Improved extraction of coal

by P. KING*, B.Sc. Hons. C. Eng., M.I.M.M., M.M., M.S., F. I. Min. E. (Visitor)

SYNOPSIS

In considering the available reserves of coal, the author points to the importance of improved recovery, and defines three extraction ratios: the geological extraction ratio (or exploitation factor), the economic extraction ratio (or mining factor), and the geometrical extraction ratio (or volumetric extraction factor). He discusses the factors affecting each of these ratios, and concludes that, although geological factors cannot be considered in isolation from technical and economic factors, the geological extraction factor is the most significant criterion of whether the best use is being made of coal resources.

SAMEVATTING

By die oorweging van beskikbare steenkoolreserwes, verwys die outeur na die belangrikheid van verbeterde herwinning en definieer drie ontginninsverhoudings: die geologiese ontginningsverhouding (of eksploitasiefaktor), die ekonomiese ontginningsverhouding (of mynfaktor), en die geometriese ontginningsverhouding (of volumetriese ontginningsfaktor). Hy bespreek die faktore wat hierdie drie verhoudings beïnvloed en kom tot die gevolgtrekking dat alhoewel geologiese faktore nie in isolasie van tegniese en ekonomiese faktore beskou kan word nie, die geologiese ontginningsfaktor die mees betekenisvolle kriterium is om die doeltreffendheid van gebruik van steenkoolbronne te bepaal.

Introduction

This paper aims to set the scene for a colloquium on mining methods and economics for improved coal extraction at a time when the rationalization and conservation of energy are of both national and global importance.

The world-wide impact of the escalation in the oil price and the prospect of a scarcity of liquid and gaseous fuels have promoted coal to the position of the most significant source of energy. The world's coal resources and production are shown in Table I.

TABLE I

WORLD COAL RESOURCES AND PRODUCTION[1]

(billion metric tons)

Estimated resources	Over	10 000 Gt
Proven reserves	Approx.	1 500 Gt
Recoverable reserves	Approx.	600 Gt
Rate of production	Under	3 Gt per year

TABLE II

SOUTH AFRICAN COAL OUTPUT

(million metric sales tons)

Year	Output	Period	Growth p.a.
1965	47,6	—	—
1970	53,1	1965–70	2,2%
1975	69,1	1970–75	5,4%
1980	114,0	1975–80	10,5%
1985	160,0	1980–85	7,0%
1990	185,0	1985–90	2,9%

In South Africa's coal-dependent economy, the manner of exploitation and utilization of the available coal resources has become a matter of public interest. In addition to the well-known energy scenario, the change in fortune that has characterized the South African coal industry during the present decade is significant.

Table II illustrates the high growth rate that is currently under way, and the substantial expansion that is expected in the future production of coal. Crucial to any consideration of present mining methods is the increasing diversification of mining systems. In this respect, 1975 marked a turning point. Before that year, conventional mechanized and some hand-got mining accounted for over 90 per cent of the output, but since then strip mining, continuous mining, longwalling, and other emergent techniques have accounted for an increasingly significant proportion of the production[2].

Expansion of the infrastructure and of output in response to inland and export sales demand is already well advanced, and the future shortage of liquid fuels is having the effect of accelerating the programme. The recently formed National Committee for Energy Research, which has a direct interest in the exploitation and utilization of coal, reflects a concern for the husbanding of energy resources — a factor of increasing importance for the coal industry.

Availability of Reserves

The coal reserves as estimated by the Petrick Commission[3], based on 1972/3 data, were 81,3 billion tons of '*in situ* mineable' coal and 25,3 billion tons of 'economically extractable' coal. These estimates have come in for a good deal of criticism on two aspects: firstly, the base data and, secondly, the assumptions made in the calculations. *In situ* reserves are substantially higher if the following are taken into account: new discoveries, shifts from inferred to proven reserves, seams below 1,2 m thick, seams with coal having over 35 per cent ash content — all of which have become legitimate in the changing economic scene. The estimated ratio of economically recoverable to *in situ* mineable reserves of 31 per cent at an average extraction of 42,8 per cent, although accurate as based on pre-1975 performance, is already outdated. There is no doubt that substantial improvement can be made; a possible figure of 60 per cent has been suggested[4]. Based on such revised parameters, the economically recoverable reserves may be double, or even treble, the figure suggested by the Commission.

*Formerly Chamber of Mines Research Laboratory, Johannesburg; now Gold Fields of South Africa Ltd, Johannesburg.

The factors that determine the acceptability of reserves and their recovery are complex, and include considerations of an economic, statutory, geological, and technical nature, none of which will change overnight. Nevertheless, pressure already exists for changes that will enable a higher proportion of coal to be extracted.

Concern has been expressed on a world level that, of the seemingly vast coal resources, only some 5 per cent can be recovered by the use of current technology[5]. The proportion of coal extracted from seams being mined by longwall methods in the UK during 1977 was barely more than 50 per cent[6]. Techniques to improve these figures are being urged in the interests of good husbandry.

Extraction Ratio

With the new interest in coal conservation, *extraction ratio* has become a popular and much mis-used term. It is necessary at the outset to clarify the meanings it might have.

There are a number of possible definitions of extraction ratio (or recovery factor), but I suggest that three will suffice for most purposes. To avoid confusion it is essential to specify which one is being used, i.e. on which basis an assessment is made.

Geological Basis. The ratio between the run-of-mine coal produced from a given area of a coalfield or colliery property versus the proven *in situ* recoverable coal deposits in the same area can be referred to as the

$$\text{Geological extraction ratio} = \frac{\text{Run-of-mine coal production}}{\text{Recoverable reserves}} \times 100\%.$$

This ratio could equally well be called an *exploitation factor*. It is a measure of the degree to which a mining operation has cleared an existing coal deposit; a figure of 100 per cent would mean that all the exploitable coal has been removed. No account is taken in such a ratio of technical or economic constraints to mining. It assumes that all acceptable coal seams above a certain minimum thickness are workable by one means or another.

Economic Basis. The ratio of the saleable tons extracted from a given area of coal seam to the proven saleable reserves can be referred to as the

$$\text{Economic extraction ratio} = \frac{\text{Tons sold}}{\text{Saleable reserves}} \times 100\%.$$

This ratio could equally well be called the *mining factor*. It takes into account the quality of the coal, mining wastage, washery discards, and the technical, statutory, and commercial constraints upon the mining methods that may or may not be used in a given situation. It is therefore a ratio that can vary from time to time according to the winning techniques available and the prevailing economics at a given moment. A figure of 100 per cent would indicate that all the coal considered to be saleable at the time of calculation of the reserves has in fact been sold.

Geometrical Basis. The ratio between the volume of coal removed from a given area of a coal seam versus the extractable volume can be referred to as the

$$\text{Geometrical extraction ratio} = \frac{\text{Volume of seam extracted}}{\text{Maximum extractable volume}} \times 100\%.$$

This is also called the *volumetric extraction factor*, and is used in the estimation of, say, the effect of barrier pillars and primary development on the extraction from panels, or in the calculation of bord-and-pillar extraction percentage. In practice, it usually serves as a target extraction for planning purposes.

It will be noted that each one of these three definitions will have a legitimate use according to whether extraction refers to the geological, economic, or geometrical factors. But for the *same situation* each could give a widely differing and misleading result. For instance, a 5 m seam of which 3 m is selectively worked by bord and pillar with a calculated geometrical (or theoretical) extraction ratio of say *70 per cent* leaving two metres as roof support, and immobilising a superincumbent 1 m seam not included in the economically extractable reserves, might have a geological (or exploitation) extraction ratio of *30 per cent*. If wastage variable washery yield, and dumped duff were taken into account the economic (or mining) extraction ratio could be 55 *per cent*.

Each percentage would be perfectly correct, but clearly the figures could lead to misunderstanding if quoted out of context.

Factors Affecting Extraction Ratio

Before consideration is given to the general features of the industry that affect the percentage recovery from coal seams, it may be helpful to briefly review the factors that will differ according to which of the three ratios is being considered.

In the case of the *geological extraction ratio*, the most important factor is the specification of criteria for recoverable reserves, i.e. the thickness, quality, and disposition of the coal seams regarded as being acceptable, bearing in mind that these criteria will determine the maximum conceivable exploitable tonnage of coal in a given area. To this tonnage will then be applied a discount for non-compensating losses, such as those due to faults, dykes, burnt coal, poor ground, washouts, lenses, and seam irregularities, and to foreseeable restrictions in mining operations. The realism of these estimates affects the extraction ratio. They will determine how accurate the figure for recoverable reserves is, against which the run-of-mine production will be compared to arrive at the extraction ratio.

The reserves can always be revised, but the run-of-mine output is fixed once it has been produced. The only factor that can bear on run-of-mine production is the method of exploitation, i.e. the mine layout and design, and the coal-getting techniques.

The *economic extraction ratio* is determined by changing factors that are of everyday concern at management level at most collieries; for example, coal quality, selective mining and blending, washery input and yield, and market requirements. The extraction ratio will be affected by the response to these factors, which will in turn depend upon the degree of control and planning flexibility at the colliery. The better these are, the higher will be the economic recovery.

The *geometrical extraction ratio* is a direct result of mine planning. Being a theoretical ratio, it is a function of whatever factors are taken into account in the mine design, for instance, depth and the requirements for stabilization of superincumbent strata.

In addition to the foregoing somewhat academic factors, there are important general aspects of the coal industry that have a profound effect in determining the extraction ratio.

The dominant factor is price control, which in the past, in conjunction with what were considered to be virtually unlimited supplies of steam coal, has constrained coal producers to adopt methods of working that were cheap. Hand-got bord and pillar was the rule, superseded by mechanized bord and pillar. To keep coal production economically viable and competitive, this method was introduced into deeper and thicker seams, where it is wasteful. Unstooped bord and pillar currently accounts for 93 per cent of underground output.

The cost of establishing a new colliery is currently some R25 or more per annual ton. It therefore makes sense to maximize the life of existing collieries. A long-term economic advantage can be gained by the adoption of more expensive, high-extraction working methods, so prolonging the life of a colliery rather than starting a new shaft elsewhere. This is particularly true in the case of tied collieries, where dependence upon a non-renewable on-site feedstock resource for power generation or steelmaking reinforces the benefits to be obtained from higher extraction ratios and hence longer life.

Tied collieries, which in 1978 accounted for 59 per cent of the coal produced, also illustrate the problem of the selective market, where coal to meet certain specifications is demanded. Seams or parts of a seam that do not meet the specifications, while quite possibly useable elsewhere, are either discarded or left underground where access to them is lost.

Statutory requirements in South Africa for ground stabilization have the effect of immobilizing or restricting extraction from coal seams to a greater extent than elsewhere.

The final factor, which, although introduced most recently into the coal mining scene, may prove to be the dominant one in the long term, is the indirect objective of energy conservation.

Incentives for Improvement

From the national conservation point of view, an improvement of 1 per cent in the economic extraction ratio would increase the coal reserves by about 800 Mt.

Looked at as an instant rather than a posterity benefit, the same 1 per cent would immediately bring some 10 Mt per year from the category of lost coal into the category of available reserves at existing collieries*. Valued at its exploration and pre-production development cost, say R1 per ton, the unused reserves resulting from an improvement of 1 per cent in the extraction ratio would be worth about R10 million per year to the industry.

In practice, considerably more improvement than 1 per cent is possible and is being looked for. The points to be made are that such an improvement results not only in an upward adjustment to a conservationist's resource estimate, nor only in a revision of the life-of-mine calculation. At a colliery that improves its recovery factor, an immediate financial benefit accrues in the form of reduced development costs, with a longer-term financial benefit in the form of greater return on capital invested. The benefit is proportional to the improvement in extraction. The dis-incentive is the additional cost that is invariably associated with increased extraction, which the recovery benefit alone can alleviate but never outweigh.

Improved Recovery

There are three approaches to the question of improving recovery from coal seams. The approaches are fundamentally different, and depend, as do the extraction ratios, on whether one is approaching the problem from a geological, an economic, or a technical point of view. Obviously there are overlaps: an improvement is an improvement no matter which approach one takes, and viewpoints are not mutually exclusive. Nevertheless, it is helpful in reviewing the overall problem to recognize differences in principle.

Improvements to Volumetric Extraction

This approach starts from a defined area of proven, economically workable thickness of a coal seam and asks the question: how should the seam be worked so as to leave as little as possible behind? It is a technical approach that will be answered in terms of available mining techniques and mine design.

First considerations will be choice of a working method to yield highest recovery, e.g. strip mining, longwalling, stooping, bord and pillar. Second-order considerations will be, in the case of underground workings, support aspects of the mine, roof control, pillar design, and the stability of access roadways, panels, and surface installations; in other words, appropriate factors of safety. Thirdly, production planning to avoid remnants and odd-shaped uneconomic areas will need to be considered. The final consideration is the adoption of mining systems that are suitable for the underground conditions so that it is not necessary to abandon difficult areas because the method used is not suitable.

It is not suggested that decisions are made in the order given nor that percentage recovery is the only, or even a major, consideration; but, if it is, the foregoing factors are relevant.

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*100 Mt per year at 31% extraction uses 322 Mt per year from reserves

100 Mt per year at 32% extraction uses 312 Mt per year from reserves.

∴ An improvement of 1% leaves 10 Mt per year in reserves and represents 3% less development.

Improvements to Economic Extraction

Economic extraction goes beyond the volumetric assessment in that adjustments are possible in the mining parameters that are independent of technical considerations. Such adjustments relate to costs of mining and market demand.

It goes without saying that costs can never be allowed to be such that the saleable products yield an unsubsidized loss. On the other hand, the more the saleable products are made to meet a market demand (and not the other way round), the higher the economic extraction can be. For collieries not fortunate enough to produce a run-of-mine coal that meets market specification — and most are not — there are two courses of action. One is to beneficiate the output: from hand-picking at the simplest end of the scale, through various degrees of sophistication in coal preparation and washing, to a 'Coalcom' complex at the other. All have as their aim the sale of as much as possible of what is saleable. The second possibility is to employ selective mining. As mentioned earlier, this is the only recourse for a colliery without a treatment plant. In practice, this means that the low-grade parts of a coal seam are excluded — and for good reason — from the economic reserves. The economic extraction ratio in the latter may be satisfactory, but from the geological viewpoint the extraction ratio might well not be satisfactory at all.

Improvements to Geological Extraction

Ultimately, it is the geological extraction ratio that matters. Although geological factors cannot be considered in isolation from technical and economic factors, in the end it is the geological extraction factor upon which to judge whether the best use is being made of coal resources.

An improvement in the geological extraction ratio — on the assumption that the technical and economic factors have been maximized — requires that as much as possible of a coal deposit should be classified as technically and economically workable reserves. In practice, this means that feasible methods have to be found for mining and/or marketing coal that would otherwise be excluded from reserves. The marketing aspect is being dealt with in the second part of this colloquium. The mining aspect simply means the use of techniques that can mine coal that would not be regarded as extractable by conventional techniques.

Opencast mining, longwalling, and mechanized stooping are three such methods, extracting all or some of the pillars that would otherwise be left behind. Papers are being presented on these topics. I should like to briefly review one potential technique that is not being presented during the course of this colloquium.

Multiple-lift longwalling and successive top-coaling in thick seams, full or partial pillar extraction, and goaf control under difficult caving conditions, are all examples of methods that give high extraction provided a technique is available for stabilization of the strata. Probably the best potential technique for such stabilization lies in the use of power-station fly-ash. Over 100 Mt of this fly-ash have been dumped in the vicinity of collieries and are being added to at the rate of about 10 Mt per year. A limited amount of ash has been disposed into old workings by hydraulic means, but this has a restricted application for the purpose envisaged.

Techniques are known for the placing of power-station fly-ash underground within working sections concurrently with coal extraction, but have never been developed in South Africa. The de-watering, transport, and selective placement or stowing (as opposed to disposal) of fly-ash, if judiciously planned as part of a total extraction programme, could enable substantially higher recovery to be achieved. This could be done without fundamental changes to existing bord-and-pillar methods if the ash were used to compensate for otherwise diminished factors of safety following top coaling, pillar splitting, sliping, or reduction in bord centres. In addition, stowing represents the only feasible technique for multiple-lift working in very thick seams; at present, such seams illustrate some of the most wasteful mining methods known.

In short, stowing represents the most likely, if not the only, technique for achieving both high extraction and relative ground stability. Development needs to be done, but there are grounds for expecting development under local conditions to be successful.

One characteristic common to all these methods for an improved geological or exploitation factor is that they involve high pre-production, capital expenditure. As mentioned at the outset of this section, in spite of its being ultimately the most significant, the geological extraction ratio cannot be isolated from the economic.

Utilization Factor

No consideration of resource availability and conservation can ignore the fact that coal seam recovery is only the first stage. A proportion of the potential energy in the ground can be mined, but a much smaller proportion is ultimately utilized and often in a manner that does not make the best use of its potential.

To eliminate the wasteful use of coal and to ensure the best use of resources by separating the various grades of coal so that each quality reaches the most appropriate category of the final demand are equally important. Hence, the concern for selective and product-specific utilization of coal expressed in the second part of this colloquium, and the recognition that the utilization factor is just as significant as the recovery factor.

References

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