

**Total Annual O/M Costs:**

The total annual O/M cost for operating the inlet station of any coal log pipeline is

$$C'_i = C'_b + C'_{cr} + C'_{ei} + C'_w + C'_{si} + C'_{pi} + C'_{pg} + C'_{cl} + C'_{hc} + C'_{oi} \quad (79)$$

where the quantities on the right of Eq. 79 are found from Eqs. 51 through 78.

**6.1.2 Outlet Facilities****(a) Capital Costs**

Referring to Fig. 3, the outlet capital costs are determined as follows:

**Sedimentation Tanks:**

The outlet sedimentation tank is assumed to have a width of  $B_s = 30D$ , and a water depth of 4 ft. This yields a mean velocity through the tank equal to

$$V = \frac{Q_{ws}}{4 \times 30 D} = \frac{0.9 Q_w}{120 D} = \frac{Q_w}{133 D} \quad (80)$$

where  $V$  is in fps (ft/sec) and  $D$  in feet. The quantity  $Q_{ws}$  is the discharge of water in cfs entering the sedimentation tank, assumed to be 90% of the water entering the pipe ( $Q_{ws} = 0.90Q_w$ ). This means 10% of the water entering the pipe is absorbed by the coal logs.

Assume that the sedimentation tank has a detention time of  $T_d = 30$  minutes. Thus, the length of the tank is

$$L_s = V T_d = \frac{13.5 Q_w}{D} \quad (81)$$

where  $L_s$  and  $D$  are in feet; and  $Q_w$  is in cfs. The length  $L_s$  is needed for determining land requirements and conveyer belt length for the outlet facilities.

Based on the analysis presented in Appendix III-J, the capital cost for the sedimentation tank needed at a CLP outlet is

$$C_s = 337 + 24.2 Q_w \quad (\text{thousand dollars}) \quad (82)$$

where  $Q_w$  is in cfs.

### Flocculation Tanks:

From Appendix III-J, the capital cost for the flocculation tank is approximately

$$C_f = 63 Q_w^{0.5} \quad (\text{thousand dollars}) \quad (83)$$

where  $Q_w$  is in cfs.

Land:

The land required for the sedimentation and flocculation tanks is estimated to be

$$\begin{aligned} A_{sf} &= (3.5L_s) (3B_s) = 10.5 B_s L_s = 4253 Q_w \quad (\text{ft}^2) \\ &= 0.0976 Q_w \quad (\text{acres}) \end{aligned} \quad (84)$$

where  $Q_w$  is in cfs.

An additional acre is provided at the power plant for crushing coal logs and other coal-log related activities. Assuming each acre costs \$2,000, the total land cost for the outlet facilities is

$$C_{Lo} = 0.196 Q_w + 2 \quad (\text{thousand dollars}) \quad (85)$$

**Centrifugal Dewatering Equipment:**

As discussed in Appendix III-J, the capital cost of the equipment needed for centrifugal dewatering of the CLP slurry at the CLP outlet can be estimated from

$$C_{cd} = 0.000153Q_cL + 197 \quad (86)$$

where  $Q_c$  is the coal throughput of CLP in tons/hr;  $L$  is the pipeline length in miles; and  $C_{cd}$  is cost in thousand dollars (\$1,000).

**Dryers:**

The dewatered coal coming out of the centrifuge is expected to contain at least 30% surface moisture; it must be dried. For simplicity, it is assumed that the cost for the drying equipment is the same as for the centrifugal dewatering equipment given by Eq. 86. This explains for the use of the factor 2 for  $C_{cd}$  in Eq. 93.

Conveyor Belts:

The total length of the conveyor belts used in the outlet facilities is estimated to be

$$L_{co} = 2 \times 3.5 L_s = 7 L_s \quad (87)$$

where both  $L_{co}$  and  $L_s$  are in feet.

From Eq. 26, the conveyor cost is

$$\begin{aligned} C_{co} &= 0.325 D^{0.485} L_{co} \\ &= 2.28 D^{0.485} L_s \\ &= \frac{30.8 Q_w}{D^{0.515}} \quad (\text{thousand dollars}) \end{aligned} \quad (88)$$

in which  $D$  is the pipe diameter in feet; and  $L_s$  is the sedimentation tank length in feet.

Crushers:

From Appendix III-E, the cost of crushers needed to serve a CLP is

$$C_{cr} = 93.3 + 0.0188 Q_c^{1.315} \quad (89)$$

where  $C_{cr}$  is in thousand dollars; and  $Q_c$  is coal log throughput in tons/hr.

Note that Eq. 89 does not include any spare crushers. It is correct for the actual number of crushers used in a project over a range of throughput between 30 and 3,500 tons/hr, corresponding to pipe size from 4" to 24". Only one crusher is required for throughput up to 735 tons/hr, and two are needed for bigger throughputs. However, a spare must be provided in each case so that the pipeline need not be shut down during crusher repair and maintenance. Including the spare, the total crusher cost for a given pipeline is thus twice that given by Eq. 89 for throughput up to 735 tons/hr, and 1.5 or 3/2 times that of Eq. 89 for throughput beyond 735 tons/hr.

#### Building:

A small building of 2,000 ft<sup>2</sup> is needed to house the workers and store supplies such as the flocculant. Assuming that the building cost \$80 per square foot, the total cost for this outlet building is

$$C_{bo} = \$160,000 = 160 \text{ thousand dollars.} \quad (90)$$

Automatic Control:

The cost for automatic control equipment for the outlet is

$$C_{ao} = \$100,000 = 100 \text{ thousand dollars.} \quad (91)$$

Other Outlet Equipment:

One million dollars is allocated to cover any outlet equipment not covered in the items discussed before. Thus,

$$\begin{aligned} C_{oo} &= \$1,000,000 \\ &= 1,000 \quad (\text{thousand dollars}) \end{aligned} \quad (92)$$

Total Outlet Facilities:

Finally, it is assumed that all the foregoing capital costs, except for the centrifugal dewatering equipment, conveyers, crushers and land, have already included construction costs. The last four must be multiplied by 1.5 to take into account of construction cost.

$$C_o = C_s + C_f + C_{ao} + C_{bo} + C_{oo} + 1.5 (2C_{cd} + C_{co} + C_{cr} + C_{Lo}) \quad (93)$$

(b) O/M Costs

The O/M costs for the outlet station include costs for flocculants, energy (electricity), salaries (labor/administration) and other maintenance/operation costs.

Flocculants:

The cost of flocculants per year is assumed to be half of that for coal slurry pipeline based on the same amount of coal flowing through pipe, namely,

$$C_f' = 3.86 \times 10^{-5} Q_c L \quad (\text{thousand dollars}) \quad (94)$$

where  $Q_c$  is coal throughput in tons/hr.

Crushers:

From Appendix III-E, the power required to operate the crusher(s) of any CLP is

$$P_{cr} = 0.29 Q_c^{0.934} + 11.6 \quad (95)$$

where  $Q_c$  is coal log throughput in tons/hr; and  $P_{cr}$  is the electrical power in kw. Note that Eq. 95 is intended for throughput between



30 and 3,500 tons/hr, corresponding to CLP pipe size between 4 and 24 inches.

### Centrifugal Dewatering:

The power required for centrifugal dewatering of the CLP slurry is

$$P_{cd} = 5.6 \times 10^{-5} Q_c L \quad (96)$$

where  $P_{cd}$  is in kw;  $Q_c$  is in tons/hr and  $L$  is in miles.

### Coal Drying:

It is assumed that the energy used in thermal trying the dewatered coal coming out of the centrifuge is the same as that for operating the centrifuges. This is reflected in Eq. 99.

### Conveyor Belts:

The power for operating the outlet conveyer belts is estimated to be

$$P_{co} = 200 D \quad (97)$$

where  $P_{co}$  is in kw; and  $D$  is in feet.

**Total Power for Outlet and Energy Cost:**

Assuming that an extra 50 kw is needed for other purposes, the total power consumed by the outlet station is

$$P_o = 0.29 Q_c^{0.934} + 5.6 \times 10^{-5} Q_c L + 200 D + 62 \quad (98)$$

If the rate of electricity is 6¢ per kwh, the energy cost per year for outlet, based on non-stop continuous operation, is

$$C'_{eo} = 0.526 (0.29 Q_c^{0.934} + 0.000112 Q_c L + 200 D + 62) \quad (99)$$

which is in thousand dollars.

**Salaries and Wages:**

The annual labor and administration (salary) cost for operating the outlet is assumed to be

$$C'_{so} = 217 D^{0.756} \quad (\text{thousand dollars}) \quad (100)$$

where D is pipe diameter in feet.

**Other O/M Costs:**

Other annual O/M costs for the outlet are assumed to be

$$C'_{oo} = 125 D \quad (\text{thousand dollars}) \quad (101)$$

### Total O/M Cost:

The total annual O/M cost for the outlet station is

$$C'_o = C'_f + C'_{eo} + C'_{so} + C'_{oo} \quad (102)$$

## 6.2 Booster Stations:

### (a) Capital Costs

The design of the booster station is based on the pump bypass concept discussed in [16]. The capital cost of each booster station includes the cost of the water storage reservoir  $C_{wrb}$ , pump cost  $C_{ub}$  (for slurry pumps), valve cost  $C_{vb}$ , pipe cost  $C_{pb}$ , building cost  $C_{bb}$ , land cost  $C_{lb}$ , the cost of automatic control equipment  $C_{ab}$ , substation cost  $C_{sb}$ , and access road cost  $C_{rb}$ . They are respectively found from the following equations:

$$C_{wrb} = 50 Q_w \quad (103)$$

$$C_{ub} = 2.4 (H_{ub})^{0.8} \quad (104)$$

$$C_{vb} = 11 KD^{1.15} \quad (105)$$

$$C_{pb} = 4 L_t (129 D^{1.34} + 102 D^{0.87} + 24 D + 20) \quad (106)$$

$$C_{bb} = 240 D^2 \quad (107)$$

$$C_{Lb} = 10 \quad (108)$$

$$C_{ab} = 100 \quad (109)$$

$$C_{sb} = 0.56 P_b^{0.6} \quad (110)$$

where  $P_b$  is given in Eq. 116, and

$$C_{rb} = 1,000 \quad (111)$$

In the foregoing equations, the reservoir cost is based on a reservoir volume equal to ten hours of the water flowing through the pipe; the pump cost is based on two slurry pumps\*, one of which serves as a spare. The valve cost is based on eleven automatic, high-pressure ball valves (two are spares). The pipe cost is based on a total length of  $4 L_t$  where  $L_t$  is the length of the coal log train in miles. The building cost is based on an area of  $3,000 D^2$  and a unit cost of  $\$80/\text{ft}^2$ . The land cost is based on an area of 5 acres per station and the price of  $\$2,000$  per acre. The substation cost is based on the assumption that the power needed at

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\* The cost of slurry pumps is analyzed in Appendix III-H. Two slurry pumps are installed at each booster station; one is a spare.

each booster station is determined from Eq. 116, and that Eq. 43 is also applicable to booster stations. The cost of access road for each booster station is assumed to be the same as for the inlet station based on 5 miles of access roads. All the costs in Eqs. 103 through 112 are in the unit of **thousand dollars**.

The total capital cost of each booster station is

$$C_b = C_{ab} + C_{bb} + C_{rb} + C_{sb} + C_{wrb} + 1.5 (C_{ub} + C_{vb} + C_{pb} + C_{lb}) \quad (112)$$

(b) O/M Costs

The power consumed at each booster station can be calculated as follows:

The power of the booster pump in kw is

$$P_{ub} = 0.746 H_{ub} \quad (113)$$

where  $H_{ub}$  is the horsepower of the booster pump.

The power in kw to operate the nine valves at each booster station is

$$P_{vb} = 45 D \quad (114)$$

The power for heating, cooling and lighting the building is

$$P_{bb} = 50 \text{ kw} \quad (115)$$

Therefore, the total power for a booster station in kw is

$$P_b = P_{ub} + P_{vb} + P_{bb} = 0.746 H_{ub} + 45 D + 50 \quad (116)$$

From the above, the annual energy consumption in kwh by each booster station, in non-stop continuous operation, is

$$E_b = 8,760 P_b \quad (117)$$

And, the annual cost of energy at 6¢ per kwh, is

$$C'_{eb} = 0.526 P_b \quad (\text{thousand dollars}) \quad (118)$$

The annual salary (administration/labor) cost for each booster station is assumed to be the same as for coal slurry pipeline, namely,

$$C'_{sb} = 122 D^{0.756} \quad (\text{thousand dollars}) \quad (119)$$

The cost for ordinary materials/supply is

$$C'_{mb} = 100D \quad (\text{thousand dollars}) \quad (120)$$

When a polymer (polyethylene oxide) is used for drag reduction (scenarios 17-19), it will be assumed that due to breakdown of the polymer by flow, 10 wppm of the polymer must be added to the flow at each booster station. From Eq. 69, this results in an annual polymer cost of

$$C'_{pb} = 99Q_w \quad (\text{thousand dollars}) \quad (121)$$

Therefore, the total annual O/M cost for a booster station is

$$C'_b = C'_{eb} + C'_{sb} + C'_{mb} + C'_{pb} = 0.392H_{ub} + 124D + 26.3 + 99Q_w \quad (122)$$

### 6.3 Pipeline Costs:

The pipeline cost, including construction, right of way, piping materials and so forth, is assumed to be identical to that of a coal slurry pipeline of the same length and diameter. Using information given in Appendix III-A, we have the following:

The construction cost for a mile of steel pipe is given by Eq. 20. Therefore, the construction cost for the entire pipeline of length  $L$  is

$$C_{pc} = (L - N_b L_t) (129D^{1.34} + 102D^{0.87} + 24D + 20) \quad (123)$$

where  $C_{pc}$  is in thousand dollars; and  $L$  and  $L_t$  are in miles. Note that the term  $N_b L_t$  accounts for the part of the pipeline occupied by the inlet station and the booster station that have been included in the capital costs of the inlet and booster stations.

#### 6.4 Calculation of Unit Cost and Freight Rate:

The foregoing equations are used in this study to calculate the capital and O/M (Operation/Maintenance) costs for each part of a CLP system, from which the total capital cost and the total annual (subsequent) cost for the system are determined using the cost analysis method and assumptions described in detail in Sections 4 and 5. This was done for coal log pipelines of different diameters (4" to 20"), and various lengths between ten miles and two thousand miles. The results, in terms of **unit transportation cost** ( $\$/T$ ) and **freight rate** ( $\$/TM$ ), are plotted as a function of **distance**, using **throughput\*** as a parameter, as shown in Figs. 4-31. An example is now given to show how the computation was conducted for each size of coal log pipeline.

Consider an 8-inch (nominal diameter), 100-mile-long coal log pipeline (CLP) operating under the conditions cited in scenario 1, using logs of specific gravity equal to 1.2. Schedule 60 steel

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\* Note that each throughput corresponds to a particular pipe diameter.



pipe was selected to withstand high internal pressure (1,500 psi) and to provide long-term service. The pipeline was assumed to operate at the lift-off velocity of  $V_L = 7.8$  ft/sec as given in Table 3\*. At 90% linefill and 100% system availability, the throughput of water  $Q_w$  and the throughput of coal  $Q_c$  are found from Table 3 to be respectively 0.87 cfs (cubic feet per second) and 2.18 MT/yr (million tons per year). These figures should be reduced by 10% ( $Q_w = 0.783$  cfs and  $Q_c = 1.96$  MT/yr) for scenario 1 which has a 90% availability. Without using polymers for drag reduction, the pressure drop and the pumping energy required for each 100 miles of the pipeline are listed in Table 3 as 712 psi and 5.05 MW (megawatts) respectively.

From Table 4, for this 8-inch pipeline the spacing between booster stations corresponding to 1,500 psi drop of pressure in the pipe is approximately 20 miles.

Substituting the numbers listed in Tables 3 and 4 into the one hundred and twenty-three (123) equations discussed before yields the cost values for each part and the system, and the unit transportation cost and freight rate of coal by CLP. Some cost breakdowns, including both capital costs and O/M cost, for the 8-inch CLP are shown in Tables 6 through 14. The way to calculate

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\* Appendix IV shows how the values of  $V_L$ ,  $a$ ,  $k$  and so forth are calculated.

the unit cost and the freight rate of an 8-inch CLP 100 miles long is illustrated in Table 15.

In the economic analysis of CLP, the average annual coal throughput,  $Q_c$ , and the average annual water throughput  $Q_w$ , should be those for continuous operation multiplied by the system availability,  $\lambda$ . Likewise, the annual energy consumption calculated from continuous operation should be multiplied by  $\lambda$  to reflect system availability. For the O/M costs other than energy, while most are proportional to  $\lambda$ , a few are not. For simplicity, they are assumed to be  $(0.8\lambda + 0.2)$  times the costs based on continuous operation.

Using the aforementioned approach, a computer program (see Appendix V) was written to calculate the **unit cost**,  $U_0$ , of coal transport by CLP, in dollars per ton of coal transported ( $\$/T$ ), for pipelines of different diameters and lengths. Dividing each  $U_0$  by the corresponding pipe length yields the unit-distance cost (**freight rate F**), in dollars per ton per mile ( $\$/TM$ ). The results (unit cost and freight rate as a function of pipeline length) are plotted as a set of curves in Figs. 4 through 35. Each of the thirty-five figures represents a separate scenario, and each curve represents a different throughput. The six throughputs plotted are those corresponding to the following five pipe diameters: 4", 6",

8", 12", 16" and 20". The distance studied ranges from 10 to 2,000 miles.

### 6.5 Discussion of Results:

For all the curves in Figs. 4 through 35, the unit cost,  $U_0$  in  $\$/T$  increases with increasing pipeline length, and decreases with increasing throughput. On the other hand, the freight rate,  $F$ , in  $\$/TM$  decreases with increasing pipeline length, and with increasing pipeline throughput. This means longer distance and larger throughput both reduce the freight rate of CLP.

All the curves about freight rate in Figs. 4-35 start leveling off when the length or distance is very long, approximately 2,000 miles. This means the freight rate for distances longer than 2,000 will be practically the same as for 2,000 miles. This is due to the fact that the cost of a long pipeline is dominated by energy cost, pipeline cost, and booster station cost, which are all linearly proportional to the distance or the length of the pipeline. The freight rate varies with pipeline length or transportation distance only when distances are relatively short.

Figure 4 gives the results for scenario 1 which is used as a standard to compare with other cases or scenarios. The assumptions used for this scenario and for the other 31 scenarios are discussed

in Section 3 and listed in Table 2 (APPENDIX I). The upper graph gives unit cost whereas the lower graph gives unit-distance cost (freight rate). The two horizontal dotted lines drawn in the upper graph of Fig. 4 correspond to unit costs of \$5 per ton and \$10 per ton. The portion of the curves below the \$5 line is the regime of CLP that can transport coal at less than \$5 per ton, and the portion of the curves below the \$10 line gives the regime of CLP that can transport coal at less than \$10 per ton.

Figure 4 shows that a 20-inch pipe (CLP) can transport approximately 18 MT/yr of coal at the unit cost of \$5 for a distance of 422 miles approximately, and at the unit cost of \$10 for a distance of 1,122 miles approximately. As will be shown later, these rates are far more economical than the lowest unit costs for transportation by unit train in 1992. The comparison of the unit cost (more precisely, the present value of average unit cost,  $U_0$ ) of CLP with the present rail tariff is appropriate only if the rail tariff increases at the discount rate  $\delta$ --8% in scenario 1. This is an important point that will be discussed later. Figure 4 also shows that for an 8-inch CLP that can transport approximately 2 million tons of coal per year, the unit costs \$5 per ton and \$10 per ton correspond to 68 miles and 272 miles, respectively. These rates may be higher than unit train rates, but are lower than current rates charged by trucks--see Section 8.

The foregoing results show that the larger the pipeline diameter and the longer the pipeline are, the more attractive it is to use CLP for transporting coal. Under the conditions of scenario 1, the unit-distance cost (tariff) of a 20-inch-diameter CLP 1,000 (2,000) miles long is in the neighborhood of 0.9¢ (0.8¢) per ton-mile.

Scenarios 1, 2 and 3 are based on identical assumptions except for a difference in the rate of coal logs produced: 0.1, 0.2 and 0.4 ft/sec of logs produced, respectively for scenarios 3, 1 and 2. Comparison of the graphs in Figs. 4, 5 and 6 shows that a fourfold increase of the log production rate from 0.1 to 0.4 ft/sec produces only a slightly noticeable decrease in the unit cost and the unit-distance cost for short pipes and no noticeable decrease in the costs for long pipes. This means in spite of the fact that many machines (compactors or extruders) are needed to supply a given pipeline, the machine cost is a small factor in the unit cost and the unit-distance cost of the CLP especially when the pipeline is long.

Scenarios 1, 4, 5 and 6 are basically the same except that the specific gravity of the logs is different: 1.05, 1.10, 1.20 and 1.35 respectively for scenarios 5, 6, 1 and 4. Comparison of the results of these four scenarios represented in Figs. 4, 7, 8 and 9 shows that generally the unit cost and the unit-distance cost for

transporting heavy logs are less than for light logs when the pipelines are short, whereas the opposite holds for long pipelines. The reason that such costs are less for heavy logs in short pipelines is that more coal is transported when the logs are heavy. However, as the pipeline becomes very long, energy cost becomes a dominant factor. Heavier logs require greater velocity and greater pump power.

Scenarios 1, 7, 8 and 9 differ from each other mainly in the pump pressure\* used: 1500, 2000, 1000 and 500, respectively for scenarios 1, 7, 8 and 9. Another difference is that while scenarios 1, 7 and 8 use positive displacement pumps, scenario 9 uses centrifugal pumps due to lower pressure requirements--500 psi. Comparison of these four scenarios as given in Figs. 4, 10, 11 and 12 indicates that the higher the pump pressure is, the less costly is the pipeline system, especially when the pipeline is long. Higher pump pressure reduces pipeline costs because higher pressure allows larger spacings between booster stations and fewer pumps. However, it should be realized that higher pressure requires thicker pipe wall. This counterbalancing factor is not included in this economic analysis. A more refined economic analysis must take this into account.

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\* By **pump pressure** we mean the pressure change along the pipeline between two neighboring pumping stations. It is about the same as the maximum internal pressure encountered by the pipeline.

Scenario 10 is the same as scenario 1 except that a "pig" is used to lead each coal log train. The use of pigs increases not only capital cost but also operation/maintenance (O/M) cost, for the pigs that go through a pipeline must be transported back to the pipe inlet either by truck or train. However, comparison of the results of these two scenarios given in Figs. 4 and 13 shows no noticeable difference. This means the cost of using pigs is very small as compared to the total cost of a CLP.

Scenario 11 is identical to scenario 1 except that fresh water instead of treated brackish water was used. They are respectively represented by Figs. 4 and 14. Again, no noticeable difference in costs exists between these two cases. This means in spite of the fact that fresh water costs several times less than treated (desalinated) brackish water, the savings by using fresh water produces a negligible decrease in the total system cost or unit costs. This is due to the fact that CLP uses not much water, and the water cost, even when treated brackish water is used, is a very small fraction of the total cost.

Scenarios 1, 12 and 13 are the same except for the length of each coal log train in the pipe: 100, 200 and 400 times of  $V_0$  for scenarios 12, 1 and 13, respectively. Comparison of the results given in Figs. 4, 15 and 16 shows that train length has negligible

effect on the system cost. This is expected to be the case as long as the trains are relatively long--say longer than  $50 V_0$ .

Scenario 14 is the same as scenario 1 except that an existing (old) pipeline instead of a new pipeline is used. In this case, it is assumed that the remaining economic life of the system is 15 years, that the purchase price of this existing pipeline is 30% of that of a new pipe calculated from Eq. 123, and that the maximum allowable pressure in the pipe is reduced to 1,000 psi. Comparison of Figs. 17 and 4 indicates that the unit cost and the unit-distance cost are generally higher for the existing pipe than for the new pipe, especially when the pipe diameter is small. The main reason that the transportation costs are higher for the existing pipeline is the much shorter economical life assumed. Should it be possible to extend the economic life of an existing pipeline, such as through the insertion of a new pipe inside the old pipe, then the economics of the renovated pipeline can be much improved. Furthermore, even if the economics of using an existing pipeline may not look as attractive as a new pipe, as in scenario 14, an existing pipeline should still be considered if right-of-way problems threaten lengthy delay of construction of a new pipeline.

Scenario 15 investigates the effect of linefill rate on the costs. Comparing Fig. 4 with Fig. 18 shows that a decrease in linefill by 10% (from 90% to 80%) produces a small but noticeable



increase in the unit cost and unit-distance cost. The profit of the system will go down even more due to a dual adverse impact: increase in unit cost and decrease in the total tonnage of coal transported through the pipe each year.

Scenario 16 is the same as scenario 1 except that no deaeration equipment is needed. Comparison of Fig. 19 with Fig. 4 shows that deaeration causes negligible increase in total system costs.

Scenarios 17, 18 and 19 are the same as scenarios 1, 4 and 6, respectively, except that drag-reducing additives are used to reduce energy consumption. Comparison of Figs. 4, 7 and 9 with Figs. 20, 21 and 22 shows that drag-reducing additives are very effective in reducing the costs of CLP, especially when the pipeline is long. This is due to the fact that the life cycle cost of long pipelines is dominated by the energy cost, which in turn can be substantially reduced by using drag-reducing agents.

Scenarios 20, 21, 22 and 23 investigate the effect of using extruders of different types and using different percentages of binders. From Figs. 23, 24, and 25, it is clear that binder percentage has a strong impact on the costs of CLP, especially when the pipelines are short. Even a 1% increase in binder causes a significant increase in costs. With 5% binder, the cost is so high

that the CLP can no longer compete with other modes of transport. This shows the great importance of using as little binder as possible in making coal logs. Comparison of Fig. 26 (scenario 23) with Fig 23 (scenario 20) shows that the use of a more costly type of extruders does not have noticeable impact on the total or unit costs.

Scenario 24 is the same as scenario 1 except that a duplicate lock system at the pipeline inlet and a duplicate pump-bypass system at each booster station are used to increase the reliability (availability) of the total CLP system from 90% to 95%. Comparing curves in Fig. 4 with those in Fig. 27 shows a rather substantial increase in the unit costs and the unit-distance costs due to the use of the duplicate systems. Since this cost increase is greater than 5% and the additional coal transported from 90% to 95% availability is 5%, the high reliability system appears unjustified. Unless the percent increase in unit cost is less than the percent increase in availability, a high reliability system cannot be justified on economic grounds.

Scenario 25 is the same as scenario 4 which uses heavy logs of specific gravity equal to 1.35, except that a coal slurry of 50% weight concentration of coal is used to suspend and transport the logs through pipeline. Assuming that the specific gravity of the slurry is 1.20, this creates a density ratio of  $\epsilon = 1.35/1.20 =$

1.125 which substantially reduces the operational velocity which is based on the lift-off velocity. Table 5 lists the key parameters of this log-slurry system. The unit cost and unit-distance cost for the slurry system are calculated in the same manner as for scenario 4 except that the headloss of the log-slurry is assumed to be that of a pure slurry flow--see APPENDIX IV. Comparing the results in Fig. 28 (scenario 25) with those in Fig. 7 (scenario 4) shows that the unit costs for the two systems are approximately the same.

Scenario 26 explores the effect of a much shorter life (15 years) for most major equipment used in CLP, including conveyors, extruders, compaction machines, mixers, binder heating tanks, deaerator equipment, pigs, crushers and so on. Comparing the result of this scenario (Fig. 29) with scenario 1 (Fig. 4) shows a rather significant increase in costs by using 10 years instead of 30 years for this costly equipment.

In scenario 27, the effect of a higher profit rate is investigated. Comparing this case (Fig. 30) with scenario 1 shows that in spite of the doubling of return (from 15% to 30%), the unit costs increase only slightly. This means companies owning and operating CLPs can take a high profit and still provide low freight rates that are competitive with railroads and trucks.

Scenarios 28 and 29 are the same as scenario 1 except that the equity rate,  $e$ , is reduced from 1 to 0.6 and 0 (zero), respectively for scenarios 28 and 29. Comparison of the results given in Figs. 31 and 32 with those in Fig 4 for scenario 1 shows that the reduction of  $e$  decreases the transportation costs slightly. This is due to reduced corporate income tax paid when more capital is borrowed (see Eq. 3). This result does not mean that borrowing money is better than investing one's own money. When one has money to invest, one should invest it in the CLP project which has an annual return rate of 15% built in the economic model. Not many other projects can yield such high return. All that scenarios 28 and 29 tell us is that the equity rate has a very minor effect on project costs and tariffs.

The effect of discount rates is explored in scenario 30 by using a discount rate of 6% instead of the 8% for scenario 1 and the other scenarios. Comparison of Fig. 31 (scenario 30) with Fig. 4 (scenario 4) indicates that the discount rate has a profound effect on the unit cost and the unit-distance cost: a 2% point reduction in the discount rate increases the costs by about 20%. This scenario shows the great importance of using a realistic value of the discount rate in this economic study.

The fact that the discount rate has a profound impact on the unit cost and the unit distance cost raises the question as to what

is the most realistic discount rate to be used. If rail and truck tariffs were calculated from costs in the same manner as for CLP tariffs, then it would not matter what discount rate to use as long as the same discount rate for CLP were also used for rail and truck. However, the rail and truck tariffs reported in Section 8 are not obtained from cost calculations; rather, they are the existing (1992) rates charged to customers--the utilities. In such a case, comparison of the calculated CLP tariffs with the existing rail and truck tariffs is meaningful only if we can assume that the rail and truck tariffs will increase in the next 30 years (the economic life of the pipeline) at annual rate equal to the discount rate used in the CLP calculations--6% in scenario 30, 7% in scenario 31, and 8% in the other scenarios. Therefore, an important question to ask is whether the discount rates used in this study are reasonable or realistic. The answer is positive because the costs for rail and truck are primarily operational/maintenance costs, wages, and fuel. They are expected to go up at a rate equal to or higher than the general inflation rate for ordinary goods and services. Therefore, if we assume the general inflation rate to be 6% as it was assumed in all the scenarios, the cost for operating rail or trucks should escalate at a minimum of 6%. This shows that the 6 to 8% of discount rate used in this study is reasonable and realistic.

more - need to  
think more  
about correlation

In scenario 31, the annual general inflation rate and the annual electricity escalation rate are assumed to be 5% and 6% respectively--one percent point below those in scenario 1. The discount rate is also assumed to be 1% below that of scenario 1. Comparison of the results for scenario 31 given in Fig. 34 with results in Fig. 4 for scenario 1 shows that the two sets of curves are about the same. This means that it is not the absolute values of the discount rate that affect the cost of CLP; it is the relative value (i.e. how much the discount rate is above or below the inflation and electricity rates) that counts. This means whenever we assume a high inflation rate and high electricity escalation rate, the discount rate assumed also should be high and vice versa. Approximately, a 1% point increase in inflation and electricity rates balances a 1% point increase in the discount rate. *True*

Scenario 32 (Fig. 35) is the same as scenario 26 (Fig. 29) except that certain main components of the pipelines, including the pipe, valves, pumps, buildings, etc. have a 45-year economic life. Comparison of the two cases reveals the advantage of assuming a longer system life when the pipeline is long.