry. In some countries, specialist commercial research centres have also developed from university research departments, eg the ISRR in Australia. In general, there has been a decline in long-term, ‘blue-sky’ research and much of the current R&D is focused on the more immediate requirements of coal producers to maintain competitive commercial performance and environmental compliance. Largely through equipment manufacturers, there is also significant transfer of proven technologies from other minerals or industrial applications to coal preparation. Examples include chemical additives and flocculants to aid dewatering, coal screening equipment and enhanced density separators for ultratine coal cleaning.

Coal preparation involves the interaction of a wide range of processes and, as such, R&D is continuing in many areas. However, major topics of current and future R&D interest, identified during this review, include:

• cleaning and dewatering of fine and ultratine coal
• desulphurisation of coal
• dry beneficiation of coal for applications in arid regions and where discharge of liquid effluent may create negative environmental impact
• monitoring and control, with particular emphasis on the development of accurate sensors for coal quality monitoring.

CONCLUSIONS

With increasing demands for tighter product specification and improved environmental performance from coal utilisation, coal preparation has gained considerable importance within the coal mining industry. However, commercial pressures continue to dictate that coal preparation must remain a low-cost route to improving the quality of the saleable product. Pressures to improve emissions from coal utilisation can be expected to increase the market for coal preparation in the future. The largest markets are likely to be India and China, where a combined production of ~1500Mt/a is predicted to rise significantly in the future and where only ~25% of coal currently undergoes any kind of beneficiation.

A wide range of coal preparation plant design is applied throughout the world. Major influences include raw coal characteristics, market requirements, local infrastructures and regional preferences. However, two major plant categories can be identified: total-washing systems to produce coal for premium markets and partial-washing systems, used primarily for the preparation of PSE. Whatever the market, the need to minimise costs has meant that there is a clear trend worldwide to design new plant with simpler process design, with single-unit processing streams, where possible.

For the individual unit operations within coal preparation, recent developments include the following:

• ROM pre-treatment is characterised by the increasing use of twin-scroll diameter DM cyclones, capable of treating a wide range of sizes in a single unit. This has helped to simplify the operation and reduce costs of DM plant. However, jig washing also remains popular because of its low capital cost and perceived ease of operation and a number of improved jigs have been introduced in recent decades. Another notable development has been the ROM jig, which has attracted interest, particularly in India, for the de-shaling of large coal.

• Perhaps the most significant development in fine coal cleaning has been the introduction of fine-density separators. Two processes now predominate, spiral concentration and rotor-bed separation. Both processes are finding wide application throughout the world and continue to be subjects for considerable R&D effort.

• Froth flotation continues to be a major processing technique for coal below ~0.6mm and is particularly predominant for the cleaning of ultratine coal. The major development in this area has been the introduction of more selective flotation systems, including variants of column flotation and the Jameson cell. A number of enhanced density separators have also attracted interest for ultratine coal cleaning. However, although these have been applied commercially in the minerals industry, further development is required before they can gain commercial acceptance in coal preparation.

• Dewatering of fine coal has long been the subject of considerable R&D effort. One of the most significant recent developments in fine coal dewatering has been the introduction the high-speed scroll centrifuge. Vacuum filtration also remains a major dewatering option for coal below ~0.5mm and, in this area, HBPs have been gaining increasing popularity.

• Tailings treatment has seen a major improvement through the introduction of high-rate thickeners/clarifiers, supported by the use of advanced synthetic polymers to improve performance. Where further dewatering of tailings is required, the traditional choice has been the plate and frame filter press. However, for some applications, the predominance of the filter press is now being challenged by the MRF, which offers the advantages of low capital costs and continuous operation.

• The past decade has seen the increasing use of on-line monitoring and control systems. However, the majority of coal preparation plant still employ a mixture of manual and automatic monitoring and control. Further scope for automation is constrained by the need for improved sensors for on-line quality monitoring and also by the need for improved logic-based control systems.

A number of development issues still face the coal preparation industry. These include the cleaning and dewatering of ultratine coal, the desulphurisation of high-sulphur coals, the development of reliable and accurate sensors for coal quality monitoring and the application of dry coal beneficiation processes for arid regions. With world coal production and utilisation predicted to increase in coming years, the indications are that the present level of R&D effort in coal preparation will continue or, indeed, increase in the future.

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