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Concept and performance of coal-log pipelines

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SYNOPSIS

The transportation, by water that flows through a pipeline, of coals in the form of water-impermeable cylinders is discussed, and shown to have distinct advantages over other forms of coal transportation, including significantly reduced costs for larger throughputs.

The description of the concept comprises various aspects of the system, such as methods for the manufacture of coal logs, their injection into the pipeline, the manner in which they are conveyed in the water in the pipe, and the methods used for their preparation as feed material to electric power stations at the end of the pipeline.

It is pointed out that the technology involved in the transportation of coal in the form of logs via pipelines is applicable also to other minerals and commodities.

SAMEVATTING

Die vervoer van steenkool in die vorm van silinders wat ondeurlatend is vir water, met water wat deur 'n pypleiding vloei, word bespreek en daar word getoon dat dit duidelike voordele vergeleke met ander vorms van steenkoolvervoer het, insluitende beduidende laer koste vir 'n groter vervoer.

Die beskrywing van die idee dek verskillende aspekte van die stelsel soos metodes vir die vervaardiging van steenkoolblokke, die inspuiting daarvan in die pypleiding, die wyse waarop hulle in die water in die pyp vervoer word, en die metodes wat gebruik word om hulle by die eindpunt van die pypleiding as voermateriaal vir elektriese kragstasies voor te berei.

Daar word op gewys dat die tegnologie betrokke by die vervoer van steenkool in die vorm van blokke deur pypleidings ook op ander minerale en kommoditeite toegepas kan word.

INTRODUCTION

Costs associated with the transportation of coal are major considerations for electric-power-generating companies. Although the costs or tariffs for the direct transportation of coal from a mine to a power station by rail, barge, or truck are readily available, the indirect costs associated with the transportation of coal are increasing. Those costs can be ascribed firstly to the impact on the environment and, possibly, health hazards arising from coal-related emissions to the air, water, and earth, secondly, to the adverse effects on roads and highways of the vehicles that are used for the transportation of coal. Such roads and highways often require increased maintenance due to the mass and frequency of shipments, become congested because of delays at railroad crossings, and suffer high accident rates as a result of the presence of large trucks. Recently, industries in the United States were faced with increased demands for cost reductions, as well as for processes with less adverse effects on the environment. Those economic and technical pressures have led to the re-evaluation of all aspects of coal transportation.

Alternative means for the transportation of coal—such as pipelines— are currently being considered. Historically, the first commercial coal pipeline in the United States started operating in 1957, when approximately 1 million tonnes of coal per year was pumped for 174 km through the 254 mm Consolidation Coal Slurry Pipeline. This coal pipeline ceased operation after only a few years because railroad rates had been reduced to competitive levels. At present, only one other coal pipeline is operating commercially in the U.S.A. This is the Black Mesa Pipeline, operated by Williams Technologies, Inc., which is used to transport 4,3 million tonnes of coal (in the form of slurry) per year over a distance of 440 km. The Black Mesa Pipeline has operated continuously since 1970.

Although pipelines have been considered as an alternative to railroads for the transportation of coal, they have faced strong economic competition from well-established railway companies.

At the University of Missouri, a new concept for the transportation of coal, known as a coal-log pipeline (CLP), is undergoing research and development (R&D). This paper describes the CLP concept, presents comparative transportation-cost data, and presents the basic design criteria for the CLP. The R&D financial support for the CLP project is from a consortium of industrial and governmental agencies.

In a coal-log-pipeline (CLP) system, coal is formed into water-impermeable circular cylinders—coal logs—that can be automatically injected into a pipeline and conveyed by water. In such a system, only one pipeline is used since no water or containers need to be returned. Figure 1 presents a schematic layout of a complete CLP system. The size of the pipeline in the CLP system depends on the required coal throughput, as is shown in Table I.

A CLP system is generally installed underground (below the frost line in cold climates), and the associated pumping stations are located at about 80 km intervals on the surface for ease of maintenance. At the CLP outlet, the coal logs are separated from the motive water and then crushed to the required size to satisfy the fuel specifications for the power plant or match existing coal supplies. Selected hydrophobic materials are used in the manufacture of the coal logs to

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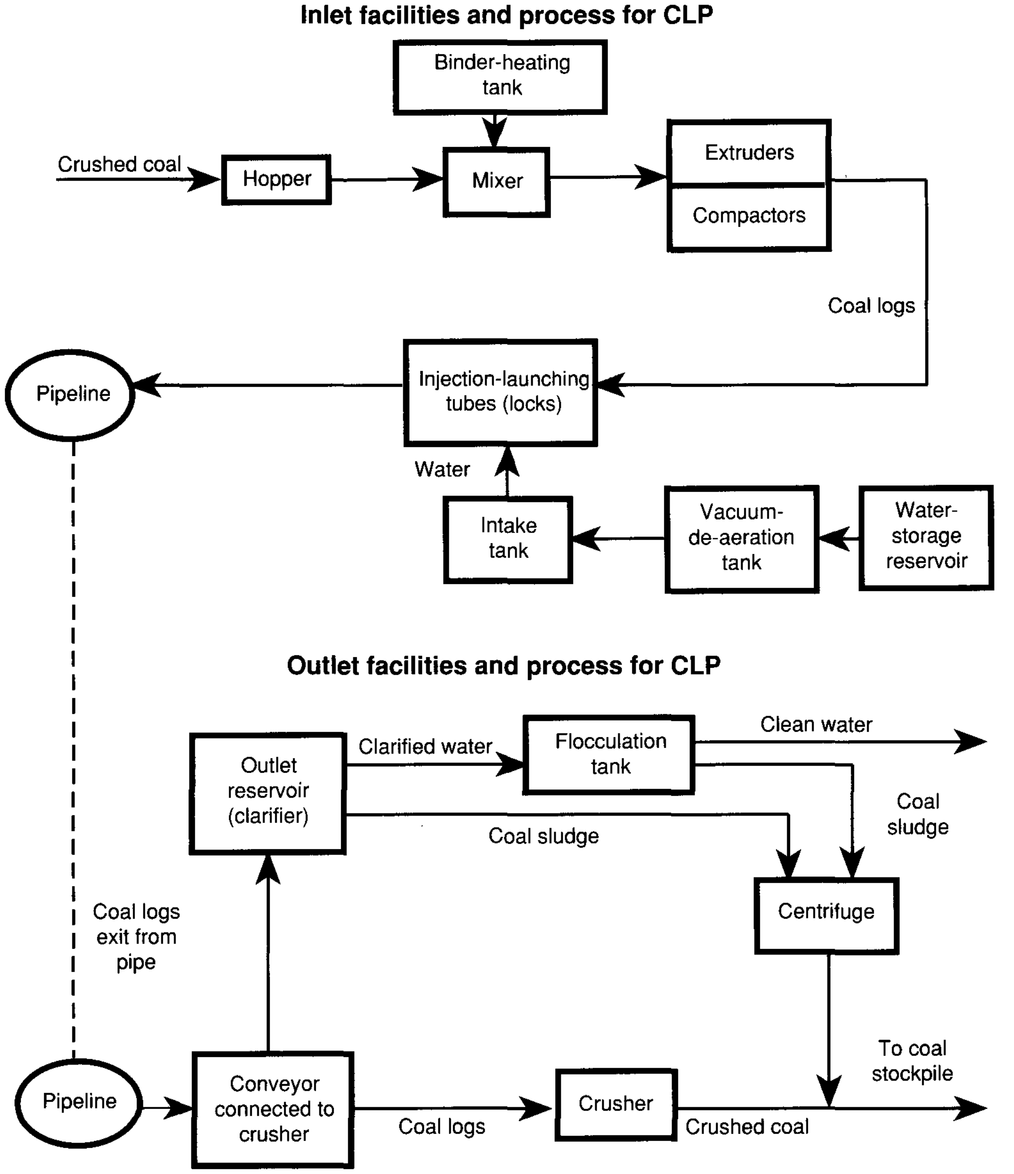

Figure 1—Conceptual flowchart of coal-log-pipeline system

Table I

Annual throughputs for coal-log pipeline (After Liu *et al.*[1])

Nominal pipe diameter mm	Lift-off velocity m/s	Throughput Water m3/s (x10^{-3})	Throughput Coal Mt/a
102	1,8	5,1	0,36
152	2,1	12,7	0,94
203	2,4	24,6	1,95
254	2,5	38,5	3,28
305	2,7	56,1	5,19
356	2,8	75,6	7,54
406	2,9	94,6	10,28
457	3,0	115,5	13,72
508	3,1	136,8	17,85

System availability 90%, linefill 0,90.

maintain log integrity during transportation. Coal logs have also been made by the use of certain processes without the addition of hydrophobic materials, and patents are pending on those new developments. Reagents for the mitigation of sulphur emissions during combustion can also be incorporated into logs that are made from coals with sulphur contents that exceed the legal emission requirements.

ECONOMICS OF COAL-LOG PIPELINES

Cost estimates of coal transportation indicate that they are about the same for unit trains as they are for pipelines[1]. The range of those costs is shown in Figure 2 for the transportation of unit trains of coal (9000-tonne loads) and coal-log pipeline. The costs for unit trains were derived from the average cost of several rail lines, which was then adjusted to the 1992 U.S. dollar. These data points represent the tariffs charged by different railroads, as listed in the Coal Transportation Reports[2,3]. Two throughputs (1,75

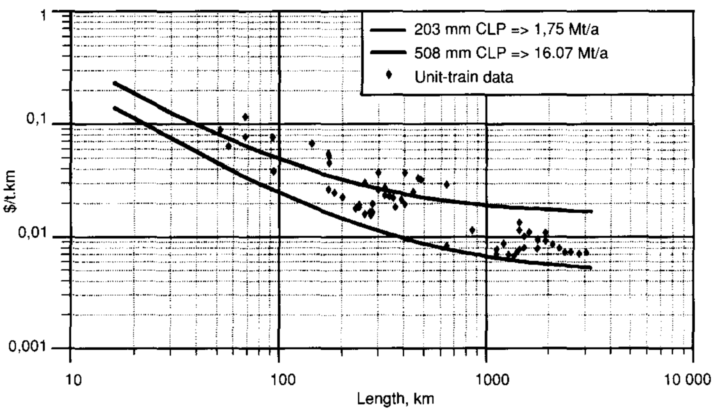

Figure 2—Unit-cost and unit-distance cost for transportation of coal unit train and CLP

and 16,1 million tonnes per year) are shown for the coal-log pipeline in Figure 2. The CLP unit-distance costs include the costs for an entire system, plus a reasonable return on investment. A comparison between the unit-train cost and CLP costs indicates that they are about the same. However, at larger coal throughputs, the CLP shows a significant reduction in unit costs.

A CLP uses only one-third to one-fifth the amount of water consumed by a coal-slurry pipeline. An estimate of the difference in cost between slurry and coal-log pipelines is presented in Table II, in which the estimates are based on the design, installation, and operation of a new pipeline[1]. For long distances, the unit cost for the transportation of coal though a CLP is one-half that of a slurry pipeline of the same diameter, and the coal throughput is more than 2,3 times greater than that of a slurry pipeline. The economic analysis of Liu *et al.*[2] also indicates that CLPs are more profitable than slurry pipelines, and that their attractiveness increases with the coal throughput, resulting in a corresponding decrease in unit costs.

Table II

Comparison of unit-distance costs* for coal slurry and coal-log pipelines (After Liu, *et al.*[1])

	Unit distance cost for 203 mm pipe, $/t.km		Unit-distance cost for 508 mm pipe, $/t.km	
Distance, km	Slurry	Log	Slurry	Log
81	0,097	0,063	0,059	0,033
161	0,070	0,040	0,033	0,017
322	0,042	0,028	0,019	0,011
805	0,028	0,021	0,011	0,0070
1610	0,022	0,018	0,0084	0,0063

* US dollars

THE COAL-LOG-PIPELINE CONCEPT

The coal-log-pipeline concept features the low energy consumption and simple dewatering at the pipeline delivery point that are typical of hydraulic-capsule pipelines used in freight-transport systems. The basic process of a CLP is the transportation, by water that flows through a pipe, of coal that has been compressed at the mine site into a cylindrical form. Coal logs can be made from run-of-mine or beneficiated coals that have been treated with small amounts of a binder, the quantity of which is a function of the type of coal and the chemical nature of the binding material.

The binder is used for manufacturing purposes and as an aid in the maintaining of log integrity while the logs are immersed in the pipeline water. For economic reasons, the amount of binder used is minimized, usually ranging from 0 to 3 per cent by mass.

When coal logs have been pumped from the mine site through the pipeline and have reached their destination, they are crushed and ground to the fuel specifications of the electric power plant.

Operations of Coal-log Pipelines

Coal logs can be injected directly or indirectly from the log-manufacturing equipment into the pipeline. The production rate of coal logs is dependent on the capacity requirements of the systems. In general, the size and mass of coal logs are controlled, the log diameters being 0,9 times the pipe-line diameter, and the preferred relative density (r.d.) of the logs about 1,1. The indirect injection of coal logs into a pipeline requires parallel launching tubes that feed the logs along conveyor belts to a high-pressure injection device. Within the pipeline, the coal logs occupy 90 per cent of the length of the line. The direct injection or underwater extrusion of coal logs requires parallel launching tubes to inject the coal logs into the main pipe. The coal logs travel in the pipeline as a train in which the first log moves slowest, and the last log fastest. Between these trains of logs a space is required so that logs can pass through pump-bypass stations.

The principle on which a CLP pump-bypass station is based is similar to that of locks used in petroleum pipelines for the handling of 'pigs' at booster stations. However, at a CLP pump-bypass station, the coal logs are not injected or ejected, but bypass the booster pumps using the system shown in Figure 3. One coal-log train at a time is routed alternately through line 1 and line 2 (S1 and S2 respectively in Figure 3). The opening and closing of eight valves (1 through 8 in the diagram) are computer-controlled, and cause the coal logs to switch between lines S1 and S2. When the four odd-numbered valves (1, 3, 5, and 7) are open, and the four even-numbered valves (2, 4, 6, and 8) are shut, the coal logs enter line S1 while water is being pumped into line S2 to clear it of coal logs. As soon as an entire train of coal logs has entered S1, valves 1, 3, 5, and 7 close, and valves 2, 4, 6, and 8 open. When S1 is full of coal logs, S2 is completely empty, and vice versa. Alternate closing and opening of the two sets of valves causes the coal logs to bypass the pump via lines S1 and S2. Only a single, continuously running pump is needed to pump the logs through lines S1 and S2.

Coal-log Hydraulics

As the water velocity increases in a coal-log pipeline, the coal logs tend to lift off the bottom surface (designated as *lift-off* in this context) and move into the centre of the pipe.

Under lift-off conditions, the outer surfaces of the coal logs are wetted by a dynamic layer of water, which separates the logs from the pipe wall. The lift-off velocity is calculated by use of the following equation.

$$V_L = 7{,}2\sqrt{|S-1|\,gak\left(1-k^2\right)D}\,, \qquad [1]$$

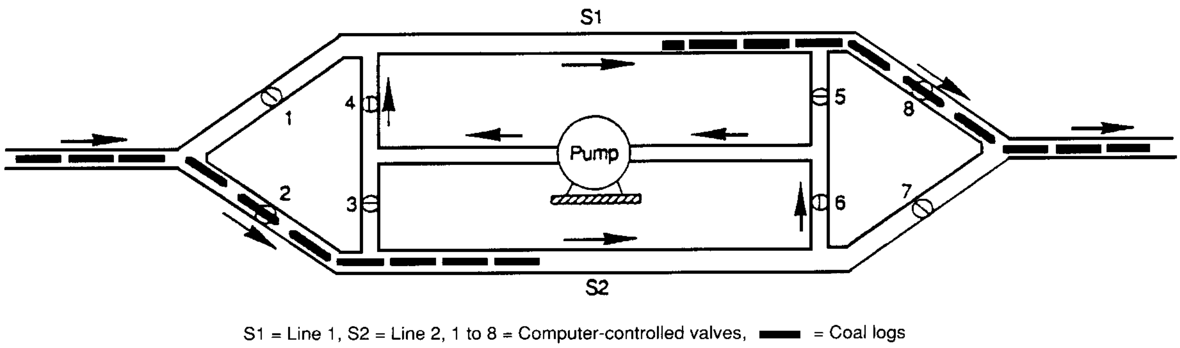

Figure 3—Configuration of the pump bypass on a coal log pipeline (After Liu and Wu[4])

where

V_L is lift-off velocity
S is relative density
g is gravitational acceleration
a is the aspect ratio, i.e. the ratio of log length to log diameter
k is the diameter ratio, i.e. the ratio of log diameter to pipe diameter
D is the inside diameter of the pipe.

Control of the operational variables for CLP allows the conditions required for the lift-off of coal logs in a pipeline to be established for given throughputs. Energy losses are minimized by the operation of coal pipelines at fluid velocities and pressure gradients slightly higher than those needed for lift-off, as shown in Figure 4. Furthermore, the losses of fluid due to friction in a CLP system are only 25 per cent higher than those of water flowing in a pipe at the same velocity.

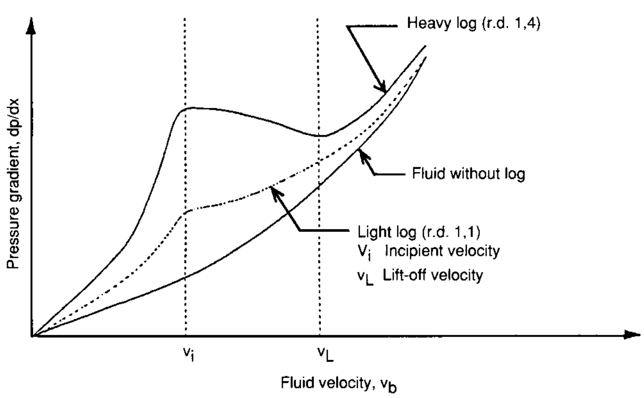

Figure 4—Variation of pressure gradient with velocity in a horizontal pipe. (After Paksanonda[5])

Manufacture of Coal Logs

Two manufacturing processes are being developed to make coal logs, namely extrusion and direct pressure. Extrusion requires the addition of a small percentage of binder to the coal, the actual content depending on the type of coal and the process conditions. The distribution of binder in a coal log can be uniform or concentrated on the surface.

Direct pressing of the logs can also be achieved without the use of a binder. This process takes advantage of the inherent chemistry of the coal, which tends to cause the particles to adhere to each other under high pressures.

So far, coal logs with diameters ranging from 25 to 200 mm have been produced. Coal logs are tested routinely for compressive strength when they are dry, as well as after being immersed in water under pressure, and for abrasion resistance under flow conditions. Additional log-characterization tests include measurement and permeability. Table III lists the coal and coal-binder mixtures that have been prepared and tested for potential application in a coal-log pipeline.

Table III

Binder evaluated for use in the manufacture of coal logs

	Compaction machine	
Type	Extruder	Press
Alkyd resin	N	Y
Asphalt cement	Y	N
Asphalt emulsions	Y	Y
Coal-tar emulsions	Y	Y
Coal-tar pitch	Y	N
Gilsonite	Y	N
Lignosol	Y	N
Paraffinic distillate	N	Y
Polyvinyl alcohol	Y	N
Wax (petroleum-based)	Y	N

Y = Binder has been tested
N = Binder has not been tested

End-of-Pipeline Features for Coal Logs

After the coal logs have been transported via CLP from the mine to the user, the logs come out of the pipe outlet onto a screen-type conveyor belt. This system allows the motive water and the logs to be separated immediately, and the logs to be conveyed automatically to crushers and grinders, or to storage piles. At the end of the pipeline, the motive water is subjected to filtration to remove suspended solids, and chemical treatment to reduce dissolved metals, so that the water can be re-used in power stations. The concentration of dissolved oxygen in the water is generally low, since the coal tends to absorb oxygen. The process of absorption is beneficial because it leads to reduced corrosion of the pipeline, and allows the requirement for deaerated water to be met more easily.

At power stations with fluidized-bed combustors, only the simple crushing of coal logs is needed, since the boilers can accept coal and limestone feeds with particle sizes up to approximately 50 mm. In that case, the coal logs are easily crushed by large commercial rock breakers. Although power stations with cyclone-type boilers, or using pulverized coal, require feeds with fine particle sizes, the coal logs need be crushed and ground only to the size distribution specified for the delivered coal, since the necessary grinding equipment to yield fine coal already exists at operating power stations. However, if asphalt-based binders are to be used in boilers using pulverized coal, the composition of the coal logs must be carefully monitored and controlled during manufacture, since small amounts of such binders can have an adverse effect on milling.

Much less water is required to transport coal logs than is required for a slurry pipeline. This is a significant advantage of transportation by coal-log pipeline. If the relative density of a coal log is 1,2, the ratio of the log diameter to the pipe diameter is 0,9, and the fraction of the pipe length that is filled with logs is also 0,9, the mass of the coal will be three times greater than the mass of the water. In that case, the coal and water content of the CLP would be respectively 76,4 and 23,6 per cent by mass. The relatively low content of water present is often lower than the inherent water content of low-rank coals. Hence, motive water for CLP transportation can also be obtained by the drying and upgrading of low-rank coals.

CONCLUSIONS

The coal-log-pipeline (CLP) system promises to be both technically and economically feasible, a field demonstration of the CLP system should follow. CLP technology is progressing rapidly, and some tests currently under way at the Capsule Pipeline Research Center include

(1) the manufacture of coal logs containing a minimum amount of binder,
(2) determination of the abrasion characteristics of coal logs under flow conditions,
(3) the automation of coal-log injection and intermediate booster-pump stations,
(4) water-hammer effects related to the flow of logs in a pipe, and
(5) determination of the handling and burning characteristics of coal logs at power plants at the end of the pipeline.

It is noteworthy that, although this paper focuses on the transportation of coal in log form via a pipeline, the technology is applicable to other minerals and commodities.

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