ECONOMIC ANALYSIS OF COAL LOG PIPELINE TRANSPORTATION OF COAL

Volume 2: Appendices

by

Henry Liu, Robert Zuniga and James L. Richards

Capsule Pipeline Research Center (CPRC)
University of Missouri-Columbia

January 1993

Note: This volume contains Appendices III through VI of the report under the same title listed above. It contains proprietary information which should be shared only with researchers at the CPRC and the sponsors of the Center's research. It should not be duplicated or released to others without written consent from Dr. Henry Liu, Director, CPRC.

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APPENDIX III: COST DATA

A: Pipeline Construction

B: Valves

C: Extruders

D: Automatic Computer Control

E: Crushers

F: Water

G: Deaeration

H: Slurry Pumps

I: Coal Slurry Pipeline

J: Dewatering

A: Pipeline Construction

1. Cost Formula Used in Previous Report

Pipeline construction costs estimates given in the 1990 report on page 28, used pipeline cost information from the Office of Technology Assessment's 1978 report A Technology Assessment of Coal Slurry Pipeline. Basically, these costs were adjusted to reflect inflation between 1978 and 1990. The equation developed for pipeline costs (1990 values) as a function of pipe diameter is

$$C_{pc} = 118\,D^{1.34} + 93\,D^{0.87} + 22\,D + 18 \qquad \text{(A-1)*}$$

where C_{pc} is pipeline costs ($1000/mile); and D is pipeline nominal diameter (ft). The cost includes steel pipe, construction (excavation, welding and insulation), coating, wrapping, valves and the right of way.

2. Oil and Gas Journal (OGJ) Average Pipeline Construction Cost (1990)

The 1990 Pipeline Economics Report of Oil and Gas Journal, December 1991, Vol. 89, No. 48, contains information on the projected costs for proposed pipeline projects based on annual reports filed with the U.S. Federal Energy Regulatory Commission (FERC).

Average construction costs for gas pipeline construction in the U.S. as a function of nominal pipe diameter for the range of 6" to 42" are given in Fig. 4 on page 48 of the Journal. These costs are determined from proposed pipeline construction projects and are listed in Table 2, pp. 46-47 (OGJ).

Current cost components include material, labor, miscellaneous, and right of way. Miscellaneous costs include surveying, engineering, supervision, contingencies, allowances for funds used during construction (Afudc), administration and overheads, and FERC filing fees (p.54 OGJ). Right of way includes the cost of obtaining the right-of-way and cost of any allowances for damages (p.54 OGJ).

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*Same as Equation 96 of the previous report [2].

The OGJ 1990 average construction costs (1990 dollars) is reproduced in Figure A.1 and listed as the "Actual" curve. In this report two estimates are done using the data provided by this "Actual" curve. The first estimate, designated as "Small" in the figure, uses a subset (8 to 20 inches nominal diameter). The second estimate, designated as "Large", uses the full range (6 to 42 inches nominal diameter pipe diameter). Both estimates were obtained from a linear regression of the points and both are plotted in Figure A.1.

The estimate** for the subset of nominal pipe diameter 8 to 20 inches, designated as "Small", in 1992 dollars is

$$C_{pc1} = 153\,D + 154 \qquad \text{(A-2)}$$

where C_{pc1} is pipeline costs ($1000/mile); and D is pipeline nominal diameter (feet).

The estimate for the full range of nominal pipe diameter 6 to 42 inches, designated as "Large", in 1992 dollars, is

$$C_{pc2} = 298\,D - 32.9 \qquad \text{(A-3)}$$

where C_{pc2} is pipeline costs ($1000/mile); and D is pipeline nominal diameter (feet). For comparison purposes, Eq. A3-1 is also plotted in Figure A3.1 and is listed as "Liu and Wu".

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*All equations are represented in 1992 dollars, based on United States Financial Data issued by the Federal Reserve Bank of St. Louis in January, 1992.

3. OGJ Pipeline Construction Cost (1984-1991)

Since the average pipeline costs given in each yearly report includes pipeline construction in all regions of the United States and for a variety of pipeline lengths, another cost estimate criteria was used to constrain the yearly data to match the construction environment that the coal log pipeline would be built. The criteria included two general constraints, physical and geographical. The physical constraints are as follows: pipeline diameter range 8" - 20" and pipeline length greater than 50 miles. The geographic constraints include the following Midwestern states: Arizona, Colorado, Illinois (Northern, excluding Chicago), Iowa, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Oklahoma, Texas, Utah, and Wyoming. Oil and Gas Journal (OGJ) Pipeline Economic Reports from 1984 to 1991 were then used to provide an estimate of pipeline construction costs ($1000/mile) as a function of nominal pipe diameter (inches) for long pipelines in the Midwestern plain region. The result yields more meaningful cost figures for long pipelines in this region than using the full data set offered by the OGJ.

The cost data obtained by applying the above criteria were converted to 1990 dollars by the use of two different indices: the **Consumer Price Index (CPI)** and the **Chemical Engineering Plant Cost Index (CEPCI)**.

Consumer Price Index (CPI)

An inflation index obtained from Stocks, Bonds, Bills, and Inflation 1991 Yearbook by Ibbotson and Sinquefield was used to represent all cost data in 1991 dollars. U.S. Financial Data provided the index needed to translate to 1992 dollars. A linear regression analysis of the resulting data yielded the following estimation in 1992 dollars:

$$C_{pc3} = 220.9D - 26.6 \qquad \text{(A-4)}$$

where C_{pc3} is pipeline costs ($1000/mile); and D is pipeline nominal diameter (feet). Equation A-4 is plotted in Fig. A.2.

Chemical Engineering Plant Cost Index (CEPCI)

A plant cost index obtained from 1984 and 1990 Chemical Engineering was used to convert all cost data in 1990 dollars. This particular cost index was chosen since the pipeline cost data contained labor as a cost component. The U.S. Financial Data was used again to translate to 1992 data. A linear regression analysis of the resulting data yielded the following estimation in 1992 dollars

$$C_{pc4} = 215.6\,D - 35.95 \qquad \text{(A-5)}$$

where C_{pc4} is pipeline costs (\$1000/mile); and D is pipeline diameter (feet). Equation A-5 is also plotted in Figure A.2.

4. Conclusion

To provide a comparison of the indexed pipeline construction cost estimations, Eqs. A-1 (Liu and Wu), A-4 (CPI), and A-5 (CEPCI) are plotted in Figure A.4. The indexed values of the pipeline construction cost estimates are relatively parallel over the nominal pipe diameter of 8 to 20 inches. Both indexed equations (CPI and CEPCI) are below the previous pipeline construction cost estimated. The effect of constraining the pipeline construction cost data available to meet the criteria of Midwestern plain regions and pipelines greater than 50 miles better approximates the conditions where the coal log pipeline will be constructed. However, to be conservative in cost estimate, Eq. A-1 [2] will be used in this report. When converted to 1992 dollars, Eq. A-1 becomes

$$C_{pc5} = 129\,D^{1.34} + 102\,D^{0.87} + 24\,D + 20 \qquad \text{(A-6)}$$

where C_{pc5} is pipeline costs (\$1000/mile); and D is pipeline diameter (feet).

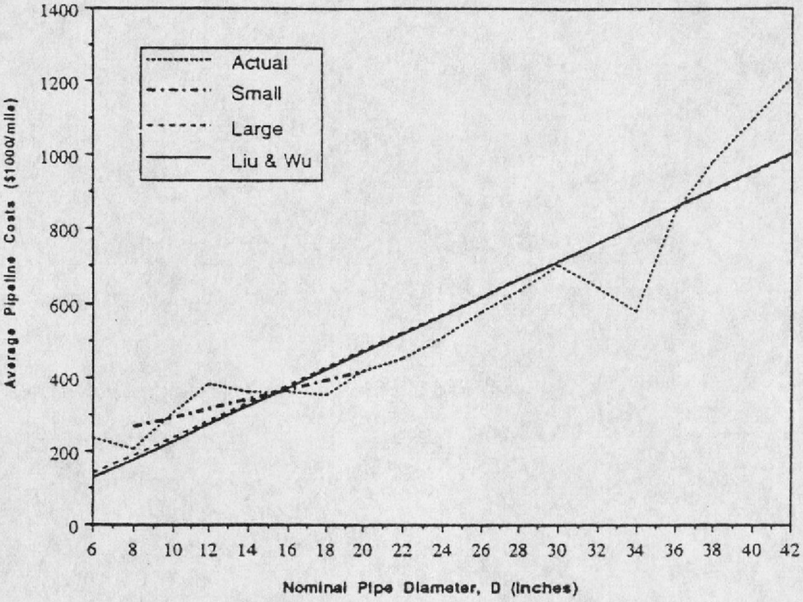

Fig. A.1. OGJ 1990 Average Construction Costs (1990 dollars).

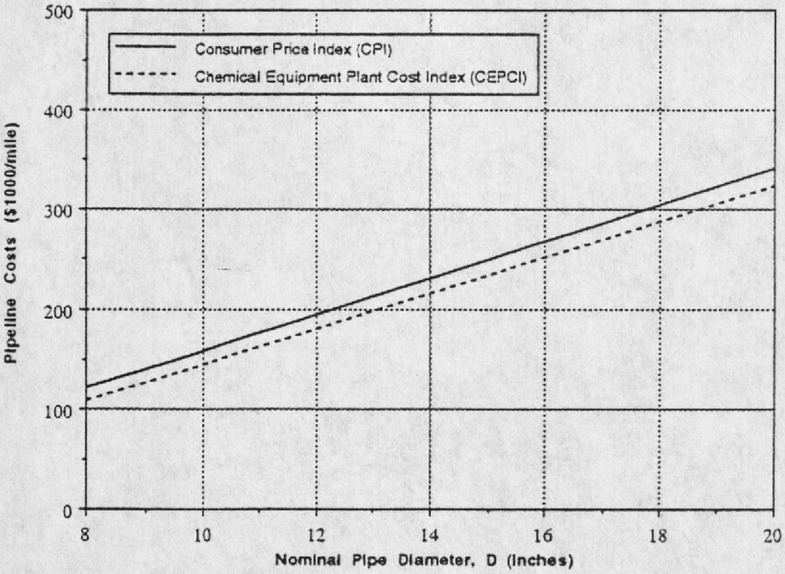

Fig. A.2. OGJ Average Pipeline Construction Costs (1990 dollars) for years 1984 - 1990.

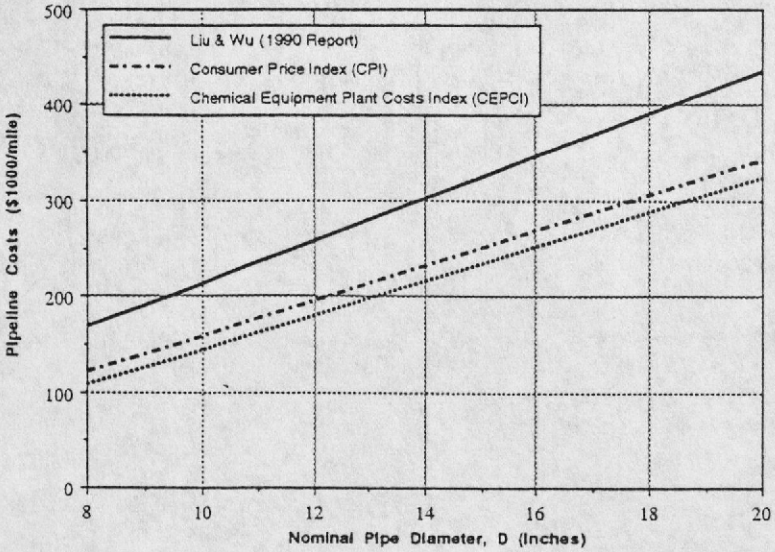

Fig. A.3. OGJ Pipeline Construction Costs (1990 dollars): Comparison of Indexed Values Based on 1984-1990 Data.

B: Valves

Listed below are preliminary budget prices for full bore flanged end connected slurry valves obtained from Mogas.

Table B-1. Cost of Each Valve

Pipe Diameter (in)	Rating 300# ($)	600# ($)	900# ($)
4	14,000	16,000	18,000
14	48,000	56,000	68,000
24	125,000	132,000	138,000

Note: 300#, 600#, and 900# represent maximum rating of 740, 1480, and 2220 psig, respectively. An additional 10% over the values given is assumed to cover actuator cost.

The cost for each valve was estimated by applying a power function to this data and adding 10 % to cover actuator costs. This resulted in the following cost relationship:

$$C = K\,D^{1.15} \tag{B-1}$$

where C is in thousand of dollars; and K is 55, 60, 63, and 66 approximately, respectively for 500, 100, 1500, and 2000 psig.

Figure B.1 shows the valve cost in Table B-1 including the cost of actuators for various pressure ranges.

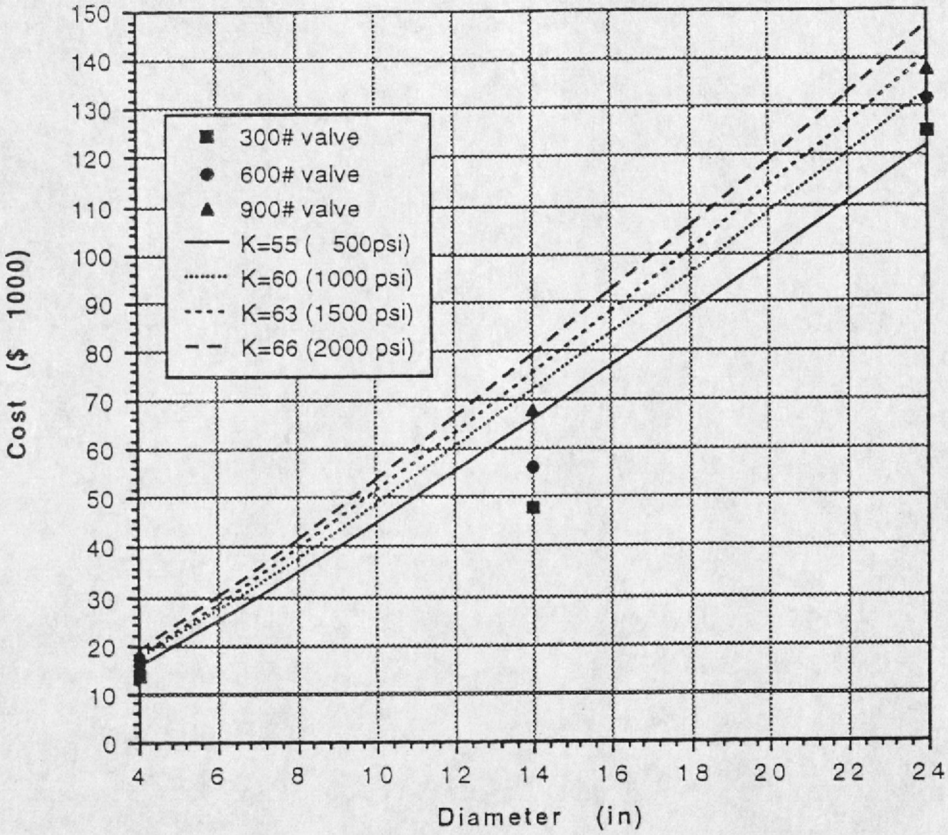

Fig. B.1. Cost of Each Valve with Actuator

(Note: The four lines are computed from Eq. B-1 using values of K listed in this figure)

C: Extruders

Extruder cost in 1990 dollars was estimated as follows in the previous report [2]:

Single Extruder: $C_{e1} = 8410\, D_c^{0.73}$ (C-1)*

Number of Extruders: $N_e = 1.8 V_L + 3$ (C-2)*

When multiplied together, the above equations represent the previous estimate of total extruder costs

$$C_e = N_e\, C_{e1} \qquad \text{(C-3)*}$$

$$C_e = 8410(1.8V_L + 3)(kD)^{0.73} \qquad \text{(1990 dollars)} \qquad \text{(C-4)}$$

$$C_e = 9198\,(1.8V_L + 3)(kD)^{0.73} \qquad \text{(1992 dollars)} \qquad \text{(C-5)}$$

where C_e is total extruder cost ($); C_{e1} is the cost of each extruder ($); N_e is the number of extruders required; V_L is the lift-off velocity (fps); k is the coal log diameter to nominal pipe diameter ratio; and D is the nominal pipe size (ft).

New (1992) cost data on extruders have been obtained from two vendors: Bonnot Company and Eirich Machines LTD. Table C-1 and C-2 on the next page summarize relevant information.

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*Same as Equations 25 , 26, and 27 respectively of the previous report (Liu and Wu, 1990).

The total extruder cost for each pipeline is dependent upon the number of extruders needed to supply the throughput of this pipeline. Extruder production rates, unit cost, number of extruders required and total cost for each vender are graphed in Figures C.1, C.2, C.3, and C.4 respectively. The large cost differences between the two vendors result from different reported extrusion rates and extruder unit costs. Linear regression analysis results in the following relationships:

<u>Production Rates (ton/hr)</u>

Bonnot $R_e = 32.404\ D - 4.55$ (C-6)

Eirich $R_e = 11.543\ D - 0.042$ (C-7)

<u>Unit Cost (1992 dollars)</u>

Bonnot $C_{e1} = 56{,}936\ D + 3{,}825$ (C-8)

Eirich $C_{e1} = 196{,}512\ D - 7{,}448$ (C-9)

<u>Total Cost (1992 dollars)</u>

Bonnot $C_e = 1{,}681{,}278\ D - 147{,}365$ (C-10)

Eirich $C_e = 28{,}937{,}480\ D - 7{,}552{,}700$ (C-11)

Cost estimates from the previous report, Bonnot, and Eirich are summarized graphically in Figure C.4 (Eqs. C-5, C-10, and C-11 respectively).

Conclusion

The foregoing analysis shows that great discrepancies (more than a factor of ten) exist in the costs of extruders from different manufacturers. Due to this discrepancy, and due to many uncertainties that exist today in using extruders to manufacture coal logs, two hypothetical types of extruders will be used in this analysis, a low-cost type and a high-cost type. The equations for the cost of each unit are:

Low-Cost Type: $C_e = 64{,}000\ D_c^{0.73}$ (C-12)

High-Cost Type: $C_e = 173{,}000\ D_c^{0.73}$ (C-13)

where C_e is in dollars; and D_c is the diameter of coal log in feet.

Approximately, Eq. C-12 describes the Bonnot extruder, and Eq. C-13 describes the Eirich extruder. As indicated in scenario 20, the extrusion rate or speed assumed is 0.2 feet per second (fps) which is far more conservative than the 0.5 fps rate assumed in the 1990 economic report. A comparison of the unit cost from Bonnot and Eirich along with the cost equations above (Eqs. C-12 and C-13) are presented in Figure C.5.

Table C-1. Cost of Extruders Supplied by Bonnot Company, 1992.

Diameter (ft)	Production Rate (ton/hr)	Extruder Unit Costs ($1000)	Number of Extruders	Total Cost ($1000)	Total Coal Log Production (ton/hr)
0.33	2.6	24.3	12	292	31
1.0	22.7	68.7	20	1374	454
1.5	48.3	83.6	30	2508	1450

Table C-2. Cost of Extruders Supplied by Eirich Machines, 1992.

Diameter (ft)	Production Rate (ton/hr)	Unit Costs ($1000)	Number of Extruders	Total Cost ($1000)	Total Coal Log Production (ton/hr)
0.33	2.75	42	11	462	33
1.167	15.43	236	48	11328	740
2.0	22.05	380	156	59280	3440

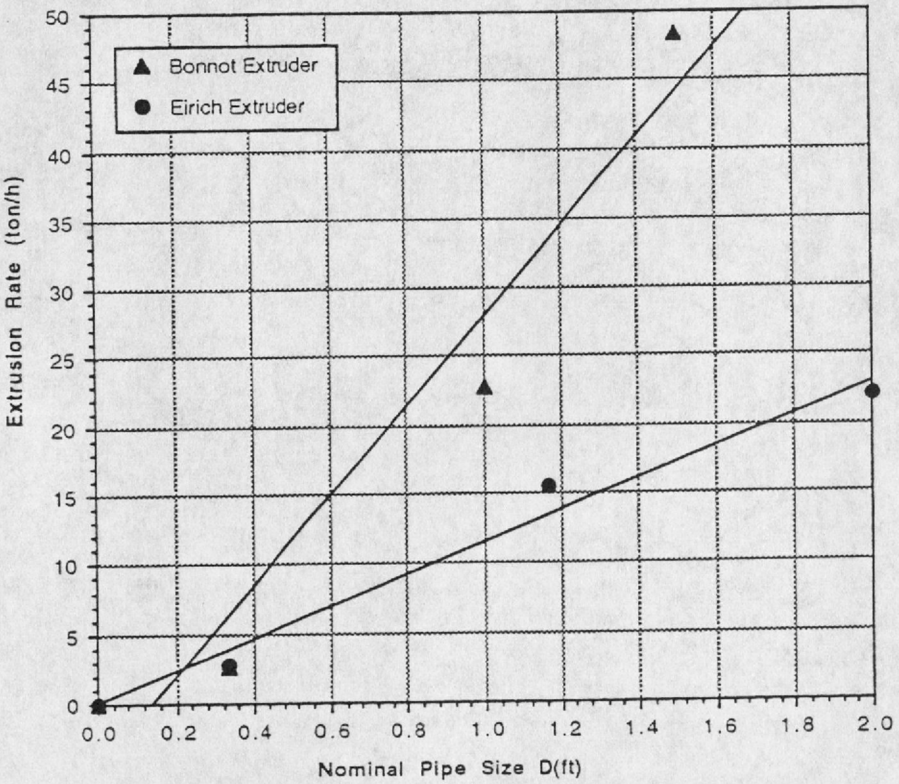

Fig. C.1. Extruder Production Rate.

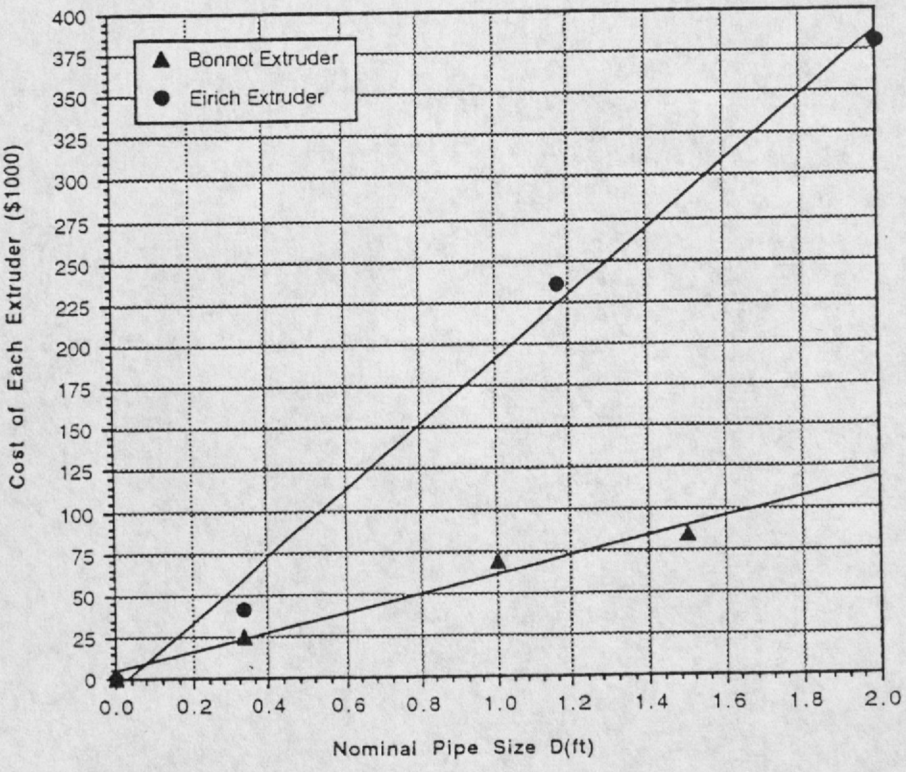

Fig. C.2. Cost of Each Extruder

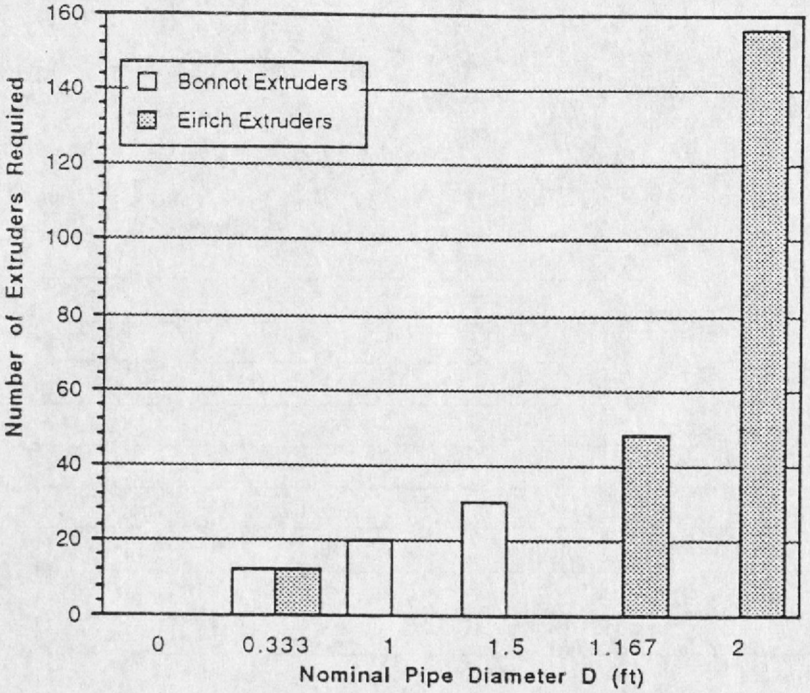

Fig. C.3. Number of Extruders Required

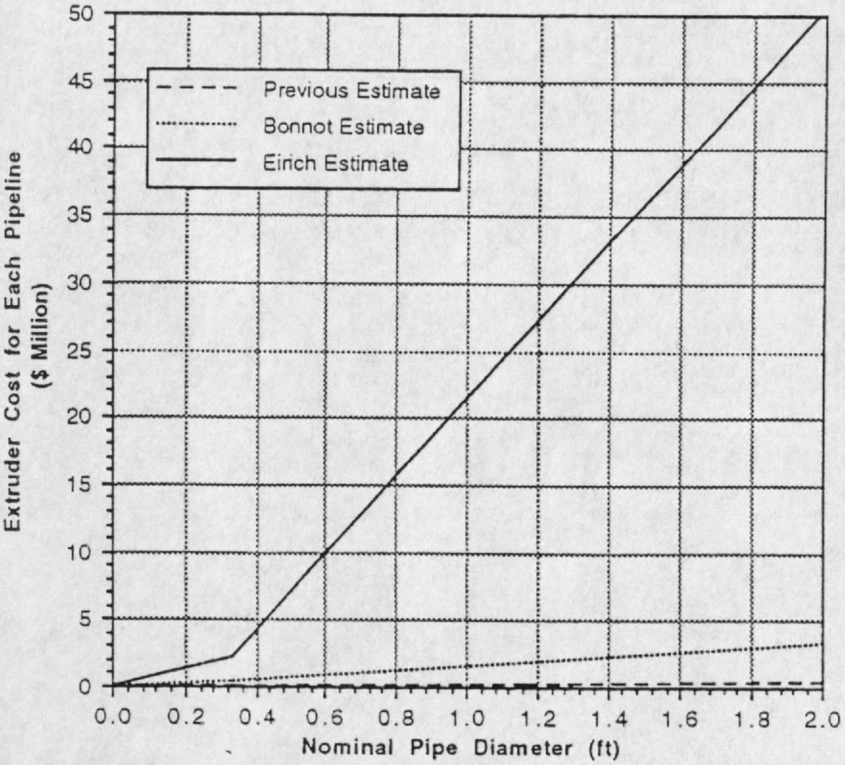

Fig. C.4. Extruder Cost for Each Pipeline

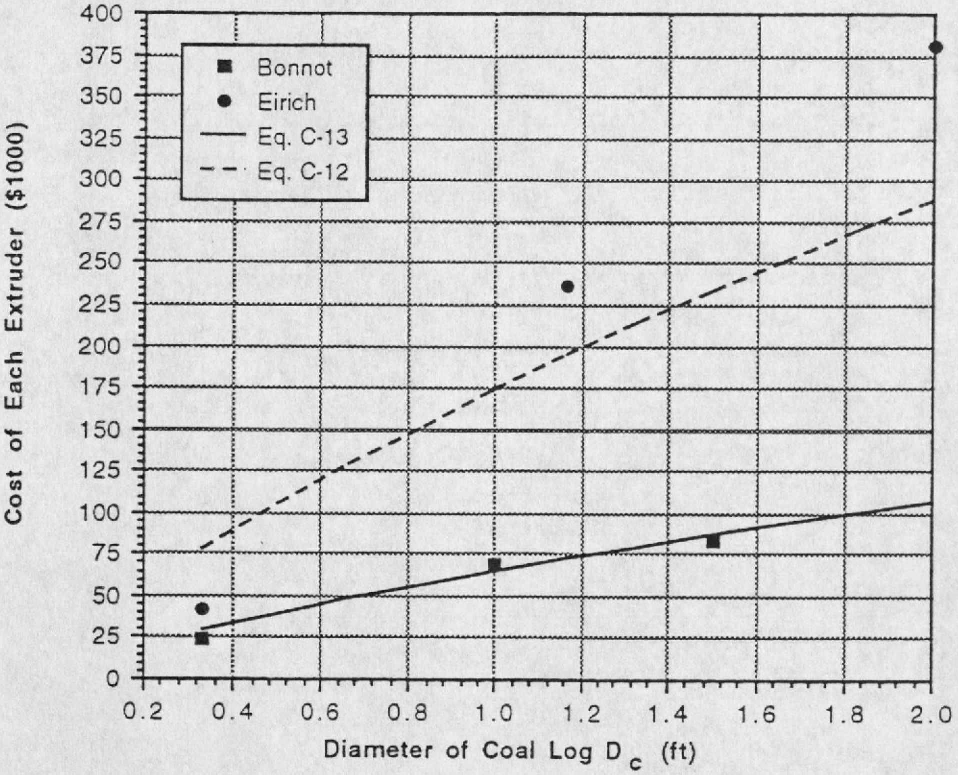

Fig. C.5. Comparison of Eqs. C-12 and C-13 with Cost Data Supplied by Two Manufacturers

D: Automatic Computer Control

Table D-1 summarizes the data on computer control supplied by Nova Tech, Inc. Based on this information, the following equations are used for computerized equipment for automatic control:

<u>Inlet</u>

2 basic systems

$$C_{ai} = 6500 + 2500 = 9000 \tag{D-1}$$

<u>Booster Station</u>

$$C_{ab} = 6200N_b \tag{D-2}$$

<u>Outlet Station</u>

$$C_{ao} = 5600 \tag{D-3}$$

<u>Overall System PC SCADA, Configuration and Computer</u>

$$C_{ac} = 26{,}000 \tag{D-4}$$

The total cost estimate for computerized control is:

$$C_a = C_{ai} + C_{ab} + C_{ao} + C_{ac} \tag{D-5}$$

$$= 40,600 + 6200N_b \tag{D-6}$$

where C_a is total cost; C_{ai} is inlet station control equipment cost; C_{ao} is outlet station control equipment cost; C_{ab} is individual booster station control equipment cost; and N_b is the number of booster stations needed.

Table D-1. Cost of Computer Equipment for Automatic Control Supplied by Nova Tech, Inc.

Inlet Station: $ 6500

2 pumps
Basic system:

- 2 conveyor belts
- 4 sensors (accumulators)
- 8 valves

(Two additional systems could be added using more cards at $ 2500 each.)

Booster Station: $ 6200

5 sensors (accumulators)
1 divertor
8 valves
1 pump

Outlet Station: $ 5600

1 sensor
1 conveyor belt
(Four more systems could be added at no cost)

PC SCADA system, Engineering & Configuration: $ 26,000

The above estimates are only for computer equipment and do not include transmission cost (installation and operating) for automatic computer control nor process control equipment related to mechanical control.

E: Crushers

Crushers are needed to crush coal logs exiting from a CLP. The costs and power requirements for three different throughputs of CLP are provided by the T.J. Gundlach Machine Company in Table E-1.

Table E-1. Costs and Power Requirements of Crushers for Crushing Coal Logs (Supplied by T.J. Gundlach Machine Company, Belleville, Illinois).

Coal Log Througput (tons/hr)	Approximate Pipe Diameter (inches)	Crusher Type	Number of Crushers Needed	Unit Price ($)	Total Price ($)	Power Required	
						(h.p.)	(kw)
30.6	4	3020D 4 Roll 2 Stage	1	95,000	95,000	25	18.7
735	14	4040D 4 Roll 2 Stage	1	204,000	204,000	200	149
3440	24	5080D 4 Roll 2 Stage	2	467,000	934,000	800	597

Based on the above data, the cost of crushers, C_{cr}, and the power required, P_{cr}, can be found respectively from:

$$C_{cr} = 93.3 + 0.0188Q_c^{1.315} \qquad \text{(E-1)}$$

and

$$P_{cr} = 11.6 + 0.29Q_c^{0.934} \qquad \text{(E-2)}$$

where C_{cr} is in thousand dollars; and P_{cr} is in kw. Note that Eqs. E-1 and E-2 should be used only in the range of Q_c between 30 and 3,440 tons/hr.

From the data in Table E-1, only one crusher is needed to crush the coal logs of any CLP with coal throughput from 30 to 735 tons/hr and only two are needed for pipelines with throughput from 736 to 3,440 tons/hr. However, an extra crusher is needed in each case to be used as a spare. This means two crushers of identical size must be provided for each pipeline with coal throughput from 30 to 735 tons/hr, and three identical crushers must be provided for any pipeline with throughput between 736 and 3,440 tons/hr. Therefore, in determining the cost of the crushers needed for a given pipeline, including a spare crusher, one must double the cost given by Eq. E-1 for throughput in the range of 30 to 735 tons/hr, and multiply the value found from Eq. E-1 by 3/2 or 1.5 for throughput between 736 and 3,440 tons/hr. The value of power remains unchanged from that determined from Eq. E-2.

The crushers in the foregoing analysis are able to crush coal logs up to 24 inches in diameter to particles less than 2 inches.

F: Water

1. Introduction

The cost estimate for water listed on page 19 in the 1990 report [Liu and Wu, 1990] is \$0.40/100 ft^3. As reported, this represents about one-half the cost of treated drinking water charged to large customers in Columbia, Missouri, 1989. This resulted in an annual water cost for the coal pipeline of

$$C_w' = 126\ Q_w \qquad \text{(F-1)}^*$$

where C_w' is the annual cost (\$1000) in 1990 dollars and Q_w is the discharge (volumetric flow rate) in cubic feet per second(cfs).

However, the availability of brackish water in dry, arid regions may provide the medium needed for coal log transport in pipelines without competing with regional water demands. Usually, brackish water is unsuitable for coal log transport unless the solids (salts) are removed. This calls for an evaluation of the technical and economic feasibility of desalination techniques for meeting the water requirements of a coal log pipeline.

2. Reverse Osmosis

Desalination techniques and their effectiveness in providing product water containing low levels of total dissolved solids (TDS) are dependent upon the initial TDS content of the raw water. The raw water is generally characterized by TDS content as **fresh water** (TDS<500ppm), **brackish water** (500ppm<TDS<35,000ppm), and **saltwater** or **saline water** (TDS>35,000ppm).

At present, reverse osmosis is the most cost effective method to desalt water in large quantities. Simply stated, reverse osmosis is the process where a semipermeable membrane separates TDS from two solutions. Raw water, under pressure, passes across the membrane where a transfer of salts is impeded by the membrane, yielding a product water containing less TDS.

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*Same as equation 21 of the previous report

Membranes are an integral part of the reverse osmosis process. Membrane types currently used in industrial applications are hollow fiber (parallel bundled tubular membranes) and spiral wound (rolled long porous membrane sheets). Fluxes and salt rejection rates have increased over the last decade with the enhancement of membrane materials and design. Given a specific plant design, the raw water is usually pre-treated to meet membrane design criteria (pH, temperature, and pressure).

3. Reverse Osmosis Costs

TDS in brackish water range widely both regionally and locally. In order to approximate desalination costs, data was taken from [2,8,10,11,12]** where desalination costs was given for various reverse osmosis plants in operation within the continental United States. While costs vary between individual plants based on the local brackish water TDS, process rejection rates, and product water quality, general costs trends over the last two decades can be determined.

Costs of desalinating brackish water in million gallons per day (MGD) plant sizes was obtained from the sources listed above and converted to 1991 dollars by two indices [1,12]. Data for three plant sizes, 1 MGD, 5 MGD and 10 MGD are plotted as a function of year in Figures F.1, F.2, F.3 respectively.

Figures F.1, F.2 and F.3 indicate the cost reductions over the last two decades of desalinating brackish water due to the advancement in membrane technology and process design. A comprehensive report issued by the Office of Technology [12] in 1988 determined desalination costs for brackish water to have decrease from $5 per 1,000 gallons in 1963 to about $1.50 to $2.50 per 1,000 gallons (1985 dollars). The report also indicates that low pressure reverse osmosis membranes can further reduce desalination costs by $0.50 per 1000 gallons (1985 dollars). This translates into $2.01 to $3.35 per 1,000 gallons with further costs reductions at low pressure of $0.67 per 1,000 gallons (1991 dollars)[1,5].

**Numerals in [ ] correspond to reference numbers listed at the end of this Appendix.

4. CONCLUSION

The previous water costs estimate was based on one-half the cost of treated drinking water charged to large customers in Columbia, Missouri. Reflected in 1991 dollars and rounded to the nearest $1,000, annual water cost were estimated to be

$$C_w' = 138\ Q_w \qquad \text{(F-2)}$$

where C_w' is annual cost in 1991 dollars and Q_w is discharge in cubic feet per second (cfs).

Costs for brackish water desalination by reverse osmosis in 1991 dollars are $2.01 to $3.35 per 1,000 gallons ($1.50/100 ft^3 - $2.51/100 ft^3). Using the average value of $2.01 per 100 ft^3, the following equation can be used to estimate the annual water cost for desalted water:

$$C_w' = 634\ Q_w \qquad \text{(F-3)}$$

where C_w' is annual cost ($1000) in 1992 dollars; and Q_w is water discharge in cubic feet per second.

References for F: Water

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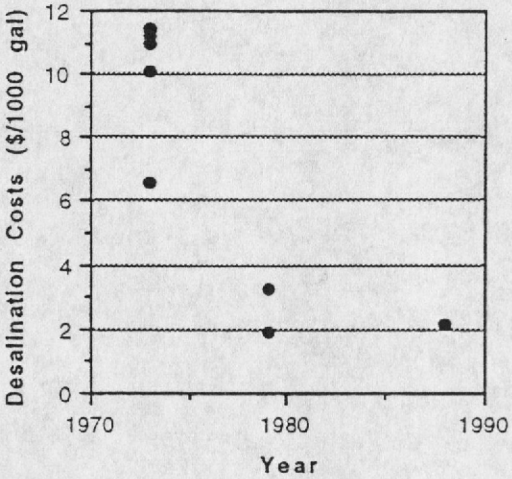

Fig. F.1. One Million Gallons per Day Plant Size Desalination Costs (1992 dollars)

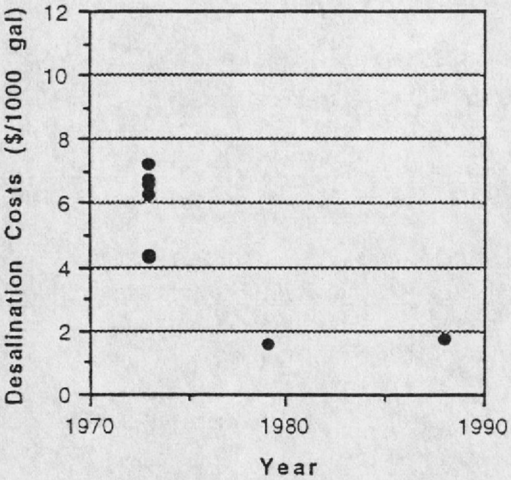

Fig. F.2. Five Million Gallons per Day Plant Size Desalination Costs (1992 dollars)

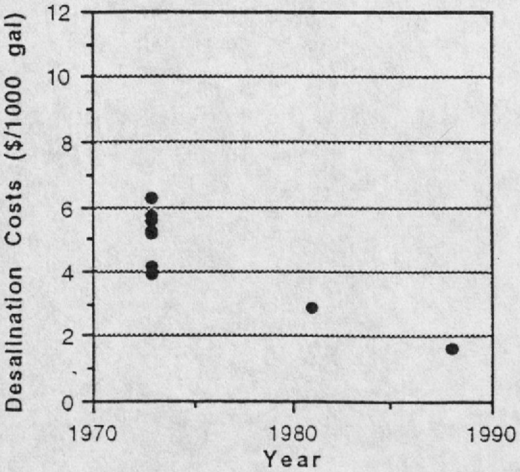

Fig. F.3. Ten Million Gallons per Day Plant Size Desalination Costs (1992 dollars)

G: Deaeration

The Graver Company in Union, New Jersey provided the following 1992 cost figures and power requirements on vacuum deaeration systems for reducing dissolved oxygen and carbon dioxide in water under room temperature:

Flow Rate (gpm)	Flow Rate (cfs)	Estimated cost ($1000)	Power Required* (kw)
54	0.120	85	9.95
911	2.03	225	153
2648	5.90	375	315

Based on the foregoing data, the following approximate equations are found:

$$C_{de} = 52 + 114Q_w^{0.585} \quad \text{(G-1)}$$

and

$$P_{de} = 111Q_w^{0.62} - 20 \quad \text{(G-2)}$$

where Q_w is the water throughput in cfs; C_{de} is deaeration equipment cost in thousand dollars; and P_{de} is the power consumed in kw.

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* Power required was converted from BHP (brake horsepower) of vacuum pumps by assuming 90% motor efficiency.

H: Slurry Pumps

The previous estimate of pump costs given on page 13 of the 1990 report (Liu and Wu) is

$$C_{u1} = 850\ (H_p)^{0.6} \qquad \text{(H-1)*}$$

where C_{u1} is pump costs in 1990 dollars, and H_p is the horsepower of the pump. The estimate was based on centrifugal water pump costs. In places where water pumps are used, as at pipeline intakes, Eq. H-1 is converted to 1992 dollars:

$$C_{u1} = 930\ (H_p)^{0.6} \qquad \text{(H-2)}$$

In the present revised study, it is assumed that the presence of coal particles in the water will require the use of slurry pumps. Cost estimates are based on data for a selected number of slurry pumps obtained from Barrett, Haentjens & Co. located in Hazleton, Pennsylvania. Pump components and costs (1992 dollars) are summarized in Table H-1 for three flowrates. A graph of pump costs as a function of horsepower is shown in Fig. H.1. A regression analysis of the curve in Fig. H.1 provides the following equation for cost estimate:

$$C_{us1} = 1122\ (H_p)^{0.805} \qquad \text{(H-3)}$$

where C_{us1} is slurry pump costs in 1992 dollars; and H_p is the horsepower of the pump.

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[*] Same as Eq. 21 of the previous report (Liu and Wu, 1990).

Table H-1 Cost Data ($1992) on Slurry Pumps Supplied by Barrett, Haentjens & Co.

<u>1850 GPM System:</u> $ 414,920

7 pumps 300 feet total developed head each
1 variable pump for 150 to 300 total developed head
8 250 horsepower 1800 rpm motors,
8 V-belt drives, 1770 rpm to 1550 rpm
1 variable frequency power supply
  460 volt, 3-phase, 0-60 Hz output for 250 hp motor
8 bases total, one for each set of pump, gear drive, and motor
2 extra sets of couplings

<u>5550 GPM System:</u> $ 900,781

5 pumps 390 feet total developed head each
1 variable pump at 350 to 450 feet total developed head
6 880 horsepower, 1800 rpm motors
6 parallel shaft gear reducers
  Input: 1770 rpm; Output: 1380 rpm
1 gear reducer, rated for 800 horsepower continuous operation
6 bases total, one for each set of pump, gear drive, and motor
2 extra sets of couplings

<u>6250 GPM System</u> $ 1,134,548

5 pumps 400 feet total developed head each
1 variable pump at 300 to 355 feet total developed head
6 900 horsepower 1800 rpm motors
1 1000 horsepower ac motor
6 parallel shaft speed reducers
  Input: 1770 rpm; Output: 1325 rpm
1 fluid coupling, 1770 rpm input speed, 100 hp continuos duty
6 bases total, one for each set of pump, gear drive, and motor
2 extra sets of couplings

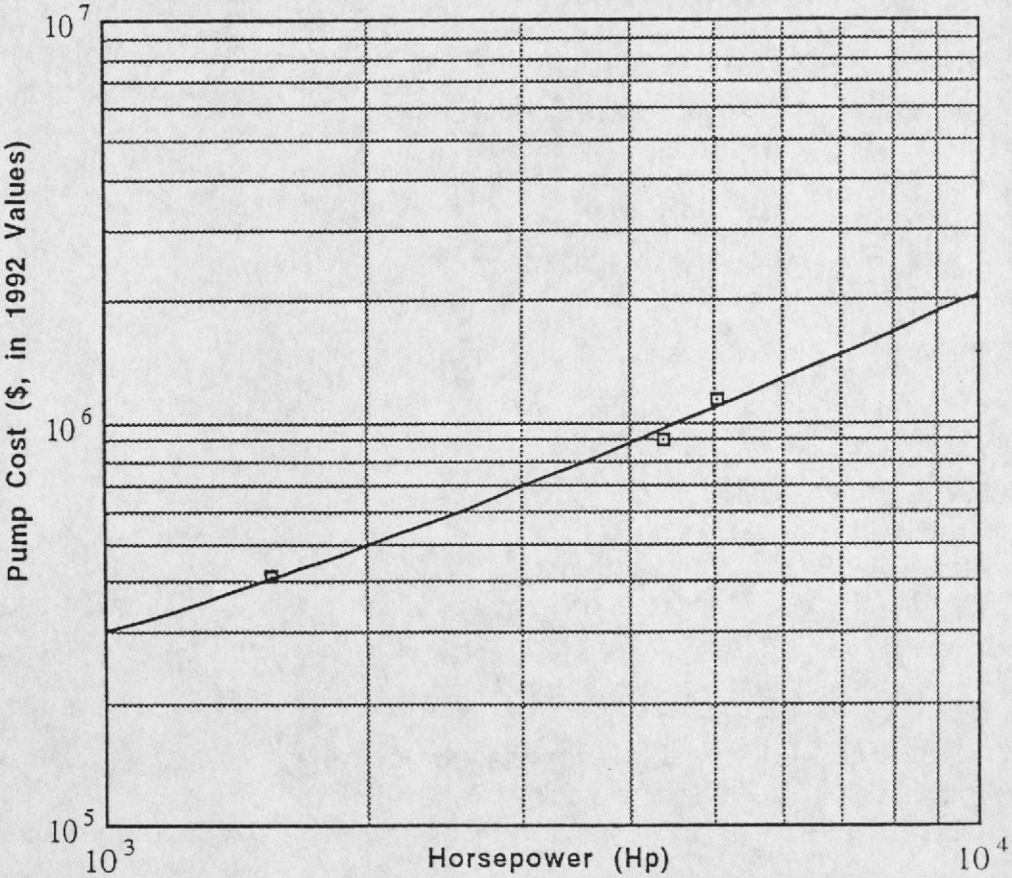

Fig. H.1 Slurry Pump Costs as a Function of Horsepower.

I: Coal Slurry Pipeline

Introduction

The detailed costs of a slurry pipeline were originally estimated in the Office of Technology Assessment's (OTA) March 1978 report entitled "A Technology Assessment of Coal Slurry Pipelines" [4]. The costs were presented graphically in figures 10 through 14 of that report. To bring that report up to date, all costs must be updated to 1992 values.

An index for general inflation [17] was used to update all the costs (except for the power costs) given in the OTA report to 1992 dollars. Those costs were increased by 2.603 times for the period of mid-1975 to 1992. This increase is reflected in all the following equations except for those that are directly related to electrical power. The amount of power needed by a coal slurry system is assumed to be the same as in the OTA report. However, the price for a kilowatt-hour (kwh) of electricity has been increased from 2.6¢ in the OTA report to 6¢ for this investigation. This increase, 2.308 times, is reflected in the updated equations (I-2, I-8, and I-13) for power.

The equations for each component of a slurry pipeline system (both the capital cost and the annual operational/maintenance cost) are presented in the ensuing sections. They are the best-fit regressions of the original OTA data after adjustment to 1992 values. Note that all costs are in thousand dollars ($1000), and the pipeline coal throughput, Q_c, is in million tons per year. The results of these equations are also shown graphically in Figs. I.1 through I.5.

Slurry Preparation Facility

The total capital cost for the slurry preparation facility, C_{spf}, is calculated from Eq. I-1 and is shown in Fig. I.1. The annual operation and maintenance costs for power, C_{pp}, labor, C_{pl}, materials and supplies, C_{pm}, and general administration, C_{pa}, of the preparation facility are calculated from Eqs. I-2 through I-5 and are shown in Fig. I.3.

$$C_{spf} = 7294\,Q_c^{\,0.823} \tag{I-1}$$

$$C_{pp} = 864\,Q_c^{\,0.808} \tag{I-2}$$

$$C_{pl} = 175\,Q_c + 1186 \tag{I-3}$$

$$C_{pm} = 282\,Q_c^{\,0.888} \tag{I-4}$$

$$C_{pa} = 38\,Q_c + 782 \tag{I-5}$$

Coal Dewatering Facility

The total capital cost for the slurry dewatering facility, C_{sdf}, is calculated from Eq. I-6 and is shown in Fig. I.1. The annual operation and maintenance costs for flocculants, C_{df}, power, C_{dp}, labor, C_{dl}, materials and supplies, C_{dm}, and general administration, C_{da}, of the dewatering facility are calculated from Eqs. I-7 through I-11 and are shown in Fig. I.4.

$$C_{sdf} = 11808\,Q_c^{\,0.886} \tag{I-6}$$

$$C_{df} = 589\,Q_c \tag{I-7}$$

$$C_{dp} = 923\,Q_c^{\,0.837} \tag{I-8}$$

$$C_{dm} = 452\,Q_c^{\,0.963} \tag{I-9}$$

$$C_{dl} = 218\,Q_c + 1024 \tag{I-10}$$

$$C_{da} = 52\,Q_c + 756 \tag{I-11}$$

Pumping Station Facility

The total capital cost for each pumping station, C_{sps}, is calculated from Eq. I-12 and is shown in Fig. I.1. The annual operation and maintenance costs for power, C_{psp}, labor, C_{psl}, materials and supplies, C_{psm}, and general administration, C_{psa}, for each pumping station are calculated from Eqs. I-13 through I-16 and are shown in Fig. I.5.

$$C_{sps} = 1210 Q_c^{0.827} \tag{I-12}$$

$$C_{psp} = 254 Q_c^{1.010} \tag{I-13}$$

$$C_{psm} = 92 Q_c^{0.695} \tag{I-14}$$

$$C_{psl} = 2 Q_c + 145 \tag{I-15}$$

$$C_{psa} = Q_c + 73 \tag{I-16}$$

Cost of Pipeline

The capital cost for the pipeline material is broken into three parts: the pipeline steel, C_{ps}; excavation, welding, installation, and backfill, C_{ex}; and coating, wrapping, valves, and right-of-way, C_{cw}. They are calculated from Eqs. I-17 through I-19, and are represented in Fig. I.2.

$$C_{ps} = 0.309 Q_c^2 + 18.68 Q_c + 110.2 \tag{I-17}$$

$$C_{ex} = -0.091 Q_c^2 + 13.84 Q_c + 106.2 \tag{I-18}$$

$$C_{cw} = -0.012 Q_c^2 + 3.39 Q_c + 52.6 \tag{I-19}$$

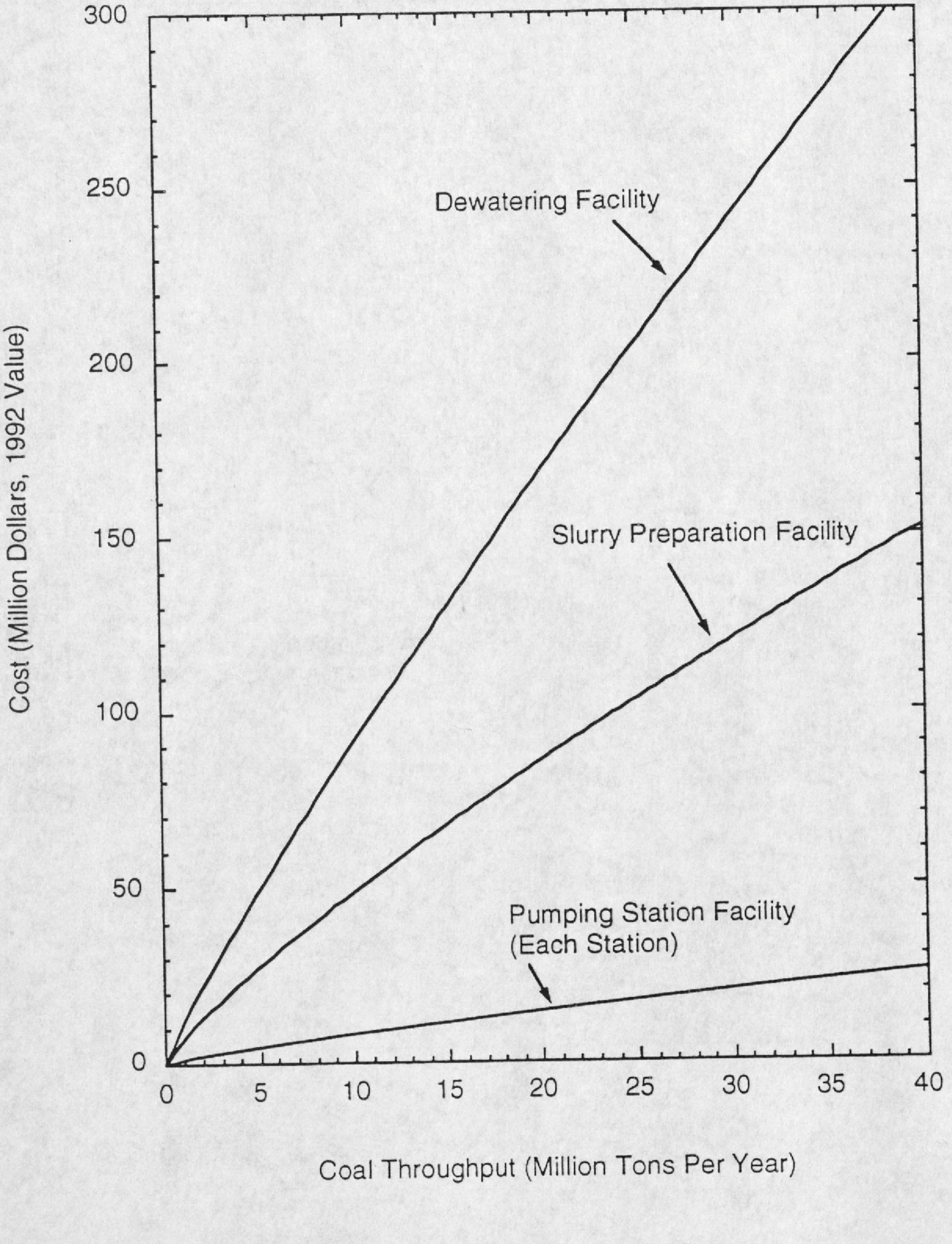

Fig. I.1. Slurry Facility Capital Costs

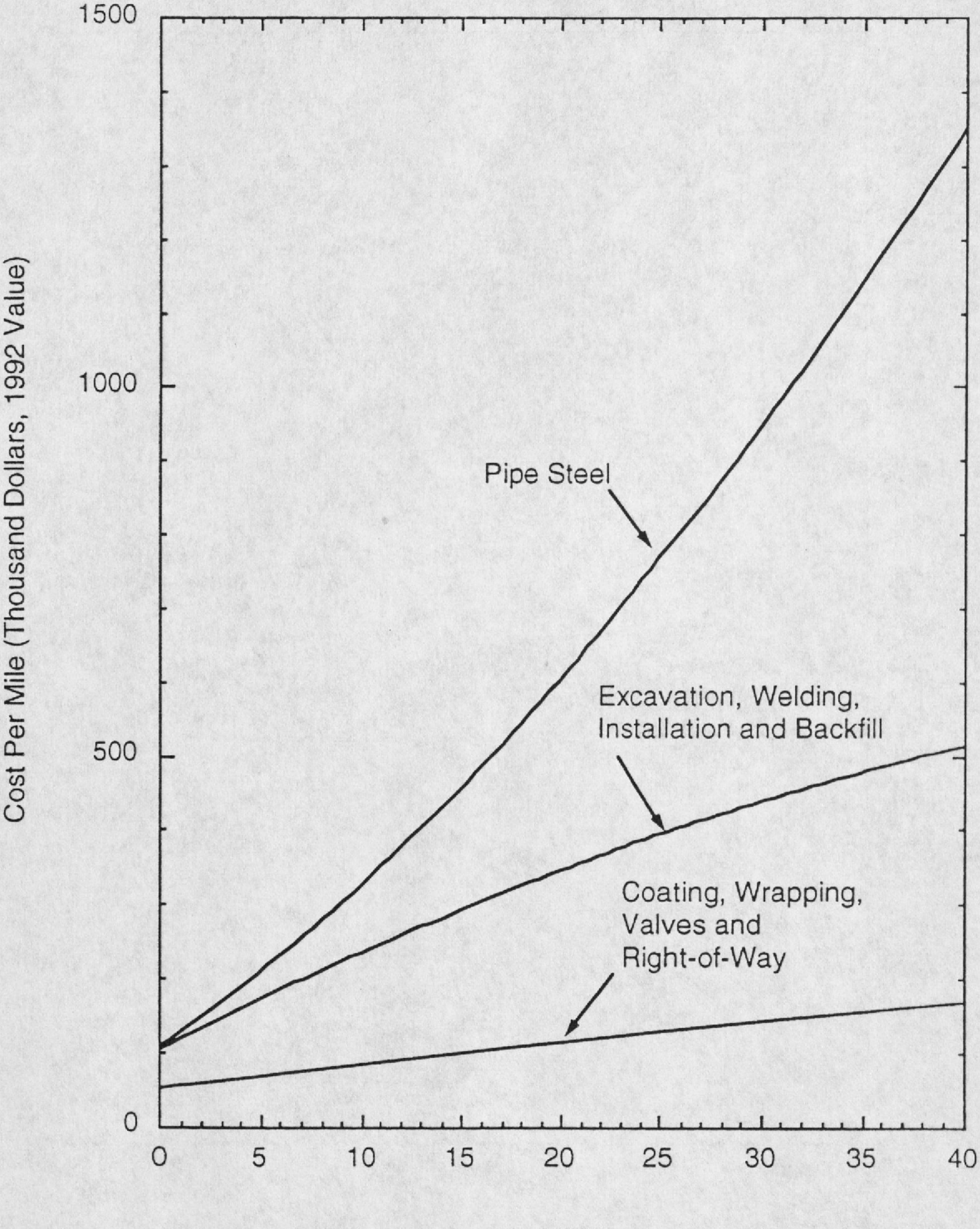

Fig. I.2. Pipeline Capital Costs

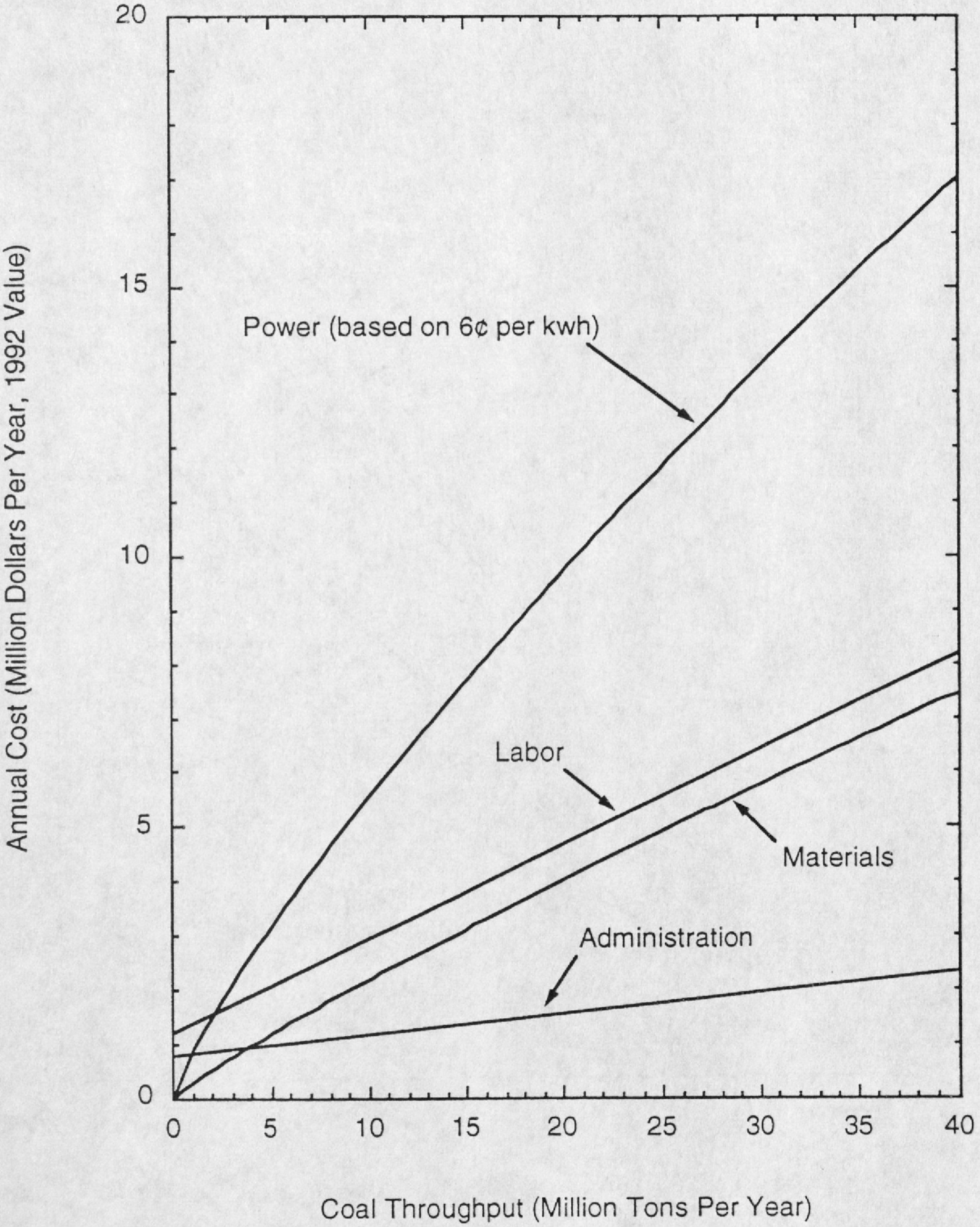

Fig. I.3. Slurry Preparation Facility Annual O/M Costs

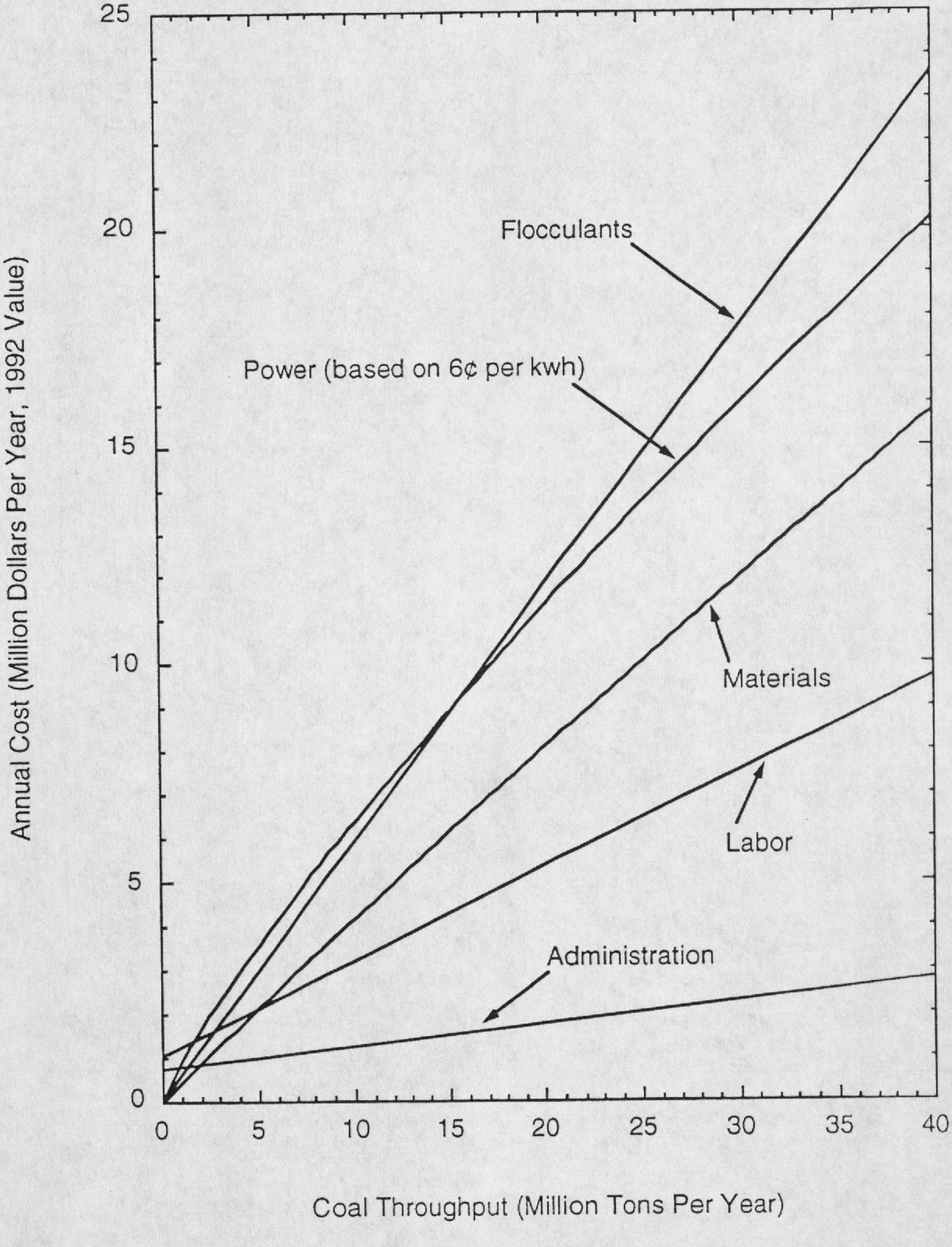

Fig. I.4. Slurry Dewatering Facility Annual O/M Costs

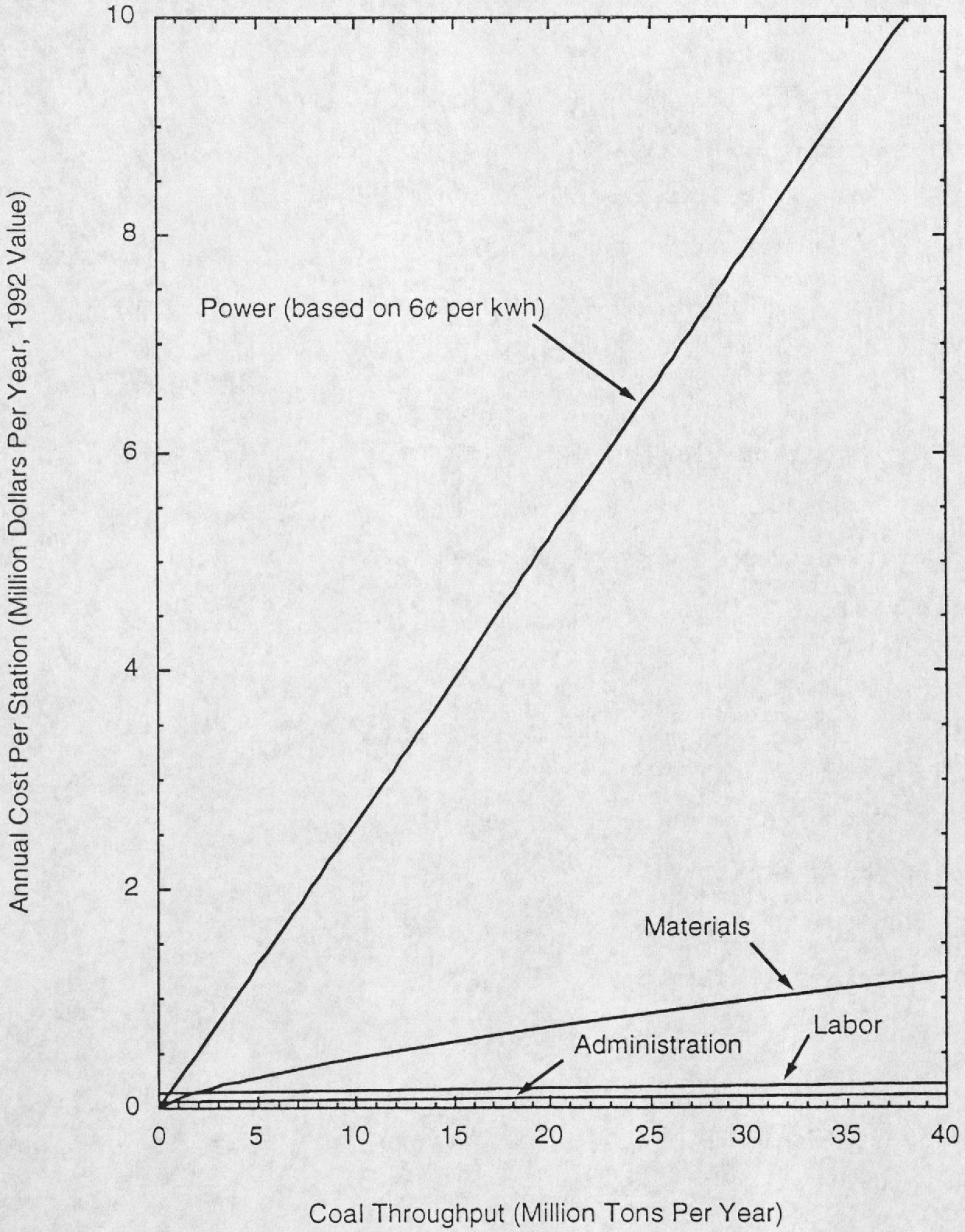

Fig. I.5. Pumping Station Annual O/M Costs

J: Dewatering

Due to the abrasion of coal logs in transportation through pipe, coal particles that are broken off coal logs are entrained in the carrier fluid (water) to form a dilute slurry. This unintended slurry, upon reaching the pipeline exit, must be dewatered to separate the coal particles from the water in the slurry. The dewatering process involves three stages:

1. **Sedimentation**--This involves using gravity to let solids settle from water in a large tank--the sedimentation tank. Note that sedimentation is effective only for settling the relatively coarse particles.

2. **Flocculation**--Flocculation follows sedimentation. The water effluent (overflow) of the sedimentation tank enters a flocculation tank where special chemicals (flocculants) are added to the water which causes the remaining fine coal particles suspended in the water to agglomerate and then settle to the bottom of the tank by gravity or by filtration.

3. **Centrifuging**--The coal particles settled on the bottom of the sedimentation tank and flocculation tank form a relatively dense slurry (sludge) which must be dewatered so that the sludge will have no more than about 30% surface water. This can be done by centrifuging.

From an EPA report [12], the capital cost for sedimentation tanks used in ordinary water treatment plants can be determined from

$$C_s = 337 + 27Q_{ws} \quad (\textit{thousand dollars}) \qquad \text{(J-1)}$$

where Q_{ws} is the discharge of water entering the sedimentation tank. Note that Eq. J-1 has been adjusted to represent dollars in 1992 value. The adjustment was made by multiplying the 1975 cost by 2.37--the cost index for the period 1975 to 1992, determined from [13] and [14].

The discharge of the water entering the pipeline is Q_w. Assuming that 10% of Q_s is absorbed by the coal logs going through the pipe, Eq. J-1 can be rewritten as

$$C_s = 337 + 24.2Q_w \quad (\textit{thousand dollars}) \qquad \text{(J-2)}$$

The size of the flocculation tank is assumed to be identical to that of the sedimentation tank. From the data in [15] adjusted to 1992 value, the capital cost for the flocculation tank is approximately

$$C_f = 1.57V_t^{0.5} = 63Q_w^{0.5} \quad (\textit{thousand dollars}) \qquad \text{(J-3)}$$

where V_t is the volume of the tank in ft^3; and Q_w is in cfs.

Costs for the centrifuging process, including both the capital cost and the O/M cost, were provided by the Bird Machine Company based on its products (Screen Bowl Centrifuges). They are listed in Table J-1.

Table J-1 **Costs and Power Requirements for Centrifuging Equipment for CLP Slurry (Supplied by Bird Machine Company, Chicago, Illinois).**

Throughput of Coal in Slurry		Machine Size	Capital Cost	Power Required		Energy Cost[1]	O/M Cost[2]
(ton/hr)	(MT/yr)	(in)	($)	(hp)	(kw)	($)	($)
0.5	0.00438	12 X 30	200,000	5	3.74	32,760	6,000
5	0.0438	18 X 28	250,000	20	14.96	131,050	7,500
20	0.175	32 X 50	400,000	100	74.80	655,250	12,000

1 The energy (electricity) cost is based on continuous operation at 6¢ per kwh.

2. The O/M cost listed here excludes the energy cost. It is based on 3% of the equipment cost.

The data in Table J-1 assume that the slurry generated in CLP contains a larger portion of coarse particles than does the slurry in ordinary coal slurry pipelines such as the Black Mesa Pipeline. Furthermore, while the CLP slurry in pipeline is rather dilute (it contains no more than 3% of coal by weight), the slurry (coal sludge) collected from the bottom of the sedimentation tank and the flocculation tank (i.e., the feed to the centrifuge) is far more concentrated (more than 20% of coal by weight).

Based on the data in Table J-1, the capital cost for centrifugal dewatering, C_{cd}, can be represented by the following equation:

$$C_{cd} = 1163\ Q_{cs} + 197 \qquad \text{(J-4)}$$

where Q_{cs} is the quantity of coal in the slurry accumulated each year (MT/yr); and C_{cd} is in thousand dollars ($1000).

Using the same data, the O/M cost, C'_{cd} , of the centrifugal dewatering process can be calculated from

$$C'_{cd} = 34.9\ Q_{cs} + 5.9 \qquad \text{(J-5)}$$

where C'_{cd} is in thousand dollars ($1000). Equations J-4 and J-5 are shown in Figs. J.1 and J.2 respectively.

The values of Q_{cs} in Eqs. J-4 and J-5 can be determined by assuming that the abrasion of coal logs in a 2,000-mile pipeline will cause the logs to lose 3% coal by weight, and that the weight loss (coal abraded) is linearly proportional to the pipeline length. Consequently,

$$Q_{cs} = 1.5 \times 10^{-5} Q_c\ L \qquad \text{(J-6)}$$

where Q_c is the coal throughput in pipe in MT/yr; and L is the pipeline length in miles.

Substituting Eq. J-6 into Eqs. J-4 and J-5 yields respectively,

$$C_{cd} = 0.0175 Q_c\ L + 197 \qquad \text{(J-7)}$$

and

$$C'_{cd} = 0.000524 Q_c L + 5.9 \tag{J-8}$$

Equations J-7 and J-8 can be used to calculate the capital and O/M costs of the centrifugal dewatering system needed for CLP. With Q_c in MT/yr and L in miles, the values of C_{cd} and C'_{cd} are in thousand dollars ($1000).

Finally, the energy data in Table J-1 are plotted in Fig. J.3 which yields the following equation:

$$P_{cd} = 426 Q_{cs} \tag{J-9}$$

where P_{cd} is the electrical power consumed in kw for centrifugal dewatering.

Substituting Eq. J-6 into Eq. J-9 yields

$$P_{cd} = 5.6 \times 10^{-5} Q_c L \tag{J-10}$$

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

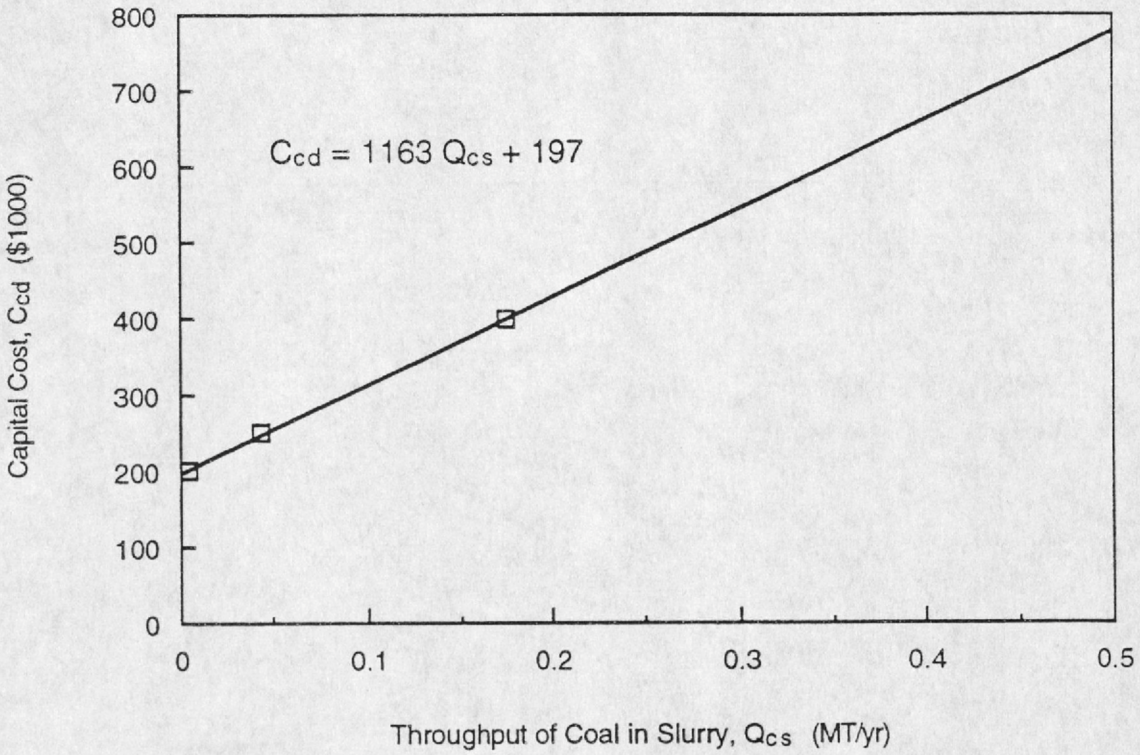

Fig. J.1. Capital cost for Centrifugal Dewatering of CLP Slurry

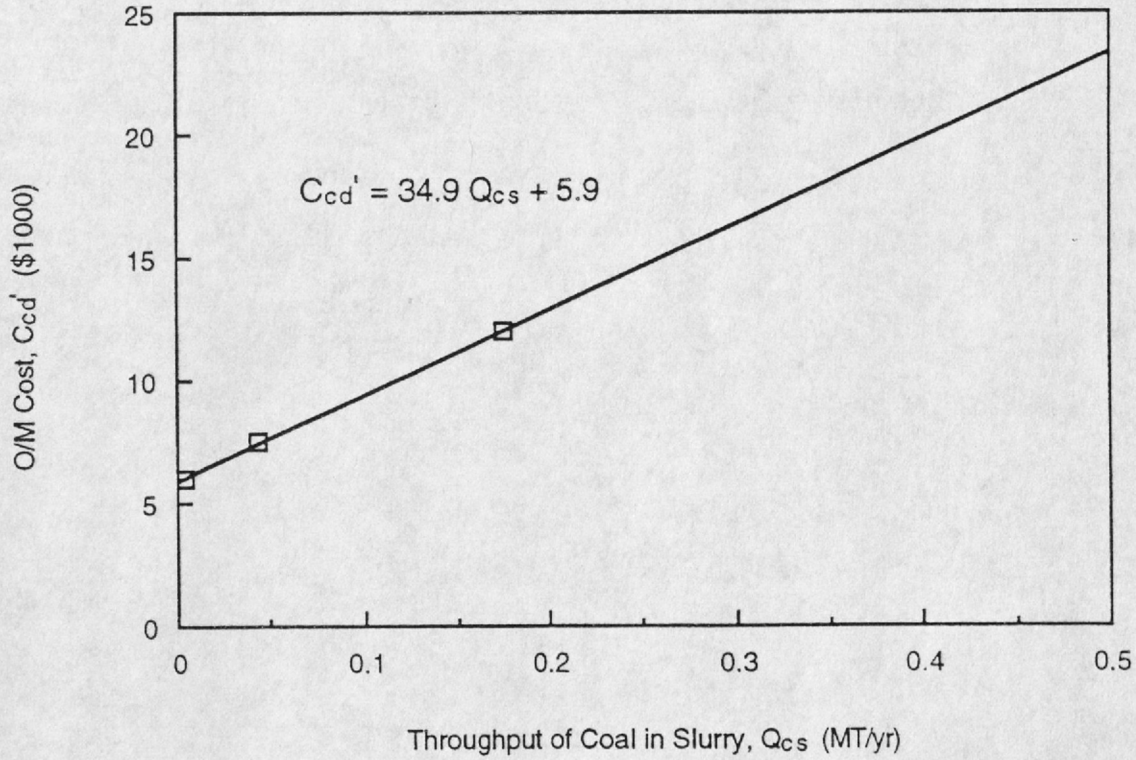

Fig. J.2. O/M cost for Centrifugal Dewatering of CLP Slurry

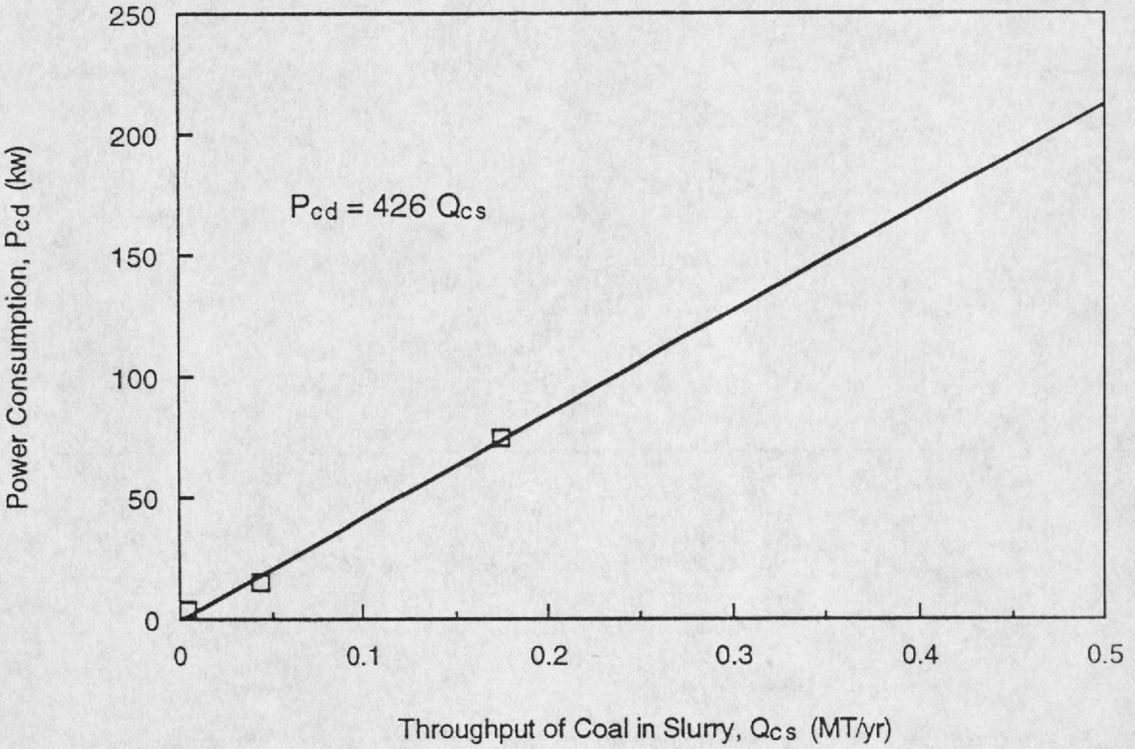

Fig. J.3. Electrical Power Consumed for Centrifugal Dewatering of CLP Slurry