OPTIMIZATION OF PASSIVE MOISTURE LOSS FROM BROWN COAL DURING TRANSPORTATION BY OVERLAND BELT CONVEYOR

by

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SUMMARY

The presence of high moisture contents in some soft brown coals is an added burden the power station designer must overcome before useful heat can be extracted from the fuel. Some soft brown coals being considered as possible fuels have in excess of 60% dry basis moisture as mined. If this can be passively reduced during the mining and transportation of the material to the power station, then significant savings can be made in the quantity of fuel required at the station. With belt conveyor transport routes of up to 60 kilometres under consideration, opportunities exist for moisture loss to occur during the time the coal is on the conveyor.

Two series of wind tunnel tests have been undertaken to identify the magnitude and rate of moisture loss by evaporation which can be expected from a conventional belt conveyor with sheetmetal covers. The tests concluded that for high moisture content coals, passive moisture loss from evaporation does occur and that, depending on atmospheric conditions, a reduction of between 3% and 5% can be expected over a conveyor route length of between 10 km and 50 km. The tests also gave indications of the optimum flight length to belt speed ratios before coal lump re-distribution should be undertaken on the conveyor to present fresh evaporation surfaces to the air stream. The effect of predominantly single size coal lump was assessed and it was shown that lump sizes of approximately 60 mm represented another optimal parameter for maximizing passive moisture loss. The effects of solar radiation on the sheetmetal covers has been reviewed and a method of exhausting saturated air from above the coal suggested.

Full scale tests on very long belt conveyors handling material other than coal, the collection of air velocity profiles in the space between moving belt conveyors and their sheetmetal covers and a further series of wind tunnel tests to establish the correlation between the model performance and operating installations are to be undertaken.

1 INTRODUCTION

Belt conveyors are commonly used to deliver coal continuously to power stations from mines. Often site selection criteria leads to the power station being located by preference some distance from the feeder mine, and the cost of transport of the fuel becomes a major economic disincentive to the choice of the preferred power station site.

With the introduction of improved designs for belt conveyor drive systems, belt tension control and belt supporting systems, belt speeds and capacities are increasing and the systems are more reliable. In the future many more long belt conveyor systems, such as the 51 km installation at Worsley in Western Australia, will be installed and some of these will be used to carry coal.

In the progression of activities from coal mining at the mine to coal usage by the power station, the coal is normally in a bulk situation, either at the mine in large stockpiles, or in bins awaiting transportation, or at the power station, again in large stockpiles or in short-term storage bins. Under these circumstances, the majority of the coal is either protected from direct air drying by its location in a large stockpile (which may be deliberately consolidated to prevent spontaneous combustion) or in fully-enclosed bins or short-term storage systems.

Little work has been done on the chemical changes which may occur to the coal during transportation by belt conveyor, and which may represent benefit or penalty to the user. The time spent by coal on a long belt conveyor may represent the best opportunity for passive and active drying of the coal during the cycle from mining to combustion.

The Electricity Trust of South Australia is particularly concerned with the issues and has supported the work which has resulted in the conclusions contained in this paper.

2 AIR DRYING MECHANISMS

The study of the air drying of soft brown coals reveals that a complicated series of mechanisms is involved. The degree of complexity suggested that direct tests based on actual measurement of the rate and extent of moisture loss may be useful in establishing working criteria for estimating moisture loss in full scale installations. The pattern of the drying of the wet solid with a gas of fixed temperature and humidity is illustrated in Figures 1 and 2 and can be described by four regimes:

- When exposure to a drying atmosphere occurs there is an initial transition period as the temperature distribution through the solid falls to steady state. The solid temperature and rate of drying may increase or decrease to reach the steady state condition. Interface surface temperature approaches the wetbulb temperature of the drying medium. Convection and conduction govern mass and heat transfer rates. See Sections A-B on the curves of Figures 1 and 2.

- As the external surface is saturated by reaching the wetbulb temperature of the drying medium, the temperature stabilizes and the drying rate remains constant. The entire exposed surface is saturated with liquid. This period continues until at point C the moisture content of the solid is unable to supply the entire surface. Convection is the primary mechanism of mass and heat transfer during this period.

- At point C the 'critical moisture content' is reached and the supply of liquid to the solid surface is unable to keep it saturated. Surface temperature rises, drying rate drops and the first falling rate period of drying is encountered. Towards point D only small patches of the exposed surface are wet. Diffusion of saturated vapour in the voids of the material starts to be the governing mechanism.

- The second falling rate period is entered at point D. The exposed surface of the solid is dry and diffusion of vapour within the solid completely governs the rate of heat and mass transfer. The path for diffusion becomes longer until the vapour pressure over the solid is equal to the partial pressure of the incoming gas and the equilibrium moisture content is reached. No further drying takes place.

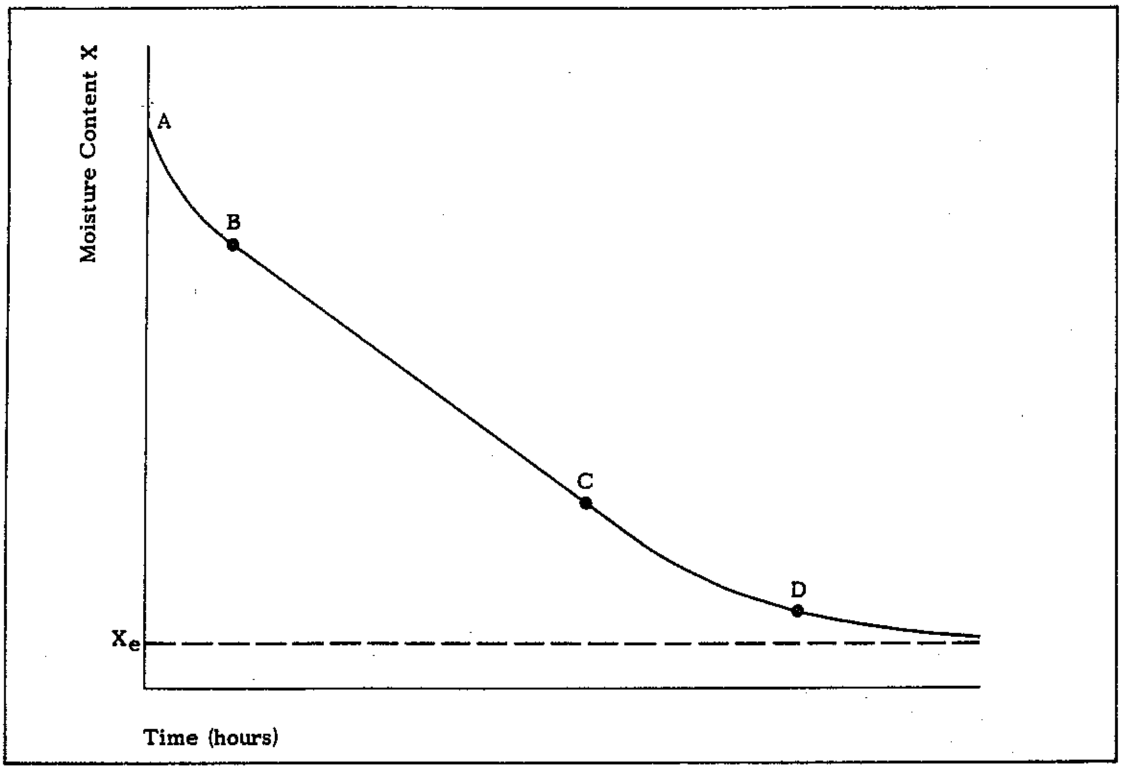


Figure 1
TYPICAL DRYING CURVE FOR CONSTANT DRYING CONDITIONS
MOISTURE CONTENT AS A FUNCTION OF TIME

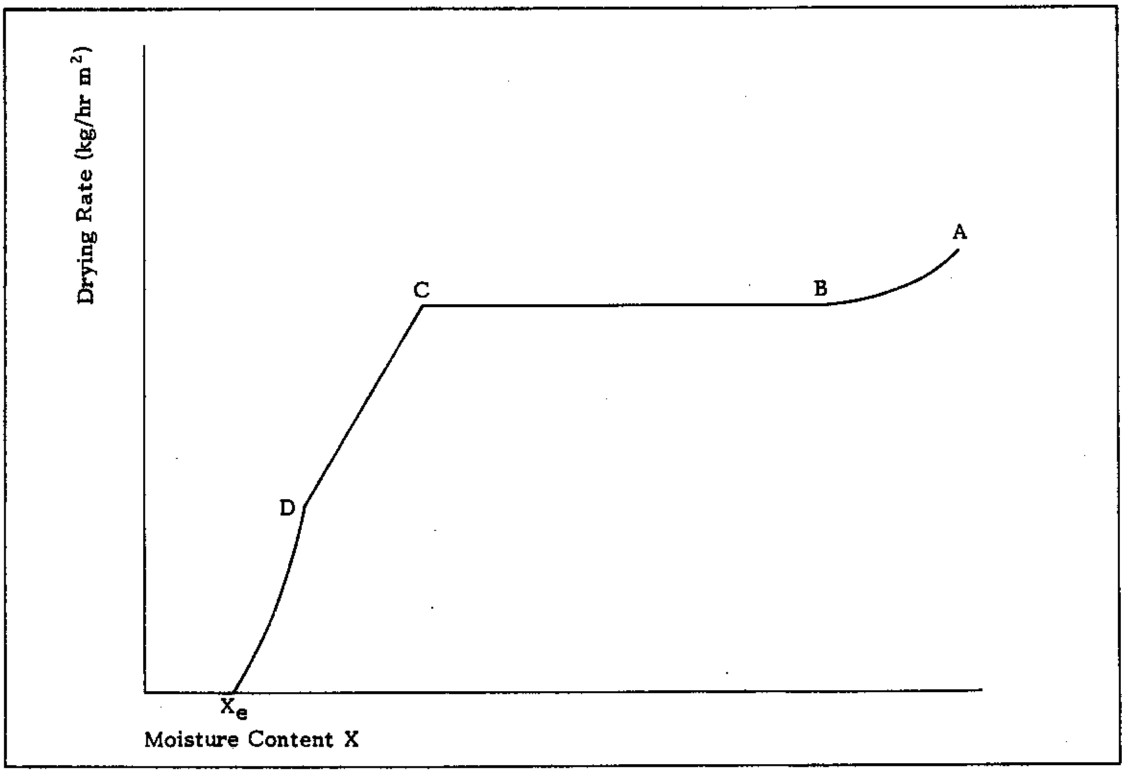


Figure 2
TYPICAL DRYING RATE CURVE
DRYING RATE AS A FUNCTION OF MOISTURE CONTENT

The constant drying rate period is of most practical interest. The balance of evaporation rate and heat transfer can be expressed as:

$$\frac{\overset{o}{m}w}{A_c} h_{fg} = h\,[T_d - T_w] \qquad \text{(EQN 1)*}$$

The only unknown is the heat transfer coefficient 'h'. No precise solution is available for flow along a packed bed; however, for much simpler geometries, solutions often take the form:

$$Nu = C\,Re^m\,Pr^n$$

For the immediate problem this equates to:

$$h = K\,V_A{}^m$$

The constant 'm' is often reported to be a number slightly less than one. (References 2 and 3). For m = 1.0, the measured data fit well to the predicted performance.

The governing relationship is then reduced to:

$$\frac{\overset{o}{m}w}{A_c} = K\,V_A\,[T_d - T_w] \qquad \text{(EQN 2)*}$$

* See Appendix A for a list of symbols.

Some values for K have been established by experiment and are presented in Section 5 of this paper.

3 TESTS

Tests were undertaken on soft brown coal carefully recovered from the Lochiel coal resource in South Australia and were conducted in a wind tunnel model representing a section of a horizontal conventional belt conveyor. The model and its test sample of coal were placed in a half metre diameter wind tunnel at the Mining Engineering Laboratories of the South Australian Institute of Technology. Figure 3 shows the layout of the wind tunnel. Blank sections, made up to the profile of the coal carrying section, were placed fore and aft of the test section in the tunnel. The shape of these sections is illustrated in Figure 4. The purpose of the blank sections was to produce fully developed air flow over the test section. Figure 5 shows a cross-section of the test section in the wind tunnel. A pitot tube entering the tunnel was used to determine the air velocity in the wind tunnel during the test.

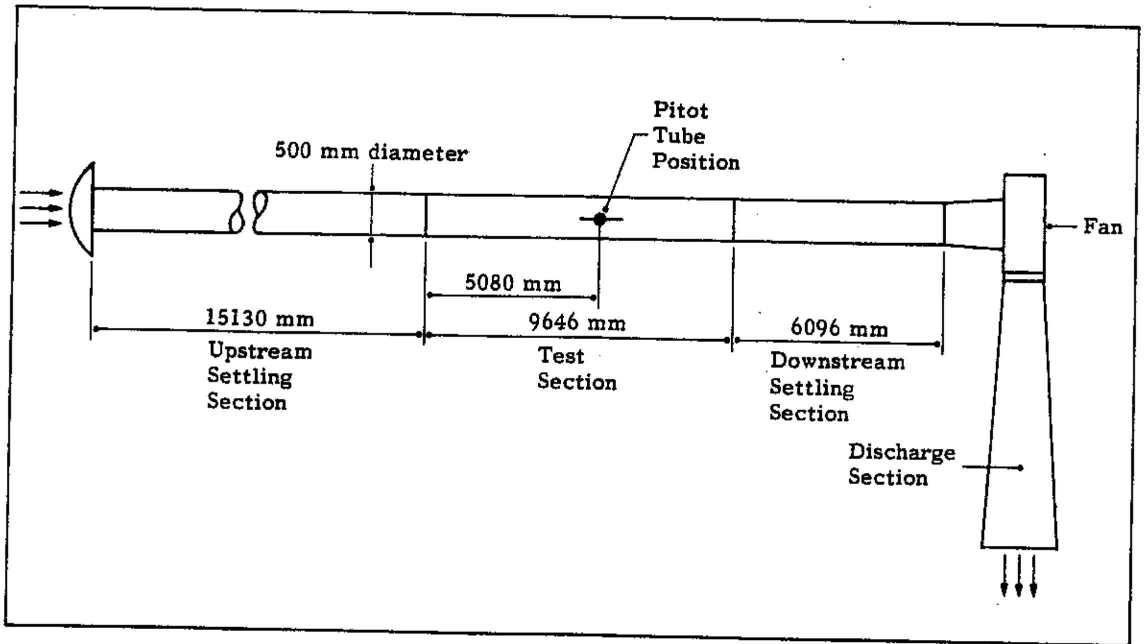


Figure 3
LAYOUT OF WIND TUNNEL

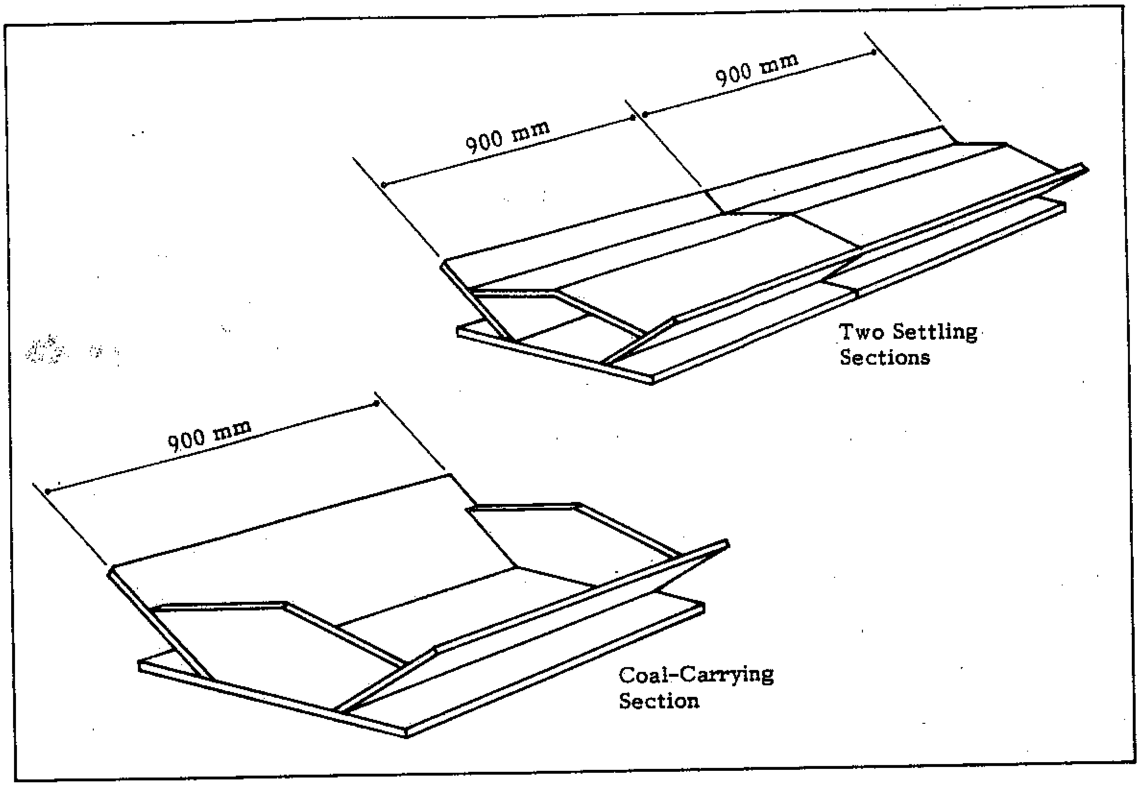


Figure 4
BLANK AND COAL-CARRYING SECTIONS OF MODEL

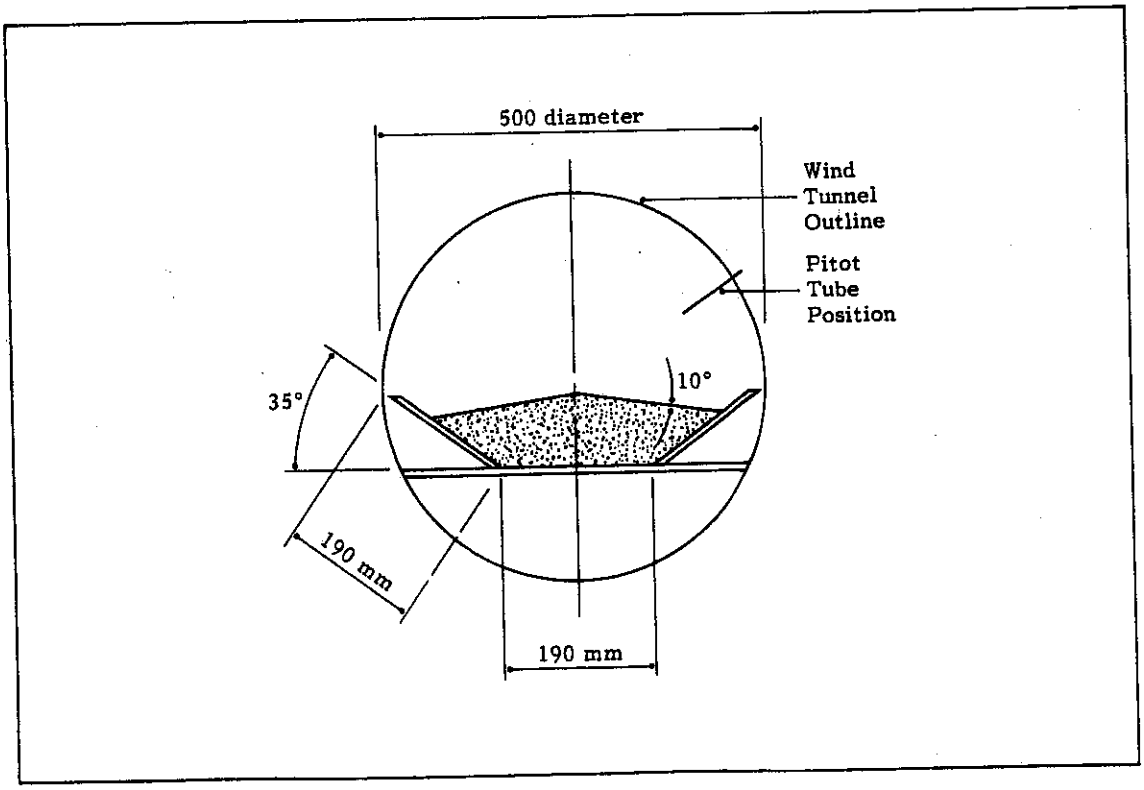


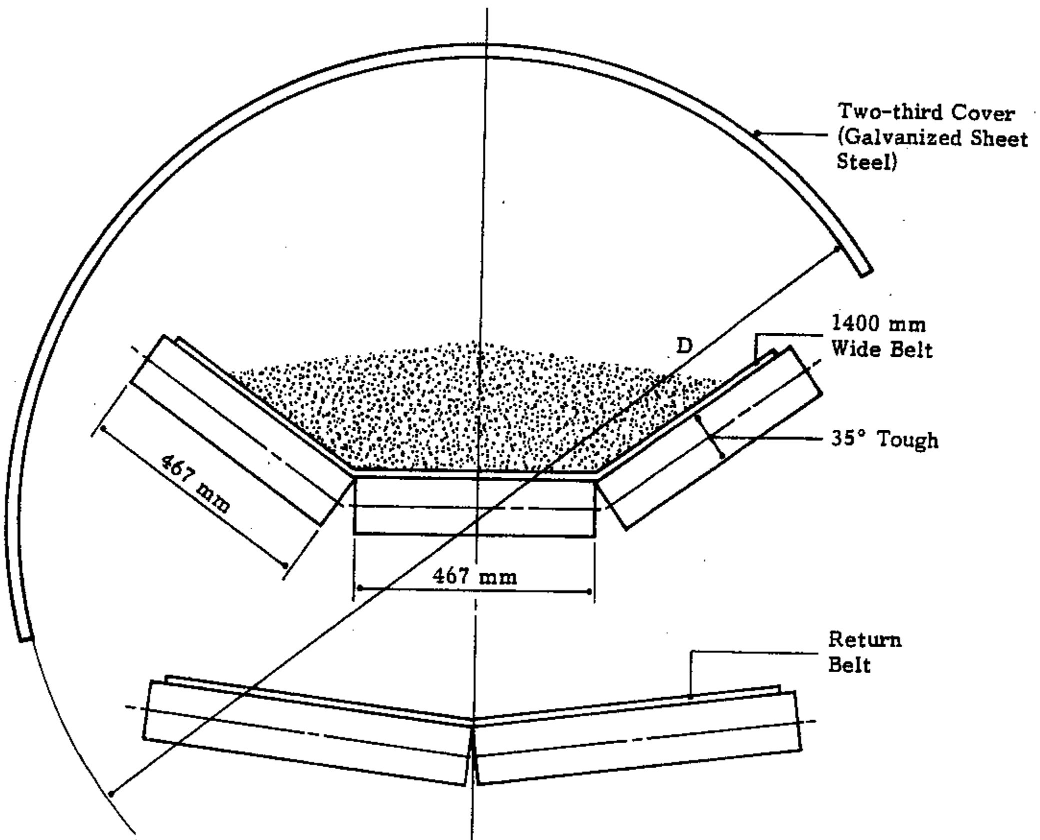
Figure 5
MODEL CONVEYOR CROSS-SECTION

4 TEST PROGRAMME

The first series, undertaken during the dry mid-summer in South Australia, demonstrated the principle that significant moisture loss from the coal can be expected during its transportation period. The second series of tests was undertaken during the more humid late winter and had the primary objective of identifying the effect of coal lump size on its passive drying rate.

The results of the first series of tests have been the subject of a separate paper (Reference 4) and are summarized by reference to Figures 7 and 8. Reference 4 concluded that for soft brown coals having a high 'as-mined' moisture content, the use of long overland belt conveyors may reduce the moisture content by up to 10% of the total mass but this may not be a reasonable expectation for a full scale installation. Increased humidity of the drying air decreases the rate of moisture loss and increases the equilibrium moisture content. Increasing the belt speed increases the rate of moisture loss and decreases the equilibrium moisture content but also reduces fine on belt . Turning the coal over to present new surfaces to the drying air restores the transient condition of moisture loss although the magnitude of the measured transients compared with the steady state moisture loss is not greatly different. The existence of a critical moisture content is indicated for each set of exposed surfaces which may be influenced by varying size gradations in the samples.

The second series of tests sought to establish the influence that coal lump size has on the rate and magnitude of moisture loss, and to identify the effect that other optimization techniques may have on the passive drying of coal during transportation by belt conveyor. The results of the second series of tests is reported in Section 5 of this paper.



D = Approximately 1700 mm

Figure 6
FULL SIZE CONVEYOR CROSS-SECTION

5 OPTIMIZATION OF COAL LUMP SIZE

The influence of lump size on the rate and magnitude of moisture loss is significant. For the particle sizes tested, the 60 mm lumps lost moisture at a rate more than twice that of tests using 30 mm lumps and 200 mm lumps. Figure 9 presents the test data rationalized to relate unit area of coal exposed to the air flow.

The tests have identified values (Table 1) for K for equation 2 which can be used by the power station system designer to establish preferred coal lump sizes to be transported to maximize the opportunity for passive moisture loss.

Table 1

Coal Particle Size (mm)	K $\left[\frac{kg}{km^{\circ}C\ m^2}\right]$
30	- 3.32×10^{-3}
60	- 7.89×10^{-3}
200	- 3.05×10^{-3}

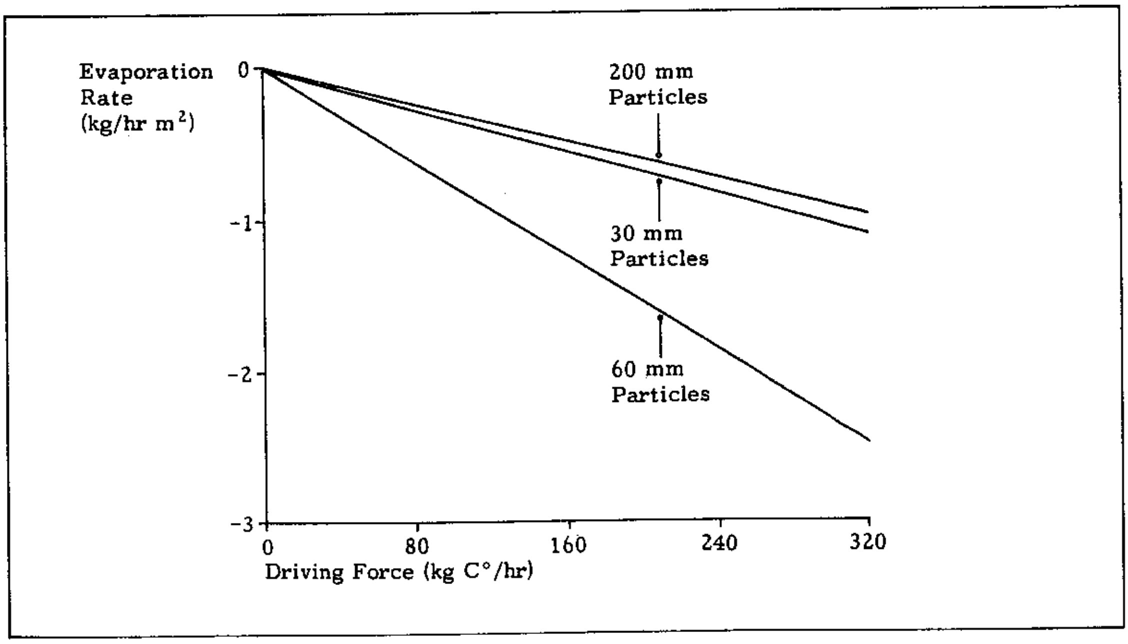


Figure 9
EVAPORATION RATE VERSUS DRIVING FORCE

6 APPLICATION OF TEST DATA

For a given cross section, conveyor geometry and belt speed and for a prescribed particle size and moisture content of the coal, and for atmospheric conditions prevailing at any given time, the instantaneous rate of evaporation can be estimated using Figure 8 and/or Equation 2. This rate can be assumed to remain constant for a given time increment after which a new rate can be calculated for updated weather data. In this fashion the moisture content of the coal can be estimated at any time and for any position on the conveyor. Table 2 has been prepared to present the comparative data for a sample analysis of the various passive coal drying mechanisms. Three sets of results are presented under the 'Solar only' section corresponding with three possible conditions for the belt conveyor cover material.

Cover 'A', is a conventional conveyor cover of galvanized sheet steel. This material has a solar absorbence of about 0.50 which means that only half of the energy striking it is absorbed; the other half is reflected away. Its emittance is about 0.25: this means that though it may eventually become warm, it will do a comparatively poor job of radiating that heat down toward the coal, while most of the heat accumulated convects back into the atmosphere.

Painting the lower side of the covering flat black (Cover 'B') increases its emittance to about 0.90 which yields a significant improvement in heat transfer.

Also painting the top side flat black (Cover 'C') results in a positive but less dramatic improvement.

A further means of enhancing the evaporation rate for the convection only mechanism is to suspend turning vanes of the type shown in Figure 10 above the moving belt. Part of the air that is being carried along with the belt will be forced to the side and therefore replaced by new air. The vanes cover half the conveyor at a time so that aerodynamic drag and operation cost is minimized. Placing such vanes, all facing the same way, every 10 metres along the conveyor will enhance the evaporation rate by 14%. It will also add marginally to the belt's power requirements. The net reduction in the coal's as-delivered moisture content is predicted to range from 0.1% in July to 0.3% in January.

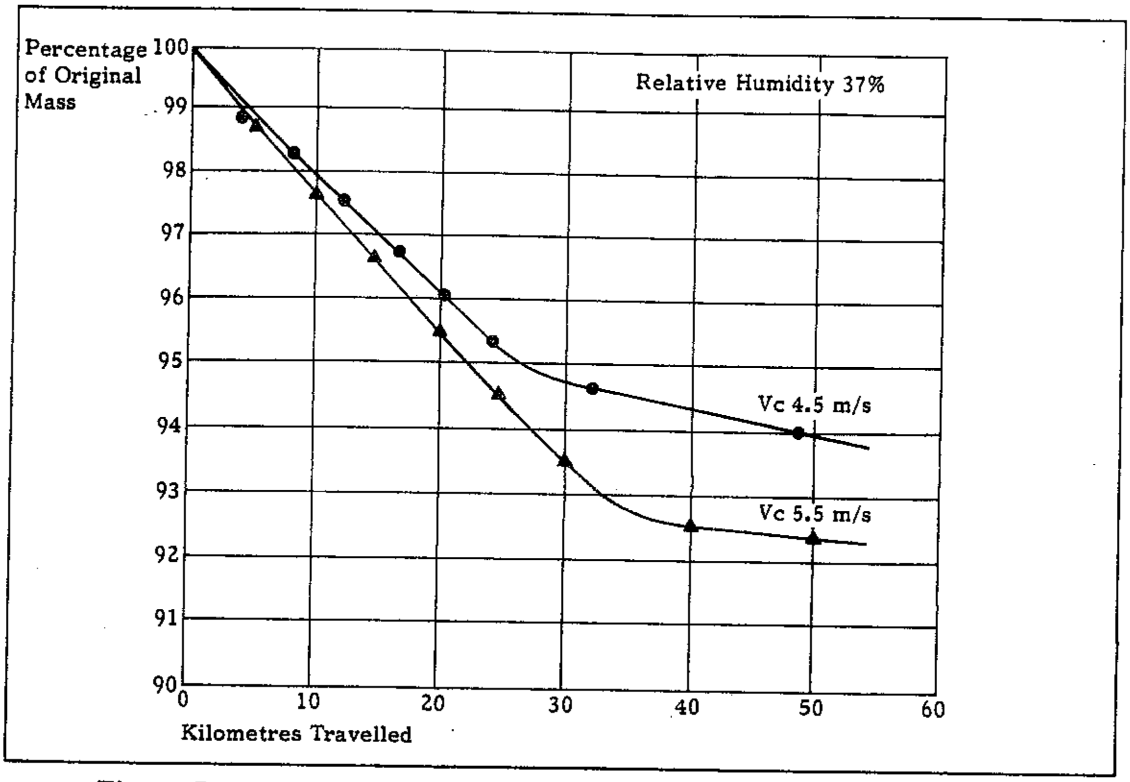


Figure 7
PERCENTAGES OF ORIGINAL MASS AS A FUNCTION OF DISTANCE

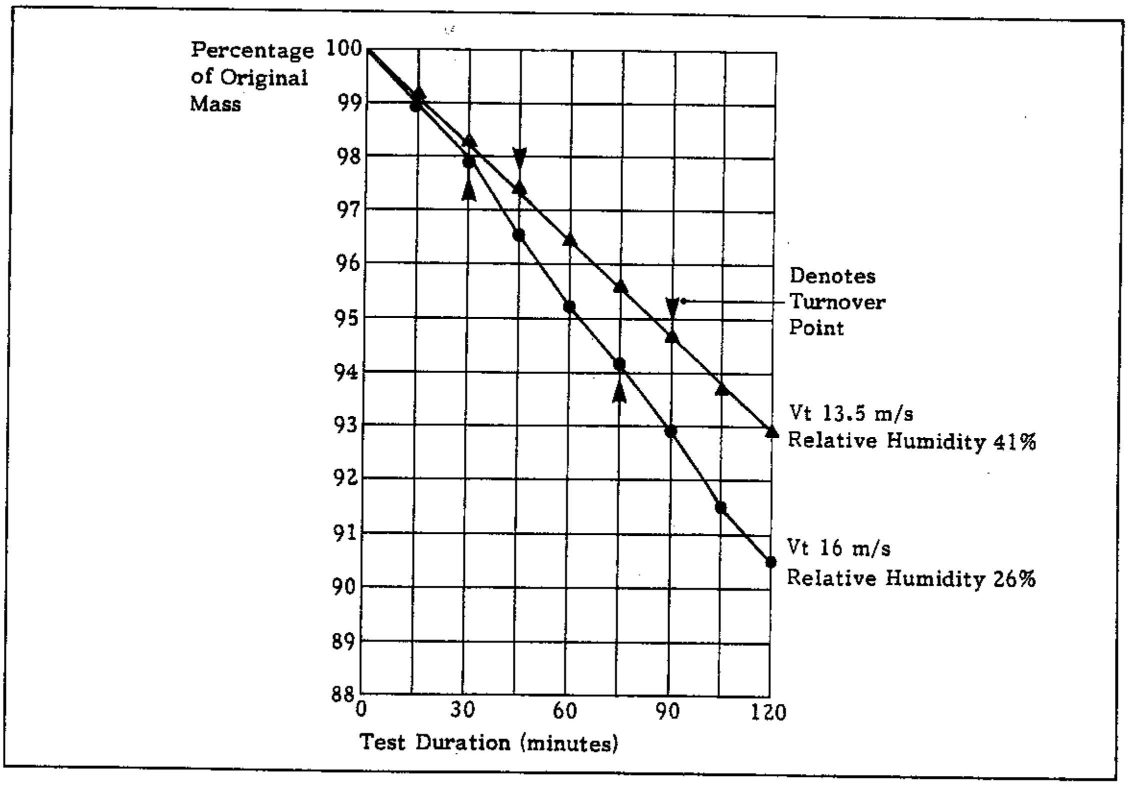


Figure 8
EFFECT OF TURNING COAL OVER

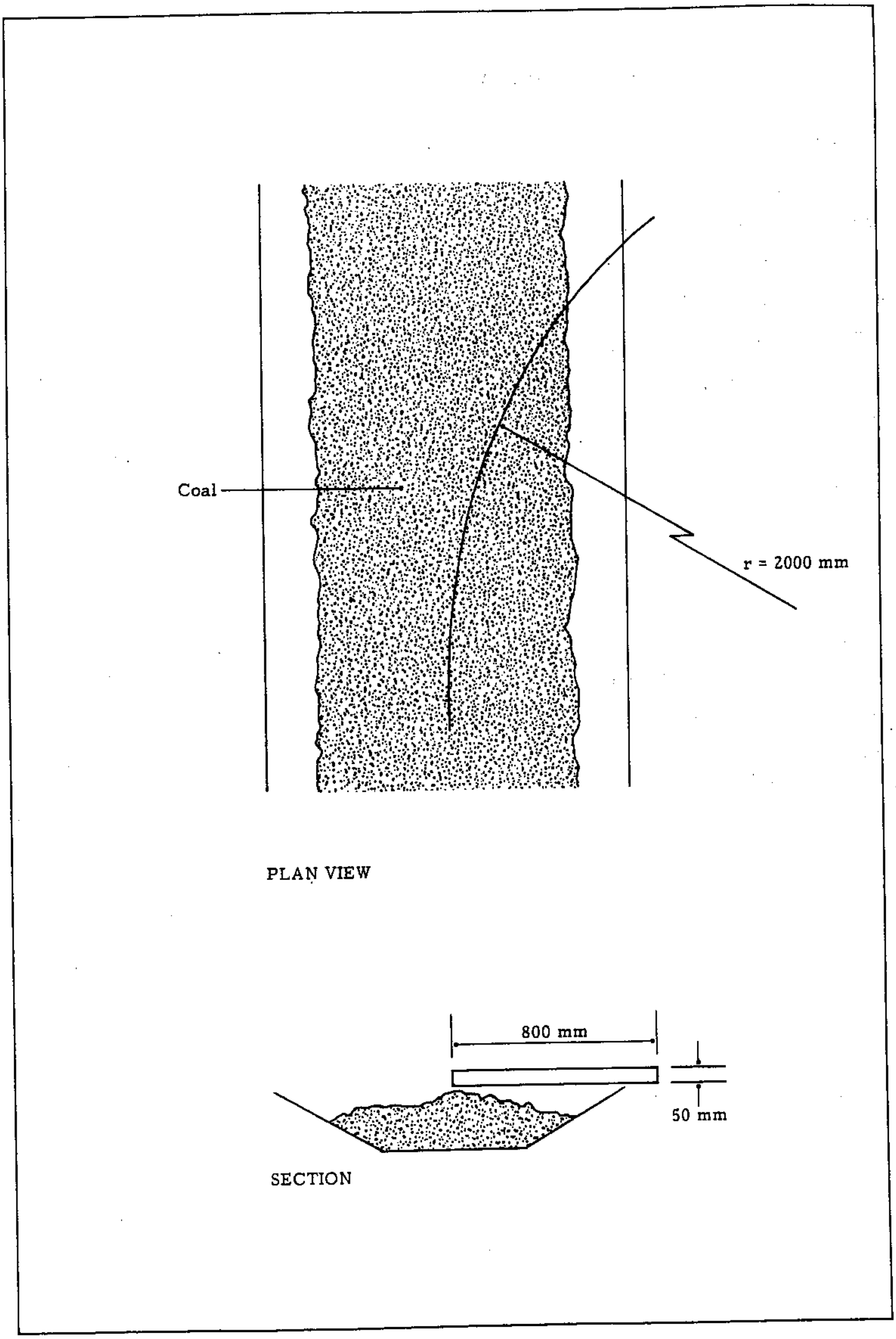


Figure 10
DEFLECTING VANE TO REMOVE SATURATED AIR FROM ABOVE CONVEYOR

Table 2 **Moisture content**

Month		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Convection only													
T_{dw}(°C)		8.0	7.6	7.4	4.9	3.3	2.2	2.1	2.6	3.8	5.2	6.5	7.4
$\mathring{m}_w$ (1000 $\frac{kg}{hr}$) for entire conveyor		68.9	65.4	63.7	42.2	28.4	18.9	18.1	22.4	32.7	44.8	55.9	63.7
Moisture content as-delivered (%)		58.0	58.1	58.2	58.8	59.2	59.4	59.5	59.3	59.0	58.7	58.4	58.2
Solar only	Cover*												
$\mathring{m}_w$ (1000 $\frac{kg}{hr}$) for entire conveyor averaged over 24 hrs	A	3.2	2.9	2.3	1.5	1.0	0.8	0.8	1.3	1.8	2.3	2.8	3.1
	B	11.2	10.2	8.1	5.3	3.5	2.8	2.8	4.6	6.3	8.1	9.8	10.9
	C	20.0	18.2	14.4	9.4	6.2	5.0	5.0	8.2	11.2	14.4	17.5	19.4
Convection and solar with Cover 'C'													
Moisture content as delivered (%)		57.4	57.6	57.7	58.5	59.0	59.3	59.3	59.1	58.7	58.3	57.9	57.6

* Cover 'A' is unpainted galvanized sheet metal.
Cover 'B' is galvanized sheet metal painted flat black on the underside only.
Cover 'C' is galvanized sheet metal painted flat black on both sides.

7 CONCLUSIONS

Passive drying of coal during belt conveyor transportation will occur. The magnitude of the moisture loss is dependent on atmospheric humidity conditions, coal lump size and conveyor belt speed. For the conditions considered over the target 60 km conveyor route, coal having a moisture content of 60% as mined will passively lose moisture during transportation and will be delivered to the power station with a moisture content of 57%.

The optimized conveyor will make use of enhancement techniques.

- Paint the sheet metal conveyor cover flat black on both sides.
- Install vanes to increase air circulation.
- Control coal lump size to about 60 mm.
- For very long overland belt conveyors, transfer points should be located at between 20 and 25 km apart to optimize the advantage of turning the coal over.
- Belt speeds should be in the order of 5 m/s (at this speed the coal will lose moisture at about 20 times the rate of a non-moving system).

A clear relationship between the speed and geometry of a conveyor, the lump size of the coal and its moisture content as it reaches the power plant has been demonstrated. Similar relations exist between the coal moisture content and the cost of producing electricity and between the speed of a conveyor and its cost. Taking these three relations together, an optimum conveyor can be designed. For the specific 1000 MW power station reviewed, the application of these optimization techniques results in a final saving of 30 tonnes/hour, which when extrapolated over the life of the mine and the power station represents a substantial cost saving.

8 ACKNOWLEDGEMENTS

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APPENDIX A LIST OF SYMBOLS

Symbol	Definition	Units
$\overset{o}{m}w$	Evaporation rate of water	$\frac{kg}{min}$ or $\frac{kg}{hr}$
A_c	Area of coal exposed to airflow	m^2
h_{fg}	Latent heat of vaporization of water	J/kg
h	Heat transfer coefficient	$\frac{W}{m^2 {}^\circ C}$
T_d	Dry bulb temperature	°C
T_w	Wet bulb temperature	°C
Nu	$\frac{hX}{k}$ Nusselt number	Dimensionless
C	Constant	-
Re	$\frac{\rho VX}{\mu}$ Reynolds number	Dimensionless
Pr	$\frac{c_p\mu}{k}$ Prandtl number	Dimensionless
m	Constant	-
n	Constant	-
K	Constant	-
V_A	Air velocity	m/sec or $\frac{km}{hr}$
R_h	Relative humidity	%
T_{dw}	Mean temperature differential	°C
n-1	Standard deviation	-
X	Characteristic length	m
k	Thermal conductivity	$W/m^\circ C$
ρ	Density	kg/m^3
V	Velocity	m/sec
μ	Viscosity	N Sec/m^2
c_p	Specific heat	J/kg