

## 6. CLP COSTS

Because CLP is an emerging new technology, no cost data exist for it. Such data must be generated from the anticipated cost of each component of a CLP system, and the anticipated O/M costs. Each CLP system analyzed includes four major parts: **inlet facilities**, **outlet facilities**, **pipeline** (including not only the pipe but also valves and fittings distributed along the pipe), and **booster stations**. Each major part includes many components. A preliminary design of an entire CLP system has been completed to determine each of the components required, its size, and operational properties. Details of this design are not revealed here due to proprietary information involved. However, two flow charts are included here showing the two most complex parts: inlet facilities (Fig. 2) and outlet facilities (Fig. 3).

In what follows, the cost for each major part and component will be evaluated at first. Then, they will be combined to determine the total initial cost (capital cost) of the pipeline analyzed. The O/M costs are evaluated separately.

## 6.1 Terminal Facilities

The terminal facilities of CLP include both the inlet and outlet facilities. The inlet facilities include conveyor belts that bring the crushed coal (0.5 inch top size) into mixers, a binder heating tank (if extrusion is used which needs binder), a number of extruders or coal log compaction machines, a network of conveyors to bring coal logs from each extruder or compaction machine to a coating (surface sealing) chamber which in turn is connected to an injection/launching tube (lock), several parallel locks, a number of valves to control capsule injection and launching, a small auxiliary pump for each lock to facilitate capsule injection, an intake water tank, a vacuum deaeration tank (if any), a water storage reservoir, and a building to house equipment/facilities excluding the long underground locks and the water reservoir. The exact number of each type of equipment varies with the throughput. It must be determined separately for each pipe size. Fig. 2 is a flow chart of the process involved at the inlet facilities.

The outlet facilities include an outlet reservoir which also serves as a sedimentation tank (clarifier) to remove coal particles, a flocculation tank to remove fine particles by forming flocs, a conveyor belt to remove coal logs from the pipe outlet and to bring the logs to crushers, and another conveyor to bring

crushed coal to the coal storage yard of the power plant. In addition, the coal particles separated from the sedimentation tank must be scooped, dewatered, dried, and reloaded on a conveyor that brings crushed coal to the storage yard. The outlet process is shown in Fig. 3.

The cost of terminal facilities, as it is the case with most other costs, depends on the coal throughput or pipe size. It is determined in the following manners:

#### 6.1.1 Inlet Facilities

##### (a) Capital Costs

##### Intake Tank:

The length of each lock tube,  $L_{Lo}$ , is calculated from

$$L_{Lo} = 210V_o \quad (9)$$

where  $V_o$  is the operational velocity in ft/sec; and  $L_{Lo}$  is in feet. Note that in this study, the operational velocity ( $V_o$ ) of the CLP is chosen to be the same as the lift-off velocity, ( $V_l$ ). The use of Eq. 9 yields a valve switching time (i.e., the period of switching valves on and off) of slightly over 3 minutes.

The length of the intake tank\* is calculated from

$$L_{ti} = 50D \quad (10)$$

where  $D$  is the pipe diameter in feet; and  $L_{ti}$  is the tank length in feet.

Assuming that the width of the intake tank is  $B = 30D$ , the area of the tank is

$$A_{ti} = 30 DL_{ti} = 1,500 D^2 \quad (11)$$

where  $A_{ti}$  is in square feet; and  $D$  is in feet.

The tank is assumed to cost \$50 per square feet (1992 value)\*\*, including design and construction. Therefore, the cost of a completed intake tank is

$$\begin{aligned} C_{ti} &= 50 A_{ti} = 75,000 D^2 && \text{(dollars)} \\ &= 75D^2 && \text{(thousand dollars)} \end{aligned} \quad (12)$$

### Building:

The length of the inlet main building is calculated from

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\* The intake tank is a closed tank (reservoir) made of reinforced concrete. It holds the deaerated water before the water enters the pipeline.

\*\* Unless otherwise mentioned, all costs are in 1992 dollars.

$$L_{mbi} = 4L_{ti} = 200 D \quad (13)$$

The width of the building is calculated from

$$B_b = 100 D \quad (14)$$

Therefore, the area of the building is

$$A_{mbi} = B_b L_{mbi} = 20,000 D^2 \quad (15)$$

where  $D$  is in feet; and  $A_{mbi}$  is in square feet.

The building cost, including design and construction, is assumed to be \$80 per square foot. Therefore, the cost of a completed inlet main building is

$$\begin{aligned} C_{mbi} &= 1,600,000 D^2 && \text{(dollars)} \\ &= 1,600 D^2 && \text{(thousand dollars)} \end{aligned} \quad (16)$$

Note that for any CLP inlet, a separate small building is needed to house the valves at the downstream end of the locks. Including both this valve station and the main inlet building, the total cost for buildings at a CLP inlet is

$$C_{bi} = 2,000 D^2 \quad (17)$$

where  $D$  is in feet; and  $C_{bi}$  is in thousand dollars.

Land:

The land cost is assumed to be \$2,000 per acre. The total area occupied by each inlet station, including parking, recreational and landscape areas, is assumed to be  $A_{Li} = 50$  acres. Thus, the land cost for inlet station is

$$\begin{aligned} C_{Li} &= 2,000 A_{Li} = \$2,000 \times 50 = \$100,000 \\ &= 100 \quad \quad \quad (\text{thousand dollars}) \end{aligned} \quad (18)$$

Intake pipe:

Assuming four launching tubes (locks), the total length of the pipe used at each inlet station is approximately 4 times the length of each lock, namely,

$$L_{pi} = 4 L_{Lo} = 840 V_o \quad (19)$$

The cost for each mile of pipe construction, as shown in Appendix III-A (Eq. A-6), is

$$C_{p1} = 129D^{1.34} + 102D^{0.87} + 24D + 20 \quad (20)$$

where  $D$  is the pipe diameter in feet; and the cost  $C_{p1}$  is in the unit of \$1,000 per mile.

The cost for inlet piping is

$$\begin{aligned} C_{pi} &= C_{p1} L_{pi} \\ &= 0.159 V_o (129D^{1.34} + 102D^{0.87} + 24D + 20) \end{aligned} \quad (21)$$

where  $C_{pi}$  is in the unit of \$1,000.

### Valves:

Assume that 20 valves are needed at the inlet station--they are motor-controlled, high-pressure, gate or ball valves. The cost of each valve is (see Appendix III-B):

$$C_{v1} = KD^{1.15} \quad (\text{thousand dollars}) \quad (22)$$

where D is in feet; and K is 55, 60, 63 and 66, respectively for 500, 1000, 1500, and 2000 systems. Equation 22 gives valve cost in thousand dollars. The cost includes not only the valves but also the actuators driving the valves.

The total cost for valves used in the inlet facilities is

$$C_{vi} = 20 C_{v1} = 20 K D^{1.15} \quad (\text{thousand dollars}) \quad (23)$$

### Inlet Pumps:

Five water pumps are used at the inlet: a main pump that provides the power to move the water and the logs to the first

booster station, and four auxiliary pumps to draw coal logs into the four parallel locks. To assure high availability, one auxiliary pump and the main pump must be provided in duplicate. This means a total of seven pumps--two main and five auxiliary--are provided for each inlet. A duplicate will be used whenever a valve is being repaired or serviced. The cost of each water pump\* will be determined from:

$$C_{ui} = 0.930 (H_p)^{0.6} \quad (24)$$

where  $C_{ui}$  is the pump cost in thousand dollars; and  $H_p$  is the horsepower of the pump.

The total cost for the seven pumps of each inlet facilities is

$$C_{ui} = 0.930 (2H_{pm}^{0.6} + 5H_{pa}^{0.6}) \quad (\text{thousand dollars}) \quad (25)$$

where  $H_{pm}$  and  $H_{pa}$  are the horsepower of each main pump and each auxiliary pump, respectively.

### Conveyors:

Assuming that each conveyor has a width equal to the pipe diameter  $D$ , the cost for the inlet conveyor belts, derived from [10], is

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\* The pumps at the inlet are all water pumps. In contrast, pumps at booster stations are slurry pumps.



$$C_{ci} = 0.325 D^{0.485} L_{ci} \quad (\text{thousand dollars}) \quad (26)$$

where  $L_{ci}$  is the total length of the conveyors in feet determined from

$$L_{ci} = 40L_{ti} = 2000D \quad (27)$$

where  $L_{ti}$  is derived from Eq. 10.

### Extruders:

As shown in Appendix III-C, the cost for extruders is determined in the following manner:

Since the size of extruders must match the size of the pipeline, smaller pipelines require smaller extruders and vice versa. In terms of coal log diameter,  $D_c$ , the cost for each extruder is

$$C_{e1} = 64D_c^{0.73} \quad (\text{Low-cost Extruder}) \quad (28)$$

$$C_{e1} = 173 D_c^{0.73} \quad (\text{High-cost Extruder}) \quad (29)$$

As before,  $D_c$  is in feet and cost is in thousand dollars.

Assume that all coal logs can be extruded at 0.2 ft/sec, the linefill rate of coal logs in the pipeline is 0.9 (90%), and logs travel at the pipeline operational velocity  $V_o$  (same as the lift-off

velocity  $V_L$ ). Then, the number of extruders required to supply sufficient logs to a pipeline is

$$N_e = 4.5 V_o + 3 \quad (30)$$

The numeral 3 in Eq. 30 accounts for three extra extruders to be used as spares. In any real project, decimals in Eq. 30 must be rounded off to make  $N_e$  an integer. However, it is unnecessary to use integer values of  $N_e$  for this cost analysis.

From the above, the total extruder cost in thousand dollars for a given coal log pipeline is

$$C_e = N_e C_{e1} = 64 (4.5 V_o + 3) (kD)^{0.73} \quad (\text{Low-cost Extruder}) \quad (31)$$

$$C_e = 173 (4.5 V_o + 3) (kD)^{1.25} \quad (\text{High-cost Extruder}) \quad (32)$$

where  $k$  is the diameter ratio  $D_o/D$ .

### Compaction Machine:

A machine to compact 8-inch-diameter, 18-inch-long binderless coal logs has been designed by Professor Yuyi Lin of the CPRC [11]. The cost of each of this machine is estimated at \$150,000. A total of 50 machines are needed to supply an 8-inch coal log pipeline; they cost a total of \$7.5 millions. Based on this cost figure, it

is assumed that the total cost of compaction machines for any coal log pipeline of diameter  $D$  (feet) is

$$C_{cp} = \frac{1560}{u} D^{0.8} \quad (\text{thousand dollars}) \quad (33)$$

where  $u$  is the coal log fabrication rate in ft/sec.

#### Coating Chamber:

Most coal logs fabricated need to be coated with a sealant for waterproofing. This can be done in a coating chamber that contains a special sealant under high pressure. A 3-chamber machine is needed to serve a given pipeline; the cost is estimated to be \$300,000 for an 8-inch pipeline [11]. Written in equation form, the cost for the coating machine for any coal log pipeline of diameter  $D$  (in feet) is

$$C_{ct} = 415D^{0.8} \quad (\text{thousand dollars}) \quad (34)$$

#### Mixers:

The cost of each mixer that mixes the coal with the binder is determined from

$$C_{m1} = 11 Q_{m1}^{0.404} \quad (35)$$

where  $Q_{m1}$  is the throughput of each mixer in tons of materials mixed per hour.

For each coal log pipeline, we will use two mixers plus a spare--a total of three. Therefore, the throughput of each mixer must be half of the coal log throughput  $Q_c$  of the pipeline, namely,

$$Q_{m1} = 0.5 Q_c \quad (36)$$

Both  $Q_{c1}$  and  $Q_c$  are given in tons per hour.

The total cost for buying three mixers for each inlet station is

$$C_m = 3 C_{m1} = 33 Q_c^{0.404} \quad (\text{thousand dollars}) \quad (37)$$

Obviously, no mixer is needed when the binderless compaction method is used to manufacture coal logs.

#### Binder Heating Tanks:

The cost of each tank used for heating binder is

$$C_{bh1} = 11 Q_{b1}^{0.361} \quad (\text{thousand dollars}) \quad (38)$$

where  $Q_{bl}$  is the binder throughput of each tank in tons/hr; the largest tank commercially available at present has a throughput of  $Q_{bl} = 5$  tons/hr.

The binder throughput (i.e. the binder heating tank capacity) to supply a coal log pipeline is

$$Q_b = \beta Q_c \quad (39)$$

where  $\beta$  is the binder concentration (i.e., the weight of binder in unit weight of coal logs), expected to be not more than 0.05 (5%). Both  $Q_b$  and  $Q_c$  are in tons/hr.

At least two tanks should be used simultaneously, each heating not more than 5 tons/hr. Therefore, when  $Q_b$  is less than 10 tons/hr, use two tanks each with a capacity of  $0.5 Q_b$ . A third one should also be installed as a spare. From Eqs. 38 and 39, the total cost of the three tanks are:

$$C_{bh} = 26 (\beta Q_c)^{0.361} \quad (\text{when } \beta Q_c \leq 10 \text{ tons/hr}) \quad (40)$$

When the throughput  $Q_b$  is greater than 10 tons/hr, more than two tanks will be needed, each capable of heating 5 tons/hr. The number of tanks needed is

$$N_t = \frac{Q_b}{5} + 1 \quad (41)$$

The numeral 1 in Eq. 41 represents a spare tank. Note that for economic analysis purpose,  $N_t$  need not be an integer. From Eqs. 41, 39 and 38, we have:

$$C_{bh} = 20(0.2 \beta Q_c + 1) \quad (\text{when } \beta Q_c > 10 \text{ tons/hr}) \quad (42)$$

Either Eq. 40 or Eq. 42 is used for calculating the total cost of heating tanks. The choice of the equation depends on the value of  $\beta Q_c$ --whether it is greater or less than 10 tons/hr.

#### Substations:

In order to bring electrical power to the inlet station, a transformer station, hereafter referred to as "substation," is required. The total cost for a substation, including both equipment and construction, is calculated from

$$C_{si} = 0.56 P_i^{0.6} \quad (\text{thousand dollars}) \quad (43)$$

where  $P_i$  is the total power in kilowatts (kw) needed for operating the inlet station, to be determined from Eq. 52.

Deaeration Equipment:

Based on results shown in Appendix III-G, the deaeration equipment cost can be determined from

$$C_{de} = 52 + 114 Q_w^{0.585} \quad (44)$$

where  $C_{de}$  is the deaeration equipment cost in thousand dollars; and  $Q_w$  is the water discharge in the pipeline in cfs. Equation 44 is applicable only in the range of  $Q_w$  between 0.1 and 6 cfs, approximately.

Additional Inlet Equipment:

Finally, it is assumed that each inlet station, regardless of the pipe size or the coal throughput, needs 1.5 million dollars of process control equipment (hoppers, screw conveyors, a truck, a fork lift, etc.), \$300,000 of sensors and transducers, and \$200,000 of computer equipment.\* This amounts to a total of two million dollars of additional equipment for the inlet station.

$$\begin{aligned} C_{ai} &= \$2,000,000 \\ &= 2,000 \quad (\text{thousand dollars}) \end{aligned} \quad (45)$$

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\* Automatic computer control equipment for CLP is estimated in Appendix III-D. The \$200,000 listed in Eq. 45 is for inlet equipment only and it does not include transmission facilities which will be included as an O/M cost.

Access Road:

It is assumed that the inlet station and each booster station needs 5 miles of excess roads. Assuming that the cost for a 24-ft-wide gravel road is \$200,000 per mile (this includes right-of-way, construction and so on), the access road cost for each station is one million dollars. Namely,

$$\begin{aligned} C_{ri} &= 1.0 \text{ millions} \\ &= 1,000 \quad (\text{thousand dollars}) \end{aligned} \quad (46)$$

Pigs:

Scenario 10 calls for the use of a "pig" to lead each train. Assume that each train has the length  $L_t = 200 V_o$ , where  $L_t$  is in ft and  $V_o$  in ft/sec. The number of trains moving in a pipeline of length  $L$  (miles) is

$$N_{tr} = 26.4 \frac{L\alpha}{V_o} \quad (47)$$

where  $\alpha$  is the bs rate.

The total number of pigs  $N_p$  needed for repeated use through a pipeline is about three times that exist inside the pipeline at any given time, namely,



$$N_p = 80 \frac{L\alpha}{V_o} \quad (48)$$

Assuming that each pig costs \$300, the capital cost of the pigs used in a CLP is

$$C_{pg} = 24 \frac{L\alpha}{V_o} \quad (\text{thousand dollars}) \quad (49)$$

#### Total Capital Cost for Inlet:

The total construction cost for the inlet, including engineering, construction supervision and so on, is assumed to be 50% of the costs for those equipment and facilities that have not included construction cost before. This includes land, pipe, valves, pumps, conveyors, extruders, coal log fabrication machine, coating machine, coal mixers, and binder heating tanks. Therefore, the total capital cost for the inlet is

$$C_i = C_{ti} + C_{bi} + C_{pi} + C_{si} + C_{ai} + C_{ri} + C_{pg} + 1.5 (C_{Li} + C_{vi} + C_{ui} + C_{ci} + C_e + C_{cp} + C_{ct} + C_{de} + C_m + C_{bh}) \quad (50)$$

Note that not all of the terms in Eq. 50 are needed. For instance, when compaction is chosen to be the method of coal log fabrication (e.g. scenario 1), the extruder cost  $C_e$  would not be

needed and hence it will be set to equal zero. When coating of coal logs is not required in any case (scenarios 4, 18 and 25),  $C_{ct}$  is zero. When deaeration equipment is not used,  $C_{de}$  is zero and so forth.

Four major items have been purposely left out in Eq. 50. They are the facilities to crush coal before logs can be made, the facilities to heat coal to the desired temperature before it is compacted or extruded into logs, the reservoir to store water for use in the pipeline, and the transmission system for remote control of pipeline by computers.

Crushing cost is not normally considered as a part of transportation cost. However, the size of the coal (1/2 inch top size) used for making commercial coal logs is expected to be smaller than the top size of the coal transported by train and other modes (2 inches). Therefore, there is a cost in reducing top size from 2 inches to 1/2 inches. This is treated as an equivalent O/M cost later. Likewise, the facilities to heat coal, to store water in a reservoir, and to communicate between headquarters and remote stations, are not included herein either because they are all treated as O/M costs in the next section.

(b) O/M Costs

The inlet O/M costs include the costs for binder if required, electrical power\*, water, salary/wages (same as labor/administration), communication by phone or satellite, transportation of pigs back to pipeline intake (if pigs are used), and regular maintenance and operation (M/O). In cases where polymers are used for drag reduction, the cost of polymers must also be included. As mentioned before, heating coal before it is extruded or compacted is also treated as an O/M cost.

Binder:

The cost for binder (asphalt) is assumed to be \$150 per ton including transportation to inlet station. Assume that the binder weight concentration is  $\beta$ , the total binder cost per year is

$$C'_b = 1,310 \beta Q_c \quad (\text{thousand dollars}) \quad (51)$$

where  $Q_c$  is the coal log throughput in tons per hour. Note that the prime for the quantity  $C_b$  and for other cost quantities to be discussed later represents annual cost in thousand dollars (1992 value).

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\* Assume that all equipment and heating are by electric power.

### Electricity:

The electrical power needed to operate the inlet,  $P_i$ , includes that for the coal log compaction machine,  $P_{cp}$ , extruders,  $P_e$ , coating chambers,  $P_{ct}$ , mixers,  $P_m$ , pumps,  $P_{ui}$ , valves,  $P_{vi}$ , conveyors,  $P_{ci}$ , binder heating,  $P_{bh}$ , deaeration of water,  $P_{de}$ , building, (lighting, heating and air-conditioning),  $P_{bi}$ , and other equipment,  $P_{oi}$ . The total is

$$P_i = P_{cp} + P_e + P_{ct} + P_m + P_{ui} + P_{vi} + P_{ci} + P_{bh} + P_{de} + P_{bi} + P_{oi} \quad (52)$$

All the power terms in Eq. 52 are in the unit of **kilowatts (kw)**.

Note that not all the terms in Eq. 52 exist for each case. For instance, when extrusion is used to produce coal logs,  $P_{cp}$  is zero, and when binderless compaction is employed,  $P_m$  and  $P_e$  are both zero and so on.

The power for compacting coal logs is a major energy-consuming item of a CLP system. In a recent study [11], it was found that between 3,000 and 3,750 kw may be required to compact the logs for an 8-inch pipeline at 8 ft/sec operational velocity. Using this information, and knowing that the energy for compacting coal logs is proportional to the tons of coal compacted, we have

$$P_{cp} + P_{ct} = 12Q_c \quad (53)$$

where  $Q_c$  is coal throughput of the pipeline in tons per hours; and the power is in kw. Equation 53 is based on the upper limit of 3,750 kw for an 8-inch pipe. It is a conservation estimate that can be used to include not only the compaction energy, but also the energy for coating,  $P_{ct}$ , which is much smaller than  $P_{cp}$ . This explains why  $P_{cp}$  and  $P_{co}$  are evaluated together in Eq. 53.

The power for extrusion,  $P_e$ , is the power required to run the extruders of a given pipeline. It is estimated from

$$P_e = 1,410D^{2.14} \quad (54)$$

where  $P_e$  is in kw; and  $D$  is in feet.

For the power of the mixers, it is assumed that it takes 1 kwh to mix thoroughly 1 ton of coal with binder. If this is the case, the total electrical power for the mixers of a CLP is

$$P_m = 1.0 Q_c \quad (55)$$

where  $P_m$  is in kw; and  $Q_c$  is the coal throughput of the pipeline in tons/hr.

The pump power in kw (kilowatts) for the inlet is calculated from

$$P_{ui} = 0.746 (H_{pm} + 4H_{pa}) \quad (56)$$

where  $H_{pm}$  and  $H_{pa}$  are the horsepower of each main and auxiliary pump, respectively. Note that only one main and four auxiliary pumps are operating at each time. The quantities  $H_{pm}$  and  $H_{pa}$  are determined from fluid mechanics in a manner shown in Appendix IV.

The power to operate the 20 automatic valves at the inlet station, averaged over a long time\*, is assumed to be

$$P_{vi} = 100 D \quad (57)$$

where  $D$  is the pipe diameter in feet; and  $P_{vi}$  is in kw.

The power in kw to operate the conveyor belts at the inlet station is estimated at

$$P_{ci} = 200 D \quad (58)$$

The power in kw for heating the binder is proportional to the binder throughput  $Q_b$ , or  $\beta Q_c$ , as follows:

$$P_{bh} = 87 \beta Q_c \quad (59)$$

where  $Q_c$  is the coal log throughput of the pipeline in tons/hr.

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\*The power of the valves must be averaged over time because these valves are activated (opened or closed) for only less than 10 seconds in every three-minute cycle.

From Appendix III-G, the power for operating the water deaeration equipment at the pipeline inlet is

$$P_{de} = 111Q_w^{0.62} - 20 \quad (60)$$

The power for lighting, heating and air conditioning of the inlet building is assumed to be

$$P_{bi} = 100 \text{ kw} \quad (61)$$

An additional 100 kw is used for other miscellaneous purposes:

$$P_{oi} = 100 \text{ kw} \quad (62)$$

Equations 53 through 62 can be substituted into Eq. 52 for estimating the total power consumed at the inlet,  $P_i$ . Once  $P_i$  is determined, the total electric energy for operating the inlet station for a year is

$$E_i = 8,760 P_i \quad (63)$$

where  $E_i$  is in **kwh**.

Assuming that each **kwh** costs 6¢, the total inlet energy cost for a year is

$$C'_{ei} = 0.526 P_i \quad (\text{thousand dollars}) \quad (64)$$

in which  $P_i$  is determined from Eq. 52.

Note that Eqs. 63 and 64 are based on continuous operation (24-hours-a-day, 365-days-a-year). To determine the actual amount of energy used and the energy cost of a year, they should be multiplied by the system availability factor  $\lambda$ .

#### Water:

The cost for using fresh water is assumed to be 50¢ per 100 ft<sup>3</sup>, which amounts to approximately 50% of the cost of treated (drinking) water charged to large customers in Columbia, Missouri. Using this assumption, the annual cost of water for a coal log pipeline is:

$$C'_w = 158 Q_w \quad (\text{thousand dollars}) \quad (65)$$

where  $Q_w$  is the discharge of water through the pipeline in cfs (cubic feet per second).

If fresh water is not available but brackish water is available for a CLP project, the brackish water can be treated (desalinated) for use to transport coal logs. The cost of such



treatment, as analyzed in Appendix III-F, is approximate \$2.00 per 100 ft<sup>3</sup>. Using this cost figure, the annual cost for using treated brackish water for a CLP is

$$C'_w = 634 Q_w \quad (\text{thousand dollars}) \quad (66)$$

where  $Q_w$  is the water discharge through the pipeline in cfs.

### Salary & Wages:

The cost for salaries and wages (i.e., the administration and labor costs) is assumed to be the same as required for operating the inlet station (slurry preparation station) of a coal slurry pipeline of the same coal throughput. From data published in an OTA study [4], with adjustment for inflation, the annual cost for salaries and wages in 1992 is

$$C'_{si} = 1000 + 0.88 Q_c \quad (67)$$

where  $Q_c$  is the coal throughput in tons per hour.

### Polymer:

The cost of the polymer used for drag reduction for a year is calculated from

$$C'_{pi} = 1.97 \times 10^6 C_{pl} \theta Q_w \quad (\text{thousand dollars}) \quad (68)$$

where  $\theta$  is the weight concentration of the polymer in water;  $Q_w$  is the discharge of water through the pipeline in cfs; and  $C_{pl}$  is the unit cost of polymer in \$/pound.

The unit cost of polymer (polyethylene oxide) is approximately \$5 per pound. With  $C_{pl} = \$5.00$  per pound and  $\theta = 20$  wppm (weight percent per million), Eq. 68 reduces to

$$C'_{pi} = 197 Q_w \quad (\text{thousand dollars}) \quad (69)$$

Note that additional polymer will be needed at booster stations to compensate for the degradation of polymer caused by the flow.

**Figs:**

Scenario 10 requires that a "pig" be used to lead each coal log train. With train length of  $200 V_o$ , the number of pigs that must be transported each year from the pipeline outlet to the pipeline intake is

$$N_{pt} = 157,680 \alpha \quad (70)$$

where  $\alpha$  is the linefill rate.

Assume that each pig has a diameter  $D$  about the same as that of the pipe, the pig length is twice the pig diameter, and the specific gravity of the pig is 1.0. The weight of each pig is approximately

$$W_{pl} = 98 D^3 \quad (71)$$

where  $W_{pl}$  is in pounds; and  $D$  is in feet.

Therefore, the total weight of pigs to be transported in a year is

$$W_p = 7726 \alpha D^3 \quad (\text{tons per year}) \quad (72)$$

Assume that the pigs are transported from the pipeline outlet to the pipeline intake by trucks, and the freight rate by truck is the following:

$$F_{tk} = 0.45 - 0.0003L \quad (1000 \geq L \geq 10) \quad (73)$$

$$= 0.15 \quad (L > 1000) \quad (73a)$$

where  $F_{tk}$  is the truck freight rate in \$/TM; and  $L$  is distance in miles.

From Eqs. 72 and 73, the annual cost for transporting the pigs of a CLP is

$$\begin{aligned} C'_{pg} &= W_p F_{tk} & (74) \\ &= 7.73 \alpha D^3 L (0.45 - 0.0003L) \quad (1000 \text{ miles} \geq L \geq 10 \text{ miles}) \end{aligned}$$

$$C'_{pg} = 1.16 \alpha D^3 \quad (L > 1000 \text{ miles}) \quad (74a)$$

where  $C'_{pg}$  is in thousand dollars per year.

#### Communication Lines:

Telephone lines will be used to link the computer at the headquarters to the field units at the inlet and each booster stations. Rental of these lines is assumed to be 0.5 million dollars each year. Therefore, the annual cost for providing communications linkage is

$$C'_{CL} = 500 \quad (\text{thousand dollars}) \quad (75)$$

#### Coal Heating:

The cost for heating coal to the temperature required for extrusion or compaction is approximately 75¢ per ton. Using this figure, the annual cost for heating coal for a given CLP is

$$C'_{hc} = 6.657 Q_c \quad (\text{thousand dollars}) \quad (76)$$

where  $Q_c$  is coal throughput of the pipeline in tons/hr.

### Coal Crushing:

Information from the Gundlach Machine Company indicates that coal crushing from 2-inch to 1/2-inch top size costs approximately \$0.23 per ton. Therefore, the annual crushing cost is

$$C'_{cr} = 2.02Q_c \quad (\text{thousand dollars}) \quad (77)$$

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

### Others:

Finally, the annual cost for regular maintenance and operation, other than those discussed before, is assumed identical to that of a coal slurry pipeline based on the same coal throughput, namely,

$$C'_{oi} = 381 + 0.784 Q_c \quad (\text{thousand dollars}) \quad (78)$$

where  $Q_c$  is in tons/hr.