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An evaluation of the equipment used in South Africa for the bord-and-pillar mining of thin coal seams

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SYNOPSIS

It is suggested that an increase in the production from thin coal seams in South Africa is necessary, and that a substantial amount of any increase will be mined by the bord-and-pillar method. For the purpose of this study, a thin coal seam was regarded as any seam 1,5 m thick or less to the minimum thickness at which mechanized equipment can operate in bord-and-pillar workings.

The equipment being utilized in thin-seam bord-and-pillar layouts includes conventional equipment, load–haul–dump cars (scoops), and drum-type and Fairchild–Wilcox continuous miners. Comparisons are made of these types of equipment for bord-and-pillar mining at various seam thicknesses within the thin-seam range. The evaluations involved production rates and the cost of extraction for South African conditions, use being made of an existing computer modelling technique in the generation of production rates.

The indications are that, for seam thicknesses greater than 0,9 m, drum-type continuous miners utilizing continuous haulage are the most productive and cost-effective equipment at present operating in thin-seam bord-and-pillar workings. Where seams thinner than 0,9 m are to be exploited, Fairchild–Wilcox continuous miners, particularly the Mark 22, produce the most coal at the lowest cost.

SAMEVATTING

Daar word aan die hand gedoen dat die produksie uit dun steenkoollae in Suid-Afrika verhoog moet word en dat 'n aansienlike hoeveelheid van enige toename volgens die pilaarmetode ontgin sal word. Vir die doeleindes van hierdie studie is 'n dun steenkoollaag beskou as enige laag met 'n dikte van 1,5 m of minder, tot die minimum dikte waarop gemeganiseerde toerusting in pilaardelfplekke kan werk.

Die toerusting wat in dunlaagpilaaruitlegginge gebruik word, sluit in konvensionele toerusting, laaistortwaens (skoppe) en trommeltipe en Fairchild–Wilcox-aaneendelwers. Daar word vergelykings tussen hierdie soorte toerusting vir pilaarmynbou met verskillende laagdiktes in die dunlaagbestek getref. Die evaluerings het produksietempo's en die ekstraksiekoste vir Suid-Afrikaanse toestande behels en daar word van bestaande rekenaarmodelleertegnieke gebruik gemaak vir die ontwikkeling van die produksietempo's.

Die aanduidings is dat vir laagdiktes van meer as 0,9 m, die trommeltipe aaneendelwers met gebruik van kontinue vervoer, die mees produktiewe en koste-effektiewe toerusting is wat op die oomblik in dunlaag-pilaardelfplekke werk. Waar lae wat dunner as 0,9 m is ontgin moet word, lewer die Fairchild–Wilcox-aaneendelwers, veral die Merk 22, die meeste steenkool teen die laagste koste.

Introduction

The bord-and-pillar method of mining is used in South Africa to extract more than 60 per cent of the coal from thin seams[1]. The total production accounted for by this technique of mining in narrow seams is, however, small. In 1981, there were only fourteen mechanized production sections in South Africa in which the bord-and-pillar method operated, producing less than 2 per cent of the total output.

It was shown in an earlier paper[2] that substantial reserves of coal are contained in thin seams in South Africa, which is in marked contrast to the current production. It is therefore considered that the proportion of mining in narrow seams must increase if the present imbalance between resources and production is to be rectified. There are indications that bord-and-pillar will remain the dominant mining method for the foreseeable future. It is therefore expected that a substantial part of any such increase will be mined by bord-and-pillar techniques.

A variety of equipment is used in South Africa for bord-and-pillar mining in narrow coal seams. This equipment includes conventional equipment, load–haul–dump trucks (scoops), and drum-type and Fairchild–Wilcox continuous miners. Generally, all the equipment is characterized by low production rates when compared with bord-and-pillar mining in thicker seams.

There is a need to evaluate the various equipment that is used in the bord-and-pillar method in low seams, so that the most effective can be established. The relatively small number of production sections, and the fact that mining conditions usually differ from mine to mine, make a comparison from actual operating units difficult. Simulation, using the FACESIM computer program, which was described in a previous publication[2], was used to facilitate comparisons of the performances of the equipment.

The Mining Parameters Simulated

Computer modelling was carried out for a range of extraction heights in thin seams, ranging from the minimum at which the equipment can be operated, to a maximum of 1,5 m. Although the simulation of pillars at 15 m centres is described, with bord widths of 6,5 m, pillar-centre distances of 30 m were also investigated. The general conclusions outlined in the present paper were found to be valid for these larger pillar centres.

Single-header sections were modelled for all the equipment evaluated. In addition, for conventional equipment

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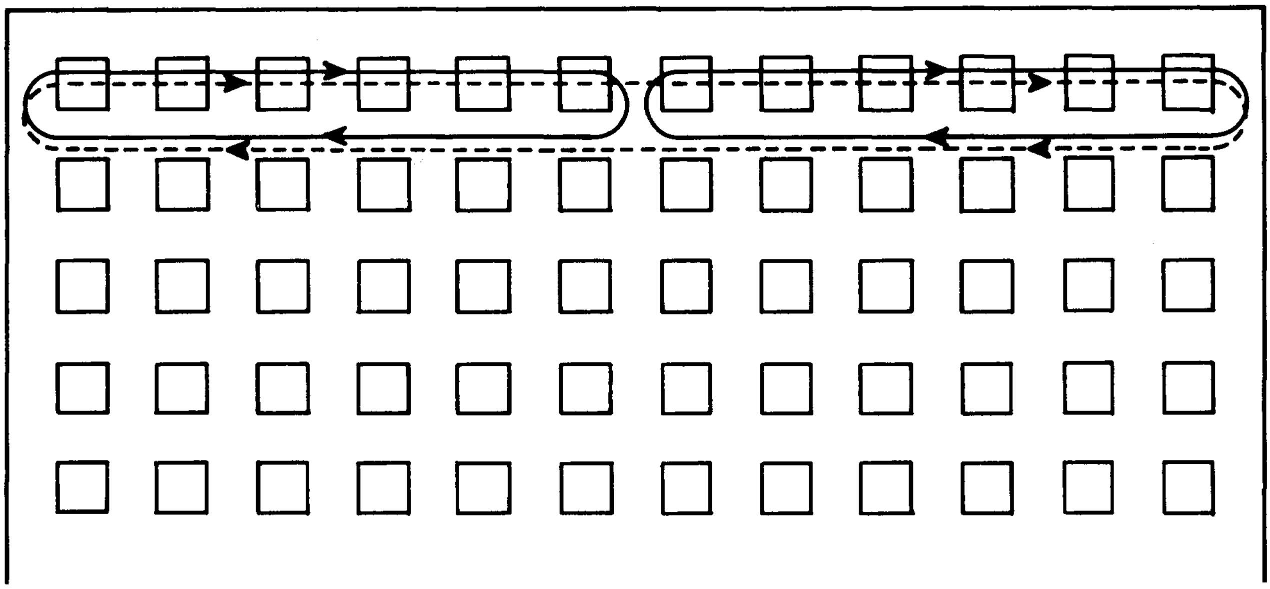

---➤---- Movement of Gathering Arm Loader, Coal Transporter and Rootbolter.

——➤—— Movement of Coalcutters, Drillers and Box Attendants.

Fig. 1 — Double-header layout with a single loader

and load–haul–dump trucks, double-header sections with one gathering-arm loader or a single set of scoops were simulated. In such a thin-seam double-header mining layout, two sets of preparatory equipment work at either side of the production section, as in double headers in thicker seams. All the prepared headings are loaded by a single set of coal-loading and transporting equipment (Fig. 1). A single roofbolter is usually adequate, although two such machines can be employed if the roof-support operation cannot keep pace with the production.

Where drum-type continuous miners with continuous coal transportation were modelled, cross slits of 60 degrees were employed. With these machines, roadway advances of 10 m were modelled before headings were changed to allow for roofbolting.

With Fairchild–Wilcox continuous miners, cross slits of 90 degrees can be employed without a loss in manoeuverability. These machines cut the entire bord width at one stand, and roofbolters can be employed at either side of the continuous haulage, in close proximity to the mining machine, while production is in progress. Simultaneous mining and roofbolting can therefore take place in one heading[3]. The full pillar-centre distance, in this case 15 m, can therefore be advanced without the need for headings to be changed for the suppport operation.

Type of Equipment Simulated

The relevant input data to the FACESIM computer program concerning the equipment used can be seen in Table I. Machines with the lowest profile were considered in all cases.

For use with conventional equipment and drum-type continuous miners, all three types of wheeled coal transportation were modelled: shuttlecars, ramcars, and tractors-and-trailers. Owing to the similarities between ramcars and tractors-and-trailers, these machines are considered to be identical for simulation purposes.

For drum-type continuous miners with continuous haulages, belt-type haulage was modelled for a seam thickness greater than 0,9 m, and chain-type haulage for the same thickness or less. Only chain-type haulages were considered for the Fairchild–Wilcox mining machines.

TABLE I

MACHINE INPUT DATA TO THE FACESIM COMPUTER PROGRAM

Payloads	
Low profile load–haul–dump car	2,4 t
Low profile shuttlecar	3,7 t
Low profile ramcar/tractor-and-trailer	5,4 t
Continuous haulage — C/V belt type	7,3 t/min
— chain type	3,7 t/min
Average Tramming Rates (m/min)	
Gathering-arm loader	25,8
Load–haul–dump car	84,7
Drum-type continuous miner	5,0
Fairchild–Wilcox Mark 22	5,0
Fairchild–Wilcox Mark 21	1,3
Shuttlecar/ramcar/tractor-and-trailer	84,7
Roofbolter	33,3
Coal cutter	19,2
Blasting team	33,3
Loading Rates (t/min)	
Gathering-arm loader	3,5
Load–haul–dump car	3,4
Drum-type continuous miner	4,0 at 1,5 m seam height
	4,0 at 1,2 m seam height
	3,3 at 0,9 m seam height
	2,7 at 0,75 m seam height
Fairchild–Wilcox Mark 21 and Mark 22	1,8
Cycle Times (min)	
Cutting (2,2 m advance)	18
Blasting	16
Drilling	13,5

TABLE II

MINIMUM EFFECTIVE EXTRACTION HEIGHT FOR EQUIPMENT

Equipment	Minimum extraction height, m
Conventional	0,90
Load–haul–dump car (scoops)	0,90
Drum-type continuous miners with wheeled coal transporters	0,90
Drum-type continuous miners with continuous haulages	0,75
Fairchild–Wilcox Mark 21	0,66
Fairchild–Wilcox Mark 22	0,75

Although only the Fairchild–Wilcox Mark 21 continuous miner has been utilized in South Africa, the newer Mark 22 machine was also modelled. The Mark 22 machine and haulage are mounted upon caterpillar tracks, unlike the Mark 21, which is sledge mounted, being pulled along by double-acting rams that incorporate a roof jack. The tramming speed of the Mark 22 is higher than that of the Mark 21, but the newer machine has a higher profile.

The minimum seam thickness in which the lowest equipment can operate under the 'good mining conditions' simulated is presented in Table II. With the exception of Fairchild–Wilcox continuous miners, the equipment evaluated can operate up to the maximum height considered, i.e. 1,5 m. Fairchild–Wilcox equipment can work only in seams to a maximum of 1,3 m at the present time.

Results Obtained from FACESIM

The calculated productivity results, measured in tons per available minute, for conventional equipment, load–haul–dump cars, and drum-type and Fairchild–Wilcox continuous miners can be seen in Table III. It must be noted that these productivity results represent the potential for the systems simulated.

Monthly Production

Productivity, measured in tons per minute, is an important factor but does not take into consideration the different engineering available times of the various equipment. Monthly production statistics were therefore calculated, use being made of both the computer-simulated productivity results and the average equipment availabilities.

The time that various types of equipment are available for production depends upon the following factors: the shift time, the time spent by men in travelling to a production unit, statutory inspection times, and the downtime of machinery. Of these factors, only the machine downtime depends upon the mining machinery used. The other components are influenced by local conditions, and average South African values were assumed as outlined in a previous paper[2].

There are differences in the available production times for the various equipment. From studies carried out by the Chamber of Mines of South Africa[4,5], the following average equipment availabilities, excluding travelling and inspection times were deduced:

(i) 83 per cent for conventional and scoop-tram equipment,

(ii) 61,4 per cent for drum-type continuous miners with wheeled coal transporters, and

(iii) 57,8 per cent for drum-type continuous miners with continuous haulages, and for Fairchild–Wilcox continuous miners.

These figures were therefore used in the derivation of the monthly production statistics.

The expected monthly production statistics for conventional equipment, scoops, and drum-type and Fairchild–Wilcox continuous miners can be seen in Table IV. Because 'good mining conditions' were modelled, the results tabulated represent the potential at the outlined availabilities.

TABLE III

PRODUCTIVITY SIMULATION (IN TONS PER AVAILABLE MINUTE)

Mining height	0,66 m	0,75 m	0,9 m				1,2 m				1,5 m			
Coal haulage	Contin. haulage	Contin. haulage	LHD*	Shuttle car	Ramcar/ t & t†	Contin. haulage	LHD	Shuttle car	Ramcar/ t & t	Contin. haulage	LHD	Shuttle car	Ramcar/ t & t	Contin. haulage
Conventional equipment, single-header section	—	—	—	0,88	0,88	—	—	1,18	1,18	—	—	1,47	1,48	—
Conventional equipment, double-header section	—	—	—	1,77	1,77	—	—	2,04	2,28	—	—	2,09	2,40	—
LHD, single-header section	—	—	0,88	—	—	—	1,18	—	—	—	1,41	—	—	—
LHD, double-header section	—	—	1,77	—	—	—	1,98	—	—	—	1,98	—	—	—
Drum-type continuous miners	—	1,50	—	1,82	2,00	2,00	—	2,36	2,58	2,65	—	2,46	2,71	2,84
Fairchild–Wilcox Mark 21	1,37	1,41	—	—	—	1,46	—	—	—	1,53	—	—	—	—
Fairchild–Wilcox Mark 22	—	1,65	—	—	—	1,67	—	—	—	1,69	—	—	—	—

* Load–haul–dump car

† Tractor–and–trailer

TABLE IV

MONTHLY PRODUCTION STATISTICS (IN TONS PER MONTH)

Mining height	0,66 m	0,75 m	0,9 m				1,2 m				1,5 m			
Coal haulage	Contin. haulage	Contin. haulage	LHD*	Shuttle car	Ramcar/ t & t†	Contin. haulage	LHD	Shuttle car	Ramcar/ t & t	Contin. haulage	LHD	Shuttle car	Ramcar/ t & t	Contin. haulage
Conventional equipment, single-header section	—	—	—	15 400	15 400	—	—	20 600	20 600	—	—	25 700	25 900	—
Conventional equipment, double-header section	—	—	—	30 900	30 900	—	—	35 600	39 800	—	—	36 500	41 900	—
LHD, single-header section	—	—	15 400	—	—	—	20 600	—	—	—	24 600	—	—	—
LHD, double-header section	—	—	30 900	—	—	—	34 600	—	—	—	34 600	—	—	—
Drum-type continuous miner	—	18 700	—	23 600	23 600	24 200	—	30 500	33 300	32 900	—	31 800	35 000	35 300
Fairchild–Wilcox Mark 21	17 000	17 500	—	—	—	18 100	—	—	—	19 000	—	—	—	—
Fairchild–Wilcox Mark 22	—	20 300	—	—	—	20 500	—	—	—	21 000	—	—	—	—

* Load–haul–dump car
† Tractor-and-trailer

TABLE V

IN-SECTION CAPITAL AND RUNNING COSTS FOR BORD-AND-PILLAR MINING

Mining equipment	Conventional		Load–haul–dump trucks		Drum-type continuous miner		Fairchild–Wilcox continuous miner	
	Single-header section	Double-header section with single loader	Single-header section	Double-header section with single set of scoops	Single-header section with wheeled coal transport	Single-header section with continuous haulage	Mark 21 machine	Mark 22 machine
Capital cost, R	1 660 000	2 049 000	1 271 000	1 645 000	1 975 000	1 744 000	1 276 000	1 304 000
Total labour cost per annum, R	242 900	315 900	232 700	311 500	220 400	210 200	210 200	210 200
Other working costs, cents per ton	200	200	226	226	186	179	179	179

TABLE VI

IN-SECTION COST PER TON (IN RANDS)

Mining height	0,66 m	0,75 m	0,9 m				1,2 m				1,5 m			
Coal haulage	Contin. haulage	Contin. haulage	LHD*	Shuttle car	Ramcar/ t & t†	Contin. haulage	LHD	Shuttle car	Ramcar/ t & t	Contin. haulage	LHD	Shuttle car	Ramcar/ t & t	Contin. haulage
Conventional equipment, single-header section	—	—	—	4,35	4,35	—	—	3,77	3,77	—	—	3,45	3,39	—
Conventional equipment, double-header section	—	—	—	3,66	3,66	—	—	3,38	3,25	—	—	3,35	3,19	—
LHD, single-header section	—	—	4,34	—	—	—	3,83	—	—	—	3,58	—	—	—
LHD, double-header section	—	—	3,74	—	—	—	3,62	—	—	—	3,62	—	—	—
Drum-type continuous miner	—	3,41	—	3,48	3,42	3,20	—	3,17	3,07	2,92	—	3,13	3,05	2,88
Fairchild–Wilcox Mark 21	3,57	3,52	—	—	—	3,46	—	—	—	3,39	—	—	—	—
Fairchild–Wilcox Mark 22	—	3,31	—	—	—	3,28	—	—	—	3,34	—	—	—	—

* Load–haul–dump car
† Tractor-and-trailer

Economic Analyses

Economic analyses were carried out for the techniques of mining under consideration, use being made of the production statistics derived and presented here. The mining costs were taken from information gathered at collieries operating in South Africa in January 1981. These costs were obtained from mines that are representative of 'good mining conditions'. Only in-panel costs were evaluated. The in-section capital and running costs for the equipment at January 1981 as operated in the bord-and-pillar method are detailed in Table V, and the in-section costs per ton in Table VI. Details of the method of economic analysis used are given in an earlier paper[2].

Conclusions

The comparison of mining equipment for bord-and-pillar mining showed that drum-type continuous miners produce more coal per available minute when operating in seams thicker than 0,9 m than any other equipment at present in operation. The use of continuous haulages in conjunction with these mining machines improves the rate of production. Where wheeled coal transporters are used, the higher-capacity ramcars or tractors-and-trailers are more efficient than shuttlecars.

If seams are exploited below a thickness of 0,9 m, Fairchild–Wilcox continuous miners are more productive than drum-type machines. The Fairchild–Wilcox Mark 22 produces more coal than the Mark 21 version. Below a seam thickness of 0,75 m, however, only the Mark 21 mining machine is able to operate.

Double-header units with a single loader or set of scoops have a higher output of coal per minute than single-headers where conventional and load–haul–dump equipment is employed. Conventional equipment has a greater output per minute than load–haul–dump trucks in this type of layout.

The highest monthly output from extraction heights of 0,9 m and greater can be expected from conventional equipment used in double-header single-loader sections. Below a seam thickness of 1,2 m, scoop trams operating in the same layout have an equivalent output. Continuous miners have the next-greatest production potential. Below a seam thickness of 0,9 m, the Fairchild–Wilcox equipment, particularly the Mark 22, has a higher monthly output than any other machinery operating in bord-and-pillar layouts. Scoop trams and conventional equipment have a similar monthly production potential.

The most cost-effective equipment to operate in the bord-and-pillar method for seams thicker than 0,9 m is the drum-type continuous miner. The most economic coal-transportation methods used with these mining machines are continuous haulages, followed by the use of ramcars or tractors-and-trailers. Below a seam thickness of 0,9 m, the Fairchild–Wilcox machinery is the choice from an economic point of view. If conventional or load–haul–dump equipment is used, double-header sections with a single set of loading equipment produce coal at the lowest cost. Conventional machinery is at a cost advantage over load–haul–dump trucks. If equipment is used in single-header units, scoops are more cost-effective than conventional equipment below a seam thickness of 1,2 m, the conventional machinery having an advantage at and above this thickness.

These conclusions are valid only for the 'good mining conditions' that were modelled. Nevertheless, the evaluation provides a guideline in a comparison of the various types of equipment being used in the bord-and-pillar method of mining in thin coal seams, which then requires a consideration of local conditions.

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