INCREASING EXISTING MECHANICAL HOISTING CAPACITY WITH SUPPLEMENTARY HYDRAULIC HOISTING

by

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(ABSTRACT)

In some U.S. coal mining operations, the available production capacity is limited by existing mechanical hoisting systems rather than mining methods. This thesis presents a research effort to supplement existing mechanical hoisting with a hydraulic hoisting system. The purpose is to overcome limitations of the mechanical hoisting system in order to attain the maximum production capacity of the coal mine. The research objectives are: to conduct a parametric study of hydraulic hoisting systems combined with mechanical hoisting methods in different mining situations; to develop models, functions, and indices for use in practical design, and; to develop procedures for estimating the technical and economic factors of supplementary hydraulic hoisting systems. This research is expected to offer an objective approach which can increase the production capacity and reduce operating costs of coal mines.

DEDICATION

This thesis is dedication to my family for their constant encouragement, support, and love during my education.

ACKNOWLEDGEMENTS

I would like to express my sincere my appreciation and gratitude to Dr. E. Topuz my advisor and chairman, for his guidance, patience, and friendship during my graduate program. I thank the other members of my graduate advisory committee, Dr. M. Karmis and Dr. M. Karfackis for their invaluable advice and criticism.

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I. INTRODUCTION

1.1 Background of the Research

The United States coal industry has been using continuous room-and-pillar mining and longwall mining methods for several decades. During this time, coal mining operators and mining machinery manufacturers have made great advances to attain the full production potential of these methods. These advances are believed to have been the main contributors to the increase in the productivity of coal mines.

Since the late'1970s, mining equipment and mechanical parts have been made more reliable and repairable in order to increase the availability of mining systems. The horsepower on the mining machines increased in an effort to increase the mining production rate. The remote control, deep cut, and dust scrubbers technologies have been introduced into production systems. These technological changes in continuous room-and-pillar mining and longwall mining reduced delays due to equipment breakdowns and increased the availability of mining systems. As a result of these advances, the productivity of coal mines has been increased. The average mining and loading rates of continuous miners have increased from about 4.5 tons per man-shift during the mid-1970s to 9 tons per man-shift during the mid-1980s (Suboleski and King, 1990). Consequently, the average production in continuous mining sections for an eight-hour shift increased from 180 tons in 1977 to 475 tons in 1987. The average productivity for longwall mining systems increased from 56 tons per man-shift in 1983 to 113 tons in 1987. Between 1977 and 1987, the annual production of continuous room-and-pillar mining and longwall mining methods grew from 186.2 million tons to 338.5 million tons (Combs, 1990; Suboleski and King, 1990, 1991).

In coal mining operations, these technological changes provided great potential for increased production capacity in continuous room-and-pillar mining and longwall mining. However, the production capacity of some existing coal mines is not fully realized because of the capacity limits of outbye haulage systems. Thus, some coal mines have the potential to increase their production rates by implementing additional measures to alleviate the limitations of outbye haulage systems. In particular, the capacity of the hoisting system is a major limiting factor in existing outbye haulage systems. Therefore, using an appropriate methodology to increase the capacity of existing hoisting systems will result in savings of both the capital investment and operating costs and will contribute to the competitive position of the coal mining industry.

1.2 Statement of the Problem

The capacity of existing mechanical hoisting systems can be increased by combining the skip or cage hoisting system with a supplementary hydraulic hoisting system. This method offers the potential to increase the existing hoisting capacity, since in many cases the existing hoisting equipment can not be easily modified or increased to a required capacity because of technical and economic factors.

In order to combine the existing hoisting system with a supplementary hydraulic hoisting system, coal sizes should be separated at the shaft bottom by means of a screening operation. The coarse coal will be carried through the existing mechanical hoisting system, while the fine coal-water slurry will be pumped to the surface by a hydraulic hoisting system. Thus, the duty load of the combined hoisting systems can be designed to satisfy the desired increase in production of the mine.

For the hydraulic hoisting system, the pumping equipment can be located at the bottom of the mine shaft or on the surface and used directly to elevate the coal-water slurry by an open or closed circuit operation. The system must be capable of independent hoisting and should be designed to operate parallel to existing hoisting systems. Generally, a hydraulic hoisting system receives the coal from the main entry belt of the outbye haulage system after it has passed through a screening device. It is then pumped to the surface by two methods. The first method is for fine coal, which is passed directly through the pump. The second method is for coarse coal and requires that the coarse coal be introduced into a high-pressure water line by a mechanical feeder or low-pressure pump from the first stage. The high-pressure water stream entrains the coarse coal and passes it up through a shaft pipeline to the surface preparation plant. The second method is much more complex due to the inability of a high-pressure pump to move the coarse coal. Nevertheless, the existing dewatering system may be considered as a main subsystem of the supplementary hydraulic hoisting system to produce the high-pressure water stream. As a result, use of the existing dewatering system could greatly decrease the costs and simplify the complexity of the hydraulic hoisting system and, consequently, make the supplementary hydraulic hoisting system technically and economically more attractive.

For the proposed hydraulic hoisting system, the screening device under the end of the main entry belt not only separates the coal into fine and coarse particles, but also divides it into two parallel flows for the main mechanical and supplementary hydraulic hoisting systems. The mechanical delivering device or low-pressure pump, storage bunker, pipelines, water supplies, and some surface facilities comprise the system. An additional space will be required at shaft bottom for the installation of the supplementary hydraulic hoisting equipment.

Considering different requirements for existing coal mines, the hydraulic hoisting procedures and equipment will be designed and/or selected depending on several factors, including the remaining production capacities of mining faces, secondary and main haulage systems, coal size distribution, water pumping rates, depth of hoisting, location of coal preparation plant, remaining coal reserves, and economic factors. The economic feasibility of a supplementary hydraulic hoisting system to increase the productivity of existing coal mines will be investigated for different mining conditions.

1.3 Objectives of the Research

The objective of this study is an engineering evaluation of the feasibility of the supplementary hydraulic hoisting system for use in existing coal mines. The specific objectives are as follows:

1. Investigating and understanding the hydraulic hoisting system's principles and operating logic, and investigating available equipment that can be utilized in a supplementary hoisting system for existing coal mines where skip or cage hoisting capacity is the major limiting factor for increasing the mine production.

2. Developing a hydraulic hoisting system which can be combined with existing mechanical hoisting systems in different situations to increase the hoisting capacity of the coal mines.

3. Studying and developing the models, functions, and indices for analyzing the technical and economic factors, and for evaluating the feasibility of the supplementary hydraulic hoisting system.

4. Conducting case studies to illustrate applications of the supplementary hydraulic hoisting system for two hypothetical coal mines.

1.4 Methods of the Research

A few coal mines where production is limited by the mechanical hoisting system will be identified. For these mines, information related to the remaining production capacity, outbye haulage systems, coal reserves, coal size distribution, depth of hoisting, water pumping equipment and pumping rates, and location of preparation plant will be collected. This information will be used in this study to evaluate the feasibility of applying supplementary hydraulic hoisting systems by the following methods:

1. Reviewing hydraulic hoisting methods in sufficient detail to determine whether the hydraulic hoisting system can be used to increase the capacity of an existing mechanical hoisting system.

2. Reviewing, identifying, and analyzing the economical factors and evaluation concepts that may affect the feasibility of supplementary

hoisting systems.

3. Collecting information related to hydraulic hoisting equipment, production, drainage, power and water supply systems, and the location of the preparation plant to establish the research data base.

4. Calculating technical and economical data which will be used to analyze various hydraulic hoisting models for different coal mining conditions. The data will be used in determining the selection of hoisting model and equipment, predicting the productivity of the coal mine, estimating the capital investment and operating costs, and performing sensitivity analysis of critical parameters.

5. Evaluating the feasibility of increasing existing mechanical hoisting capacity by supplementary hydraulic hoisting systems in the case study.

6. Developing a computer program for calculations of the technical and economical data to determine the most favorable hydraulic hoisting configuration for a given coal mine condition, and to assist the decision maker in the evaluation of the feasibility study.

1.5 Scope of the Research

Hydraulic hoisting as a supplementary system can be used to increase the capacity of the existing mechanical hoisting system. However, the structure and operations of the supplementary system will depend on the existing conditions of the coal mine. Therefore, these conditions should be investigated carefully. In order to achieve the ultimate objectives, this research follows these guidelines:

1. Depending on the water pumping rates of existing coal mines, the supplementary hydraulic hoisting system can be classified into open flow and circulating flow models. The open flow model is considered for use in a coal mine with high pumping rates. Therefore, this model is simpler because the existing dewatering system can be used to entrain the coal to surface by its high-pressure water stream. The circulating model is considered for use in a coal mine with low water pumping rates where the model would require water recirculation. For many coal mines, the first model may be a more appropriate means for implementing a supplementary hydraulic hoisting system because more tons of water than tons of coal are removed from underground to surface each year (Scott, 1983).

2. The existing conditions of the coal mines should be considered and fully

utilized for successful installation of the supplementary hydraulic hoisting system. Thus, this study will assume that the initial conditions in existing coal mines can be modified for use of the supplementary system. The study will not consider the coal cleaning methods, equipment availability, dewatering procedures, or black water treatments in preparation plants.

3. The economic evaluation incorporates the cost estimating relationship of annual production costs of the coal mine, existing hoisting and drainage systems, and supplementary hydraulic systems.

II. LITERATURE REVIEW

Many research reports and articles have been written on the application of hydraulic hoisting systems in underground mining, estimation procedures for capital and operating costs of the underground coal mine, and the methods for the economic evaluation of industrial projects have been discussed in published articles and handbooks. These sources have provided the background for the engineering analysis and design of the supplementary hydraulic hoisting system in this study. A brief literature review in these areas is summarized below.

2.1 Hydraulic Hoisting Equipment

The rationale for pump selection is not simple and involves certain technical, economic, and operational considerations. Pump selection is normally done according to the requirement of the flow and maximum pressure ratings and other considerations in initial capital investment and operating costs. The positive displacement pumps, hydraulically-driven positive displacement pumps, and centrifugal pumps have been commonly used in coal-water slurry transportation. The major pumps described by Laubscher (1973), Jeremic (1983), Stewart and Wood (1984) are as follows:

Plunger pump (see Figure 2.1): This pump is suitable for pressures in the range of 15 MPa or higher, slurry of a maximum particle size of 3 mm (up to 6 mm may be handled if special valves are fitted), and low or high flow rating.

Piston pump (see Figure 2.2): Normally used for discharge pressure up to 15 MPa with a maximum particle size of 3 or 6 mm (with special valves are fitted).

Double piston pumps (Figure 2.3 shows a double action piston diaphragm pump): the more conventional pump is of the double action design and is used for material with a miller number less than 30 mm.

Diaphragm pump (see Figure 2.4): An advantage of this pump is some pump parts can be separated with coal-water slurry by a diaphragm to eliminate abrasive wear of these parts and reduce maintenance requirements. The pump can be designed for the discharge pressure of 16 MPa and lower pump speeds.

Hydraulic exchange pump: The pumps have been pumping coal-water slurries through a vertical distance of 975 m at concentrations of up to 60 wt% in a test. In this system, the coal-water slurry is delivered to the high-pressure (approximately 14 MPa)

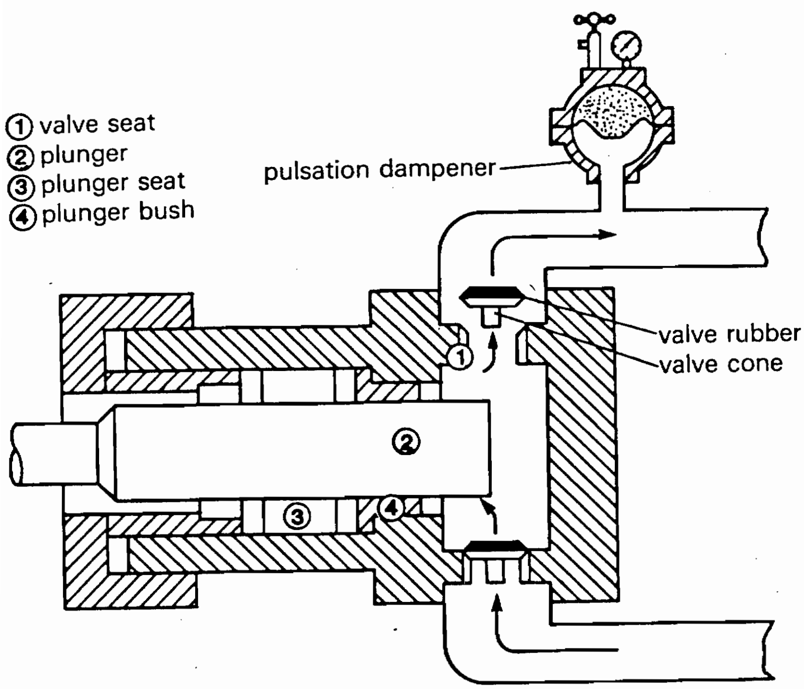


Figure 2.1 Representation of the Plunger Pump

(After Holthuis and Simons, 1981)

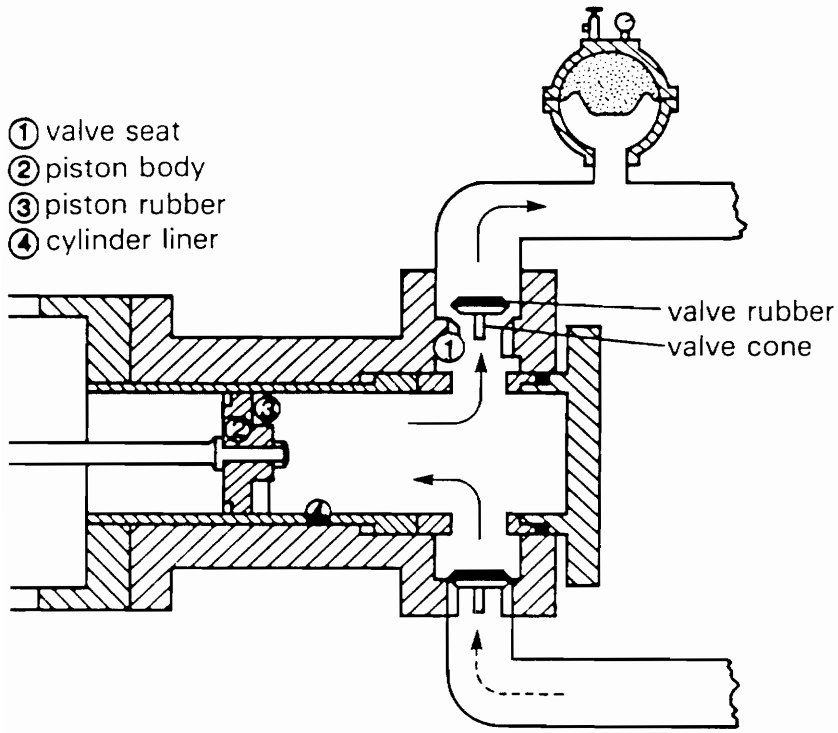


Figure 2.2 Representation of the Piston Pump

(After Holthuis and Simons,1981)

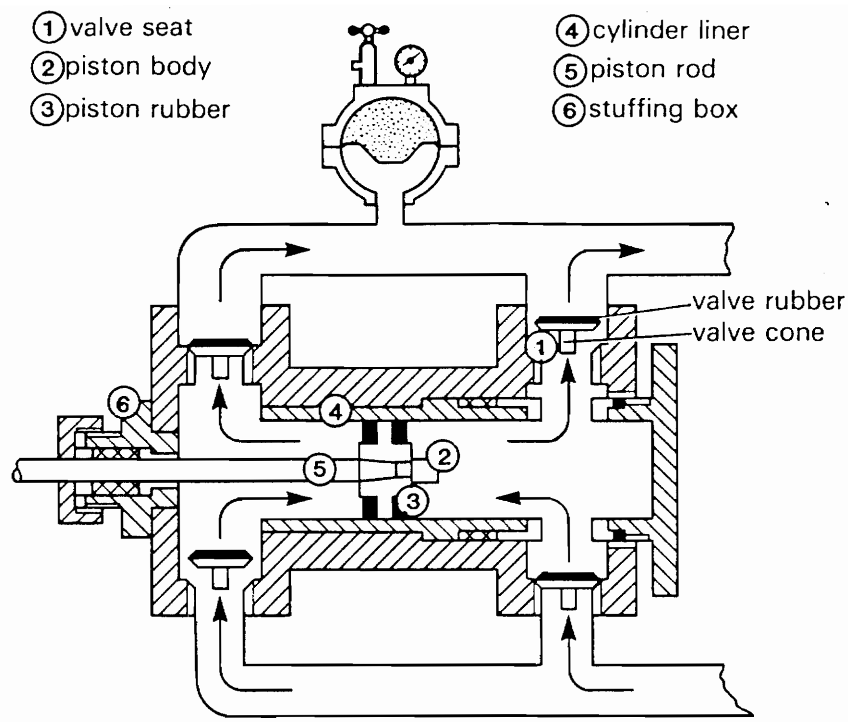


Figure 2.3 Representation of the Double Piston Pump

(After Holthuis and Simons,1981)

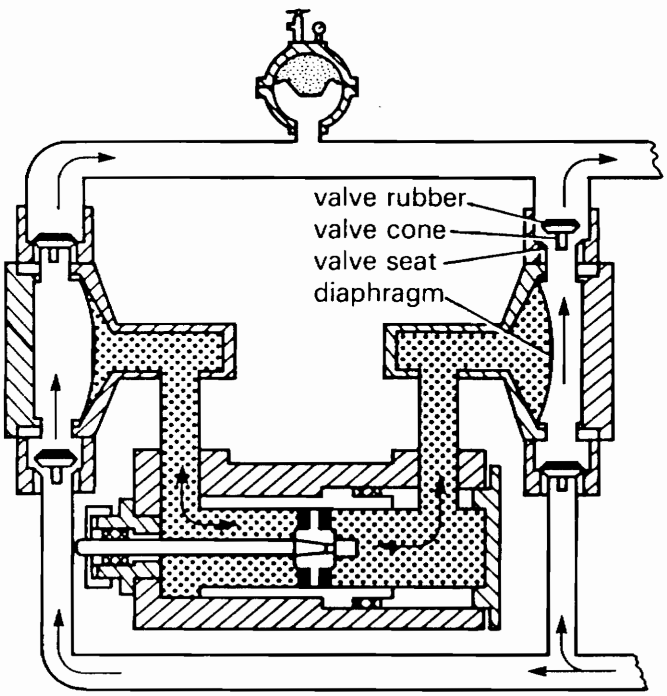


Figure 2.4 Representation of the Diaphragm Pump

(After Holthuis and Simons,1981)

pump at 28 to 40 kPa by a centrifugal or positive displacement pump. The schematic arrangement of pumps is shown in Figure 2.5.

Hitachi hydrohoist: Developed by Hitachi Ltd., Japan. This hoist is powered by a centrifugal pump handling clean water and uses the bang-bang method to control three chambers or feed pipes. It is suitable for applications requiring pressure of up to 15 MPa and flow rates of up to 30 m^3/min. Its overall power efficiency is approximately 20% higher than the centrifugal slurry pumps. Figure 2.6 shows the schematic arrangement of the hydrohoist in which there are three feeding pipes, twelve plate valves, a low-pressure slurry pump, and a high-pressure centrifugal water pump. Smooth and continuous discharge and feed of the slurry is achieved by each feed pipe operating in sequence in the following cycle: Valves A and C close and valves B and D open, then slurry from the slurry pump fills the feeding pipe until the slurry reaches the limit of the feeding pipe. Valves B and D close to trap the slurry in the feeding pipe. Valves A and C open and high-pressure water from the centrifugal pump enters the feeding pipe through valve A and forces slurry to discharge into the transport pipeline through valve C until the tail end of slurry passes the end of the feeding pipe.

Rotary ram pump: A four cylinder, multi-sectioned, prototype, rotary ram pump is shown in Figure 2.7. Rotary ram pumps can be designed for long distance pipelines and can transport up to 600 ton/hr for a distance of approximately 100 km.

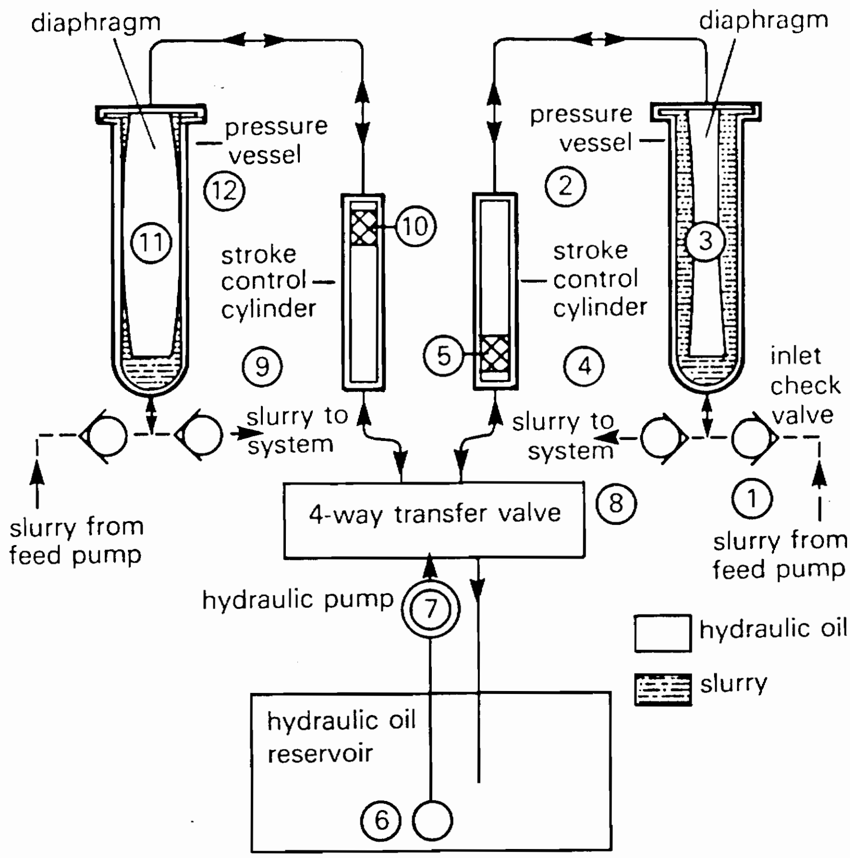


Figure 2.5 Schematic Arrangement of the Zimpro Hydraulic Exchange Pump

(After Chowdhury and Zoborowski, 1981)

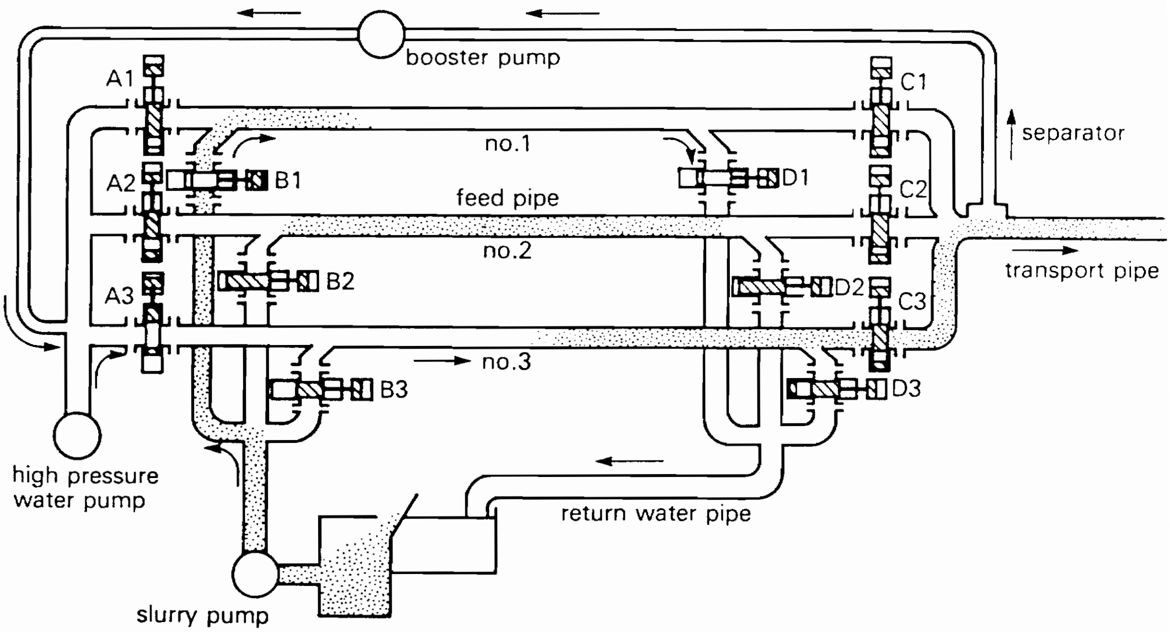


Figure 2.6 Schematic Arrangement of the Hitachi Hydrohoist

(After Sakamoto and others, 1983)

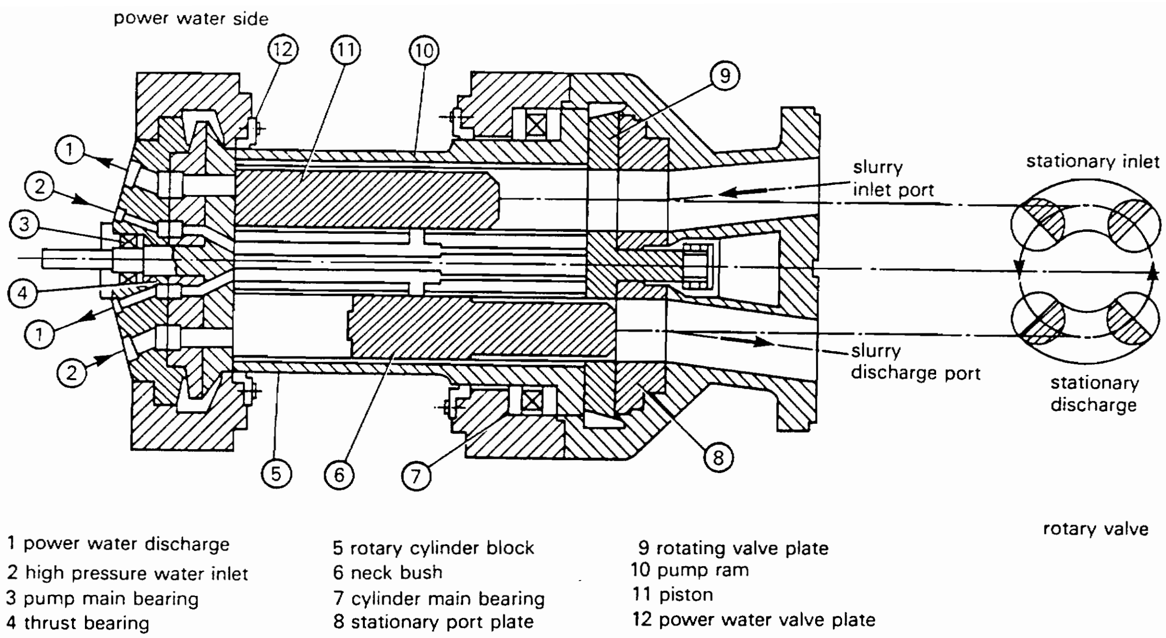


Figure 2.7 Representation of the Rotary Ram Pump

(After Boyle and others, 1981)

Centrifugal pump: Broad area of usage for handling particles up to a size of 150 mm at discharge pressures up to a of 6.9 MPa by at least six pumps in series. The centrifugal pump has low pressure output, lower capital investment costs, and higher specific power costs because of the pump's low mechanical and hydraulic efficiency when compared with the positive displacement pump.

Piston-centrifugal pumping systems (see Figure 2.8): In this system, the coal from the connecting belt drops into a small hopper and then into the low-pressure chamber where the pressure comes from the double acting, compressor-air-operated piston pump. This coal goes into a tube connecting to the pump section; here transport water is injected into the side of the tube near the pump in the direction flow, so that the centrifugal pump suction is supplied with a mixed coal-water slurry. This system has the advantages of low maintenance and less spillage in the operations. The compressed air is required to drive the piston pump.

Screw-pump systems (see Figure 2.9): This system consists of a hopper that receives coal from a connecting belt, with the coal dropping into a screw feeder which forces the coal into a suction side of the centrifugal pump. Another suction side of this pump receives the transport water; then the pump discharges the coal-water slurry into the pipeline at a uniform rate.

Injection systems (see Figure 2.10): Studied by the U.S. Bureau of Mines. This

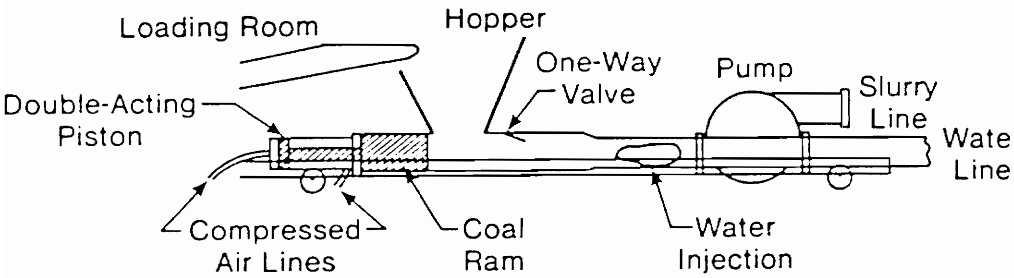


Figure 2.8 Piston-Centrifugal Pumping Systems

(After Jeremic, 1981)

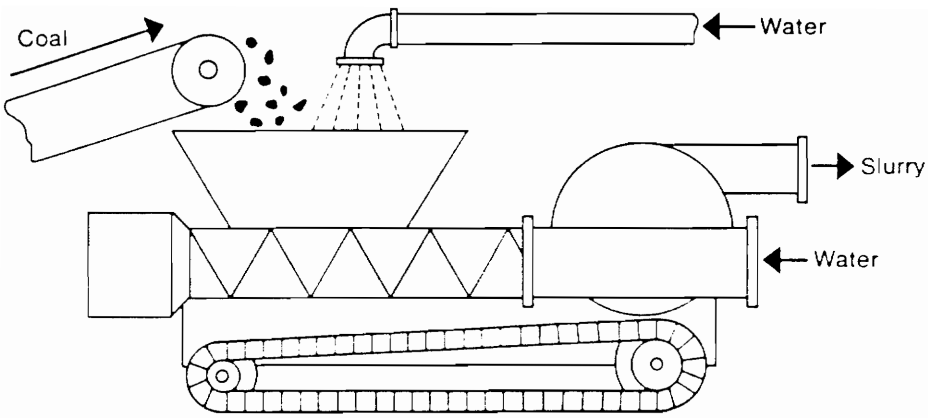


Figure 2.9 Screw-Pump Systems

(After Jeremic, 1981)

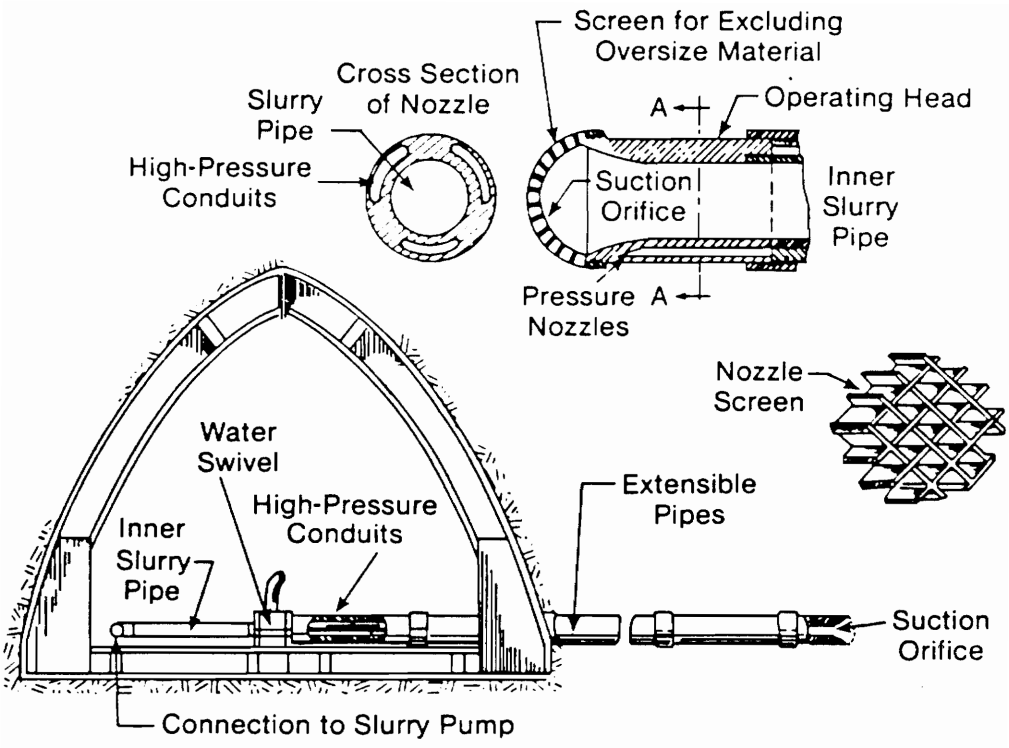


Figure 2.10 Injection Systems

(After Jeremic, 1981)

method is based on the general principle that dry coal is introduced into a moving, and high-pressure water stream. Coal solids as large as 10 cm are sucked into an inner slurry pipe, where the high-pressure water circuit is established. The high-pressure water is directed to the surface through conduits around the perimeter of the slurry pipe, and then coal solids are carried over the mine.

Mars pump: Developed by the Mitsubishi company of Japan. The principle of the operation is shown diagrammatically in Figure 2.11. The main advantage of the pump is that the slurry never comes into contact with the piston or cylinder and there is, therefore, little wear.

Jupiter pumping systems: Developed by Haggie Rand Ltd. of South Africa. The schematic operating procedure is shown in Figure 2.12. The system is similar to the Mars pump; however, the reciprocating movement of the oil is not produced by a piston pump, but by pumping water into and out of the so-called driving chamber A using a centrifugal pump.

Lock-hopper and High-pressure water stream hoisting systems: Uses a lock-hopper feeder to introduce the coal-water slurry into the high-pressure water stream which is produced by a centrifugal pump. The lock-hopper feeder (see Figure 2.13) usually has two chambers which are alternately loaded with coal and water, then pressurized to force slurry into a pipeline.

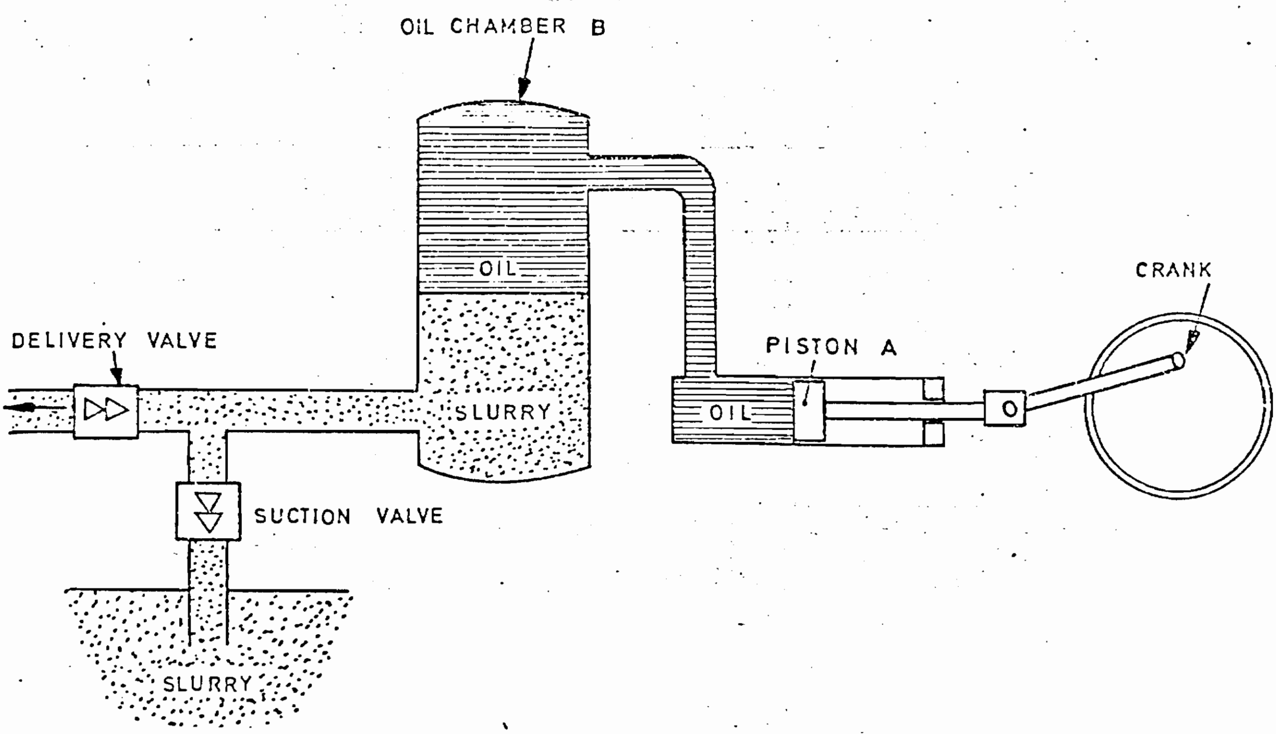


Figure 2.11 Schematic Arrangement of the Mars Pump

(After Laubscher, 1983)

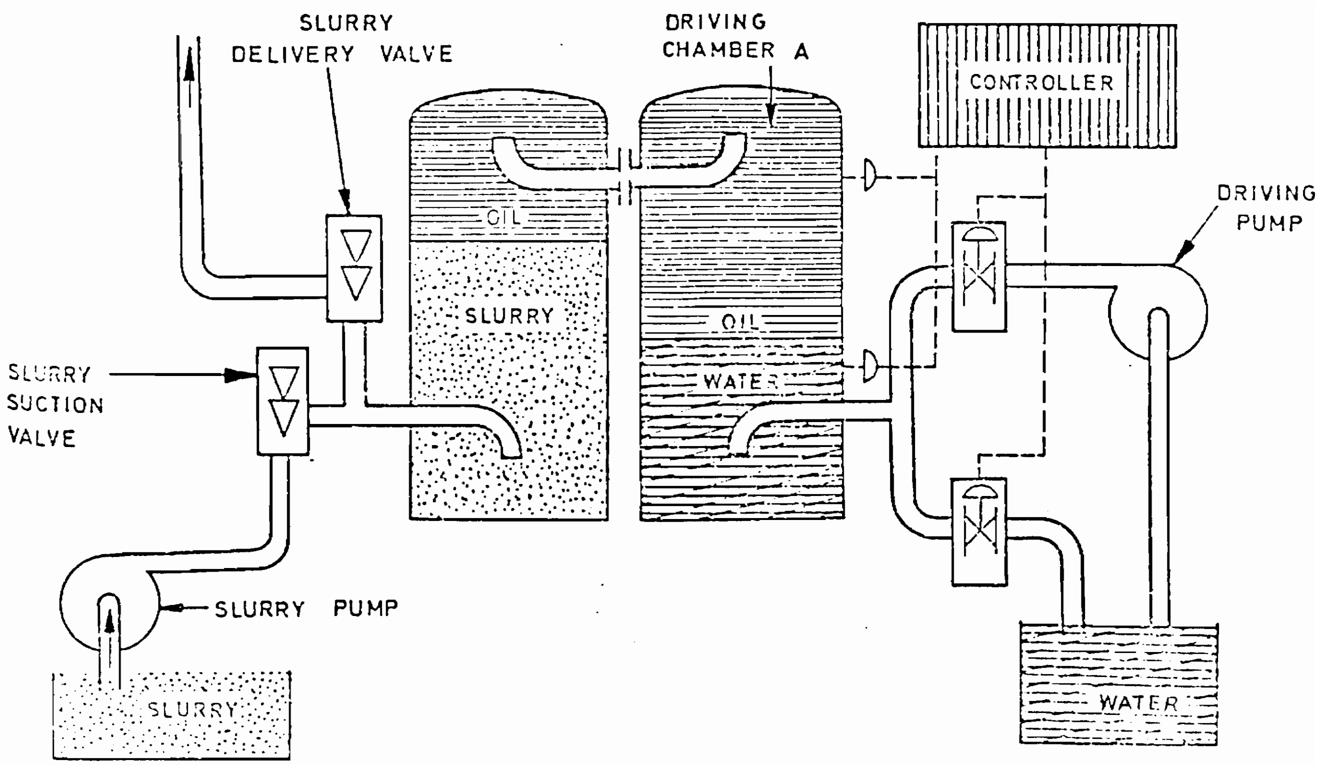
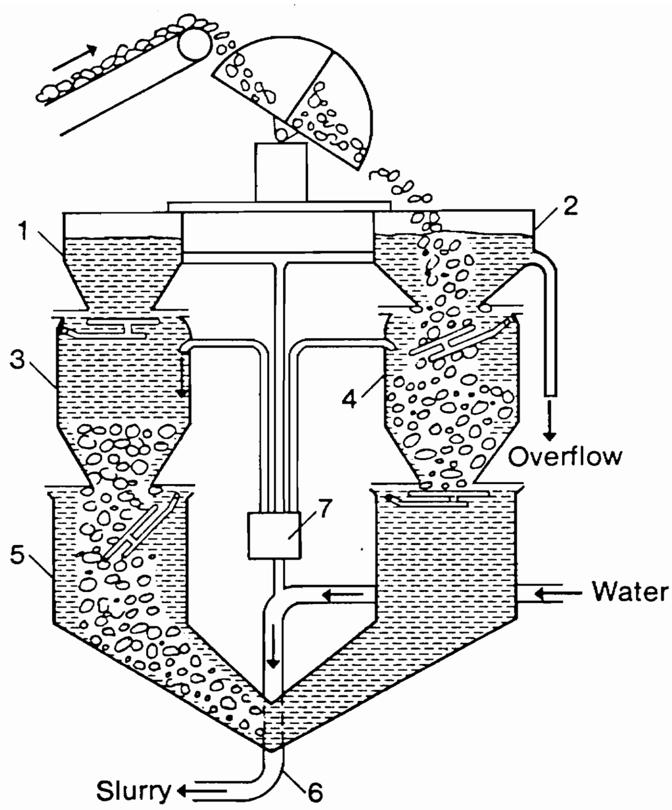


Figure 2.12 Schematic Arrangement

of the Jupiter Pumping System

(After Laubscher, 1983)



1 & 2 Hoppers;
3 & 4 Pressure Chambers;
5 Unloading Chamber;
6 Ring-Shaped Injector
7 Pump

Figure 2.13 Schematic Arrangement of the Lock-Hopper and High-Pressure Water Stream Hoisting System (After Laubscher, 1983)

2.2 Screening and Storage of Run-of-Mine Coal

Separation of run-of-mine coal according to size usually is undertaken to promote maximum capacity for the hydraulic hoisting equipment. Screens are generally used for size separation. Stewart and Wood (1984) state that the rotating probability screen is one new concept in screening which uses rotation instead of vibration and thus helps to solve the "blinding" problem caused by wet, or clayey coal. The screen can accept coal up to 30 mm in size and handle it at a rate of at least 100 t/hr. The screen's surface capacity for making a specific separation can be determined by multiplying the chart reading by the factors adjusting for efficiency, number of decks, % fines, wet screening, type of deck factor, and bulk density. This is discussed in Fuerstenau and others (1973). Using this method may automatically control the capacity of the screen surface by varying the coal particle sizes during operation.

In order to ensure continuity of run-of-mine coal supply for the supplementary hoisting and eliminate the effect of the hydraulic hoisting's downtime on the outbye haulage system, the separated coal from the screen must be temporarily stored. Nelson (1990) and Bernard (1990) point out that the bunker storage system, a popular concept, can be used for a multitude of situations in existing haulage systems, without major modification, to increase their output and operable capacity. In the U.S. three types of bunker systems have been used for underground coal mining: moving bed, moving car, and static/bin. When these bunker systems are used in existing coal mines, the type of system must be carefully selected according to the mine layout and required capacity of temporary storage. The brief conclusions about the three types of bunker systems were given as follows:

1. The moving bed bunker system (see Figure 2.14) provides a storage capacity from 250 to 500 tons. The installation of this type of bunker can reduce the amount of excavation in comparison to other types of bunkers and its operation is relatively simple.

2. The moving car bunker system (see Figure 2.15) can be designed for storage capacities up to 2,000 tons. When it is installed, additional capacity can be added at a small incremental cost. The bunker has little downtime due to the system's simple operation.

3. The storage capacity of the static/bin bunker system is 2,000 tons maximum. Operation of the system is simple and generally automated. The system operation requires the use of a surge bin with a capacity of 10 to 25 tons.

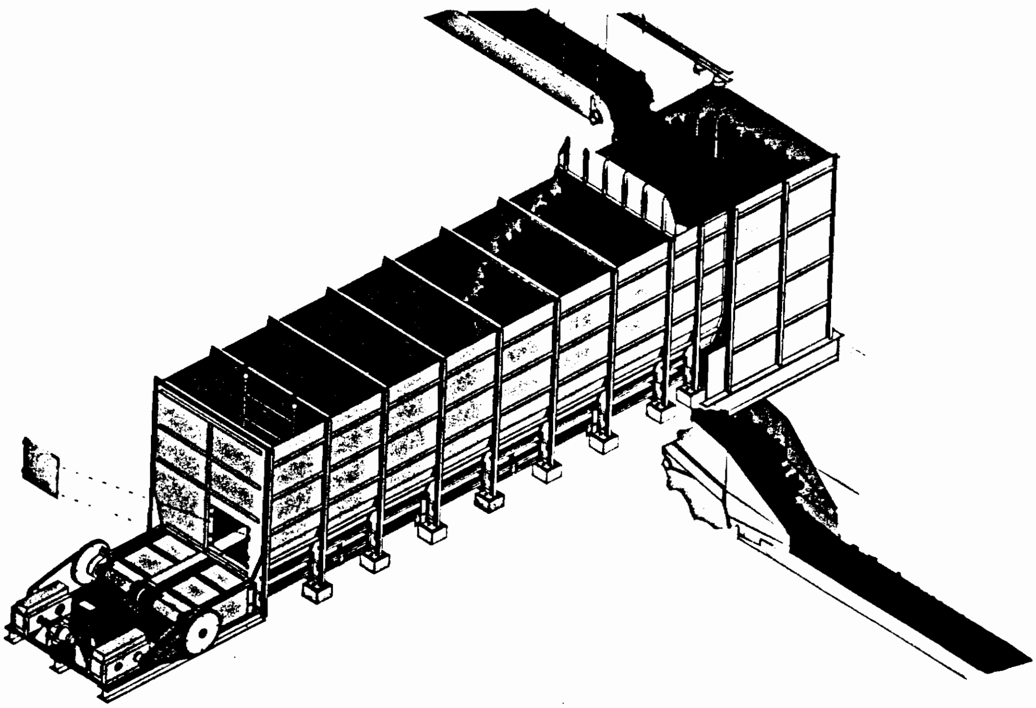


Figure 2.14 Moving Bed Bunker

(After Stamler Corporation, 1992)

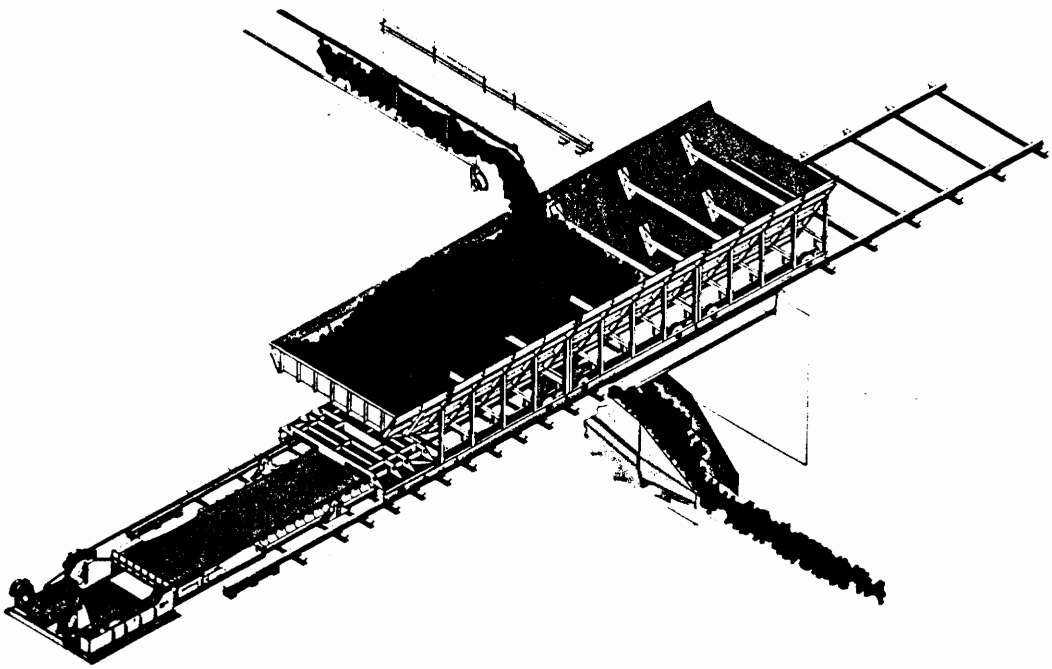


Figure 2.15 Moving Car Bunker

(After Stamler Corporation, 1992)

2.3 Successful Installation of Hydraulic Hoisting Systems

Hydraulic transportation of coal from the mine to the surface has received considerable attention for many years. Many operators believe the method offers the potential to improve mine health, safety, and coal production.

In 1981, Mr W.C. Andrews was granted a United States patent for the transport of coal in water. His process was later applied in Pennsylvania for transport of washery waste back into worked-out portions of coal mines (Link, et al, 1975). Gyngell (1970) states that a scheme had been completed by the middle of 1971 for pumping 25,000 dry tons per month of quartzite fines from 2,195 m depth by means of Mitsubishi Mars reciprocating pumps. Stewart and Wood (1984) state that the rotary pump, which is used in Australia, has successfully pumped coal particles up to 10 mm in size through a 50 mm diameter pipe using a water content of approximately 30 wt%. According to Ruehe and Kaemmerer (1988), the Preussag's 4-piston pump and pumping technique are able to satisfy the requirements of heavy duty mining conditions, allowing for a continuous pumping of high density phases at a high pressure level with uninterrupted long term runs. Froehlich (1988) states that the 4-piston pump as a low-pressure feeder was projected for a combined hydraulic hoisting in the Preussag-owned, Bad Grund lead-zinc mine. It was intended to service the mining of 1.9 million tons of ore over a period of eight years. The pump may guarantee a continuous feeding of the dense phase ore without pressure shocks, and its pumping sequence is controlled and regulated by a special computer program. In this combined hoisting, a 7-step centrifugal pump with variable speed drive is used for pumping clear water. The diluted ore-water mixture is hoisted up to the surface over a vertical distance for 700 m.

According to Alexander and Shaw (1984), the Loveridge mine in West Virginia has installed a hydraulic hoisting system. This system is used to lift a vertical distance about 260 m and deliver a horizontal distance about 4 km of the run-on-mine coal from mining faces to a coal cleaning plant. For this system, seven centrifugal pumps in series are used to transfer the coal-water slurry through the vertical and horizontal pipeline with a diameter of 0.3 m. The particle size of coal solids is about 70 mm, and the transport water is decanted at the coal cleaning plant and then recirculated to the feeding station in the mine.

A hydraulic exchange pump is used for hoisting of settled sludge solids (Hastings and Zorobowski, 1986). In this case, specific gravity of the solids is 4.3 maximum, at 35 to 45% concentration by weight results in slurry specific gravity of 1.4 to 1.5. The solids are pumped at the capacity of 0.21 to 0.228 m^3/min vertically 699 m and then horizontally 762 m via a single pump lift with a tubular diaphragm positive displacement high slurry pump. This pump has two parallel air diaphragm feed pumps to charge the high pressure, and a high duty screen is used to pass 6 mm solids.

Singhal (1970) and Wakabayyashi (1979) cite that the Hitachi Hydrohoist system can be used for high flow rates with heads up to 1,000 m and a particle size equivalent to one-third the pipe diameter. The hydrohoist consists of a low-pressure sand pump, a high-pressure pump, three feed pipes, plate valves, and control devices for the motors and valves. The practical application of the hydrohoist in the Sunagawa Colliery of the Mitsui Mining Corporation is installed for hoisting the run-of-mine coal with a maximum particle size of 30 mm, which is fed to the mixing tank by a chain feeder, and a depth of 515 m. The hoisting capacity of the hydrohoist is 100 ton/hr with pipe diameter of 188 mm, slurry velocities of 3.5 m/sec (horizontal) and 2.5 m/sec (vertical) at a density of 25% concentration, and the driving power is 1,100 kw for the high-pressure water pump. For the Yoshima Colliery of the Furukawa Mining Corporation, the hydrohoist is used to hoist raw coal with a maximum particle size of 58 mm. At 20% concentration the density is 1.68; the mean pipe velocity is 3.8 m/sec, and the depth of shaft is 259 m, with capacity for 100 ton/hr. In this system, the high-pressure water pump with capacity of 5.3 m^3/min is driven by a 750 kw motor, the Bladeless sand pump with capacity of 4.8 m^3 is driven by a 55 kw motor, and the pipe diameter is 168 mm.

Merritt (1978) and Harzer and Kortenbusch (1981) point out that the Ruhrkohle, AG, West Germany achieved success using the hydrohoist in the Hansa coal mine by trial hydrohoist installations at the Consolidation mine in 1972, the Carl Funke mine in 1973, and the Gneisenau mine in 1974. For the Hansa mine, the hydrohoist was combined with a three-chamber pipe-feeder and a paddle wheel type centrifugal pump and pumped the slurry to ground level for 860 m by means of high-pressure water inside pipelines within the shaft. The advantage of this system is that the high-pressure centrifugal pump and the shaft. The advantage of this system is that the high-pressure centrifugal pump and gate valves are not in contact with solids, so that coal with grain sizes up to 60 mm and a water-coal ratio of 1:6 can be pumped without undue wear on these critical components.

The centrifugal slurry pump is used for hoisting run-of-mine coal from shaft bottom at 200 m depth level in the Jubilee coal mine (Jeremic, 1983). Three pit-bottom sumps receive coal up to 70 mm in size from the crusher; three pumps, each connected to one of two 350 mm shaft pipelines, then pump the slurry with a water-coal ration of 1:7 and capacity of 10,000 tons to the surface.

2.4 Economic Feasibility of Hydraulic Hoisting

The economic considerations in hydraulic hoisting in existing coal mines strongly affect the feasibility of a hydraulic hoisting installation. An economic evaluation of hydraulic hoisting in a schematic example is described by Sellgren (1987). The evaluation is based on the complete comparison of investment and operating costs of new hydraulic hoisting installation with existing mechanical hoisting and pumping systems when the pumping system is integrated to the hydraulic hoisting system. In the cost calculation of hydraulic hoisting, the equipment life of 10 years and interest rate of 16% are assumed, and positive displacement pumps are used for the shaft depth of 800 m, with a capacity of 2,660 ton/hr. The calculated cost in annual total costs is 3.62 SEK/ton. In contrast with conventional mechanical hoisting and water pumping for this schematic example, the total cost of hydraulic hoisting was approximately the same as the operating costs of conventional systems.

Qureshi and Darby (1981) point out that a set of economic parameters must be chosen as a basis for the calculation of cash flow in the economic analysis of the Methacoal pipeline. In this set, the amortization period is for 30 years, depreciation is straight line, debt/equity ratio is 0.8/0.2, the interest rate is 10%, income taxes are 50%, and the reference period for capital cost is early 1979. The sensitivity analysis of economic parameters selected such as the cost decreases with an increased amortization period, and the interest rate increases with a cost increase.

Hydraulic hoisting as an economic alternative in the deepening of underground mines has been pointed out by Sellgren and others (1989). This study demonstrates that the existing hoisting capacity can be increased by hydraulic hoisting installation with low investment and operating costs by comparing hydraulic hoisting with existing hoisting and pumping systems in the total cost analysis for a schematic mine.

Two research reports on the basic estimated capital investment and operating cost for underground coal mines have been reported by Katell and others (1975) and Duda and others (1976). The capital investment and operating costs for mines with annual production of 1.06 to 4.99 tons by continuous mining, and mines with annual production of 1.5 to 3 million tons by longwall mining are given in these studies. In Capital and

Operating Cost Estimating System Handbook (Clement, and others, 1978), provided formulas and curves that can be used in estimating various mining costs.

Canada and Sullivan (1989) state that the feasibility (or justification) analysis of prospective systems involves complex economic factors. Therefore, combining traditional engineering and financial analysis techniques with the evolving discipline of multiattribute decision analysis can be used to solve problems such as described above.

III. BASIC DESIGN OF HYDRAULIC HOISTING SYSTEMS

The most important consideration in the basic design of a hydraulic hoisting system is the selection of certain parameters so that the system can be operated at its maximum hydraulic efficiency. Some basic assumptions, engineering calculation equations, and results of the pilot-plant investigation will be adopted in this research, due to the apparent absence of the hydraulic hoisting design data. The theoretical principles underlying the design of hydraulic hoisting have been investigated by Kostuik (1966), Leeman and Laubscher (1970), Hartman and Reed (1973), and Laubscher (1973). The relationship between the parameters of hydraulic hoisting is given by their equations; however, the details of the derivations are not presented here. Those who are interested in a detailed discussion of the subject are urged to peruse the references given above.

3.1 Assumptions

The following assumptions are required for the basic design of the hydraulic hoisting system. For these assumptions, a close relationship to actual mining conditions has been aimed in making a generalized study of hydraulic hoisting.

3.1.1 Run-of-Mine Coal

Size distributions: The size distribution of run-of-mine coal depends on the structure and hardness characteristics of the coal seam and the mining method employed. The analysis of the size distribution presented in Table 3.1 has been taken from various mines that are using continuous miners in the Pittsburgh seam coal (Anderson, 1979). From this

Table 3.1 Size Distribution of Coal Produced by Continuous Mining Machines of Different Design

Size	Continuous Miner A WT%	Continuous Miner B WT%
+2 in. (50 mm)	8.72	11.70
2 x 1 1/4 in. (50 x 31.5 mm)	9.78	8.10
1 1/4 x 3/4 in. (31.5 x 19 mm)	17.55	12.10
3/4 x 1/2 in. (19 x 12.5 mm)	14.49	12.00
1/2 x 3/8 in. (12.5 x 9.5 mm)	9.78	8.00
3/8 x 1/4 in. (9.5 x 6.3 mm)	11.49	10.00
1/4 x 1/8 in. (6.3 x 3.2 mm)	11.07	13.20
1/8 in. x 30 mesh (3.2 x 0.6 mm)	10.73	15.60
-30 mesh (-0.6 mm)	6.46	9.30

Source: Anderson, 1979.

table, one can observe that the size distribution of run-of-mine coal is less than 6.3 mm (1/4 in), about 28.3 to 38.2%, and less than 3.2 mm (1/8 in), about 17.2 to 24.9%.

Current coal producers and coal washing operators recognize that longwall mining produces somewhat finer coal than that produced from continuous miners. In this research, the above data will be adopted as the data basis of the size distribution of run-of-mine coal produced by continuous miners or longwall mining systems in underground coal mines. As a result, the proposed supplementary hoisting system can contribute about 20-30% of the mine production capacity. In addition, for this size of coal a nominal diameter (d_n) of 2 mm (0.08 in) and the coal particle drag coefficient (C_D) from 1.2 to 2.0 are assumed.

Specific Gravity: In order to provide a conservative estimate for the supplementary system's design, a specific gravity value of run-of-mine coal can be chosen as 1.5 t/m^3.

3.1.2 Transport Media

In the U.S. coal industry, most below the water drainage level coal mines pump out more tons of ground water than tons of coal each year. For the old anthracite region of Pennsylvania, the average was around 36 tons of water for each ton of coal produced, and about 5-6 tons for bituminous mines (Berry, J.K., 1973). For this reason, the only transport media being considered for application in this study is that of coal mine water. The use of mine water simplifies the supplementary hydraulic hoisting system and may save money both in investment and operating costs. Assuming that the coal cleaning process is not sensitive to the coal mine water, the influence of the water quality has not been discussed in this research.

3.1.3 Coal-Water Slurries

The coal-water slurry may be divided into two major mixture classifications: settling and non-settling, according to the magnitude of the settling rate of the coal solids. Experience and laboratory tests have shown that the settling velocity of the non-settling slurry is less than 0.0006 to 0.0015 m/s and the size of coal particles less than 35 to 60 microns, so the settling slurry could be higher than this settling velocity (Govier and Charles, 1961). Since the run-of-mine coal, with particles bigger then 60 microns is to be transported by hydraulic hoisting, the coal-water slurry is considered as a settling mixture in this research. Therefore, the several parameters of the flow are combined to determine the transport regime within the pipe as shown in Figure 3.1 (Bain and Bonnington,1970). According to Figure 3.1 and the above assumptions, the coal-water slurry flow is transported by saltation (or moving bed) regimes.

3.1.4 Pumping Pipelines

The coal-water slurry will be pumped through the commercial steel pipeline. In the basic design of the hydraulic hoisting system, a pipe diameter (D) can be selected from existing pumping pipeline or standard pipe sizes. For the commercial steel pipes,

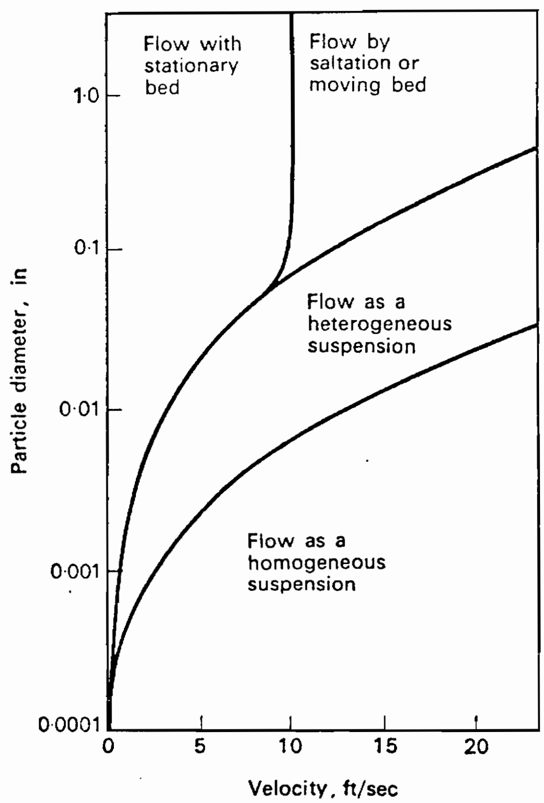


Figure 3.1 Transport Regime of the Solid-Liquid Flow

(After Bain and Bonnington, 1970)

the absolute roughness (k) can be assumed as 0.04572 mm, which will be used to calculate the friction factor (Westaway and Loomis, 1979).

3.2 Basic Design of the Hydraulic Hoisting System

The basic design of the hydraulic hoisting system in this section will be used to determine and calculate the relative parameters and the carrying capacity, velocity, concentration, power required, and hydraulic efficiency of the system. The procedures for the optimum operating conditions of the system may have to be repeated several times until the assumed and calculated parameters are achieved; however, the optimum parameters can be obtained from the repeated procedures which will be presented in the next chapter.

3.2.1 Carrying Capacity

The volume flow rate of coal solids lifted by the hydraulic hoisting system, Q_c (m^3/h), is given by

$$Q_c = \frac{T}{S} \tag{3.1}$$

where T is expected capacity of the hydraulic hoisting (t/h),

S is specific gravity of the run-of-mine coal is a chosen value of 1.5 (t/m^3).

The volume flow rate of the coal-water slurry lifted by the hydraulic hoisting system, Q_s (m^3/h), can be calculated from

$$Q_s = \frac{Q_c}{C_v} = \frac{T}{C_v\, S} \tag{3.2}$$

where C_v is volumetric hoisting concentration of coal solids, which can be obtained from equation 7 in section 3.2.3.

The volume flow rate of the water in the coal-water slurry, Q_w (m^3/h), is now given by the following equation:

$$Q_w = Q_s - Q_c = \frac{T}{S} \left(\frac{1 - C_v}{C_v} \right) \tag{3.3}$$

3.2.2 Velocity Required

For the coal-water slurry with settling velocities above 0.005 ft/s in the vertical hoisting system, providing a flow velocity that exceeds the settling velocity of the coal solids is required. The settling velocity, V_s (m/s), of coal solids to be hoisted must be determined by

$$V_s = \sqrt{\frac{4}{3{,}000}\frac{gd_n(S-1)}{C_D}} \qquad (3.4)$$

where d_n is weighted mean particle diameter (mm),

C_D is particle drag coefficient,

g is acceleration due to gravity, which is equal to 9.81 m/s^2.

The mean velocity of the coal-water slurry in the uplift pipeline, V (m/sec^2), is given by the following equation:

$$V = \frac{Q_c}{900\pi D^2 C_v} \qquad (3.5)$$

where: D is diameter of uplift or downflow pipeline (m).

The velocity of the coal-water slurry in the horizontal feeding pipeline, V_h (m/sec), is equal to 17 V_s (Kostuik, 1966).

The hindered settling velocity of a coal particle in the bed, V_s'(m/sec), may be calculated using the following equation:

$$V_s' = V_s(1 - C_v')^{\beta} \qquad (3.6)$$

where β is values assigned by the Reynolds numbers of different particles (in this study, it will be natural to assume β is equal to 1, since the particle is concerned with a moving bed in a hydraulic hoisting pipeline, along with the hindered settling velocity of the particles in the bed. For this assumption, the particles in hydraulic hoisting pipelines will seldom be of spherical uniform size [Laubscher,1973]),

C_v' is volumetric special concentration, which can be selected from section 3.2.3.

3.2.3 Concentration Required

The volumetric spatial concentration (C_v') of the coal-water slurry is a ratio of the volume of solids to the volume of slurries present in any section of the system. As a start, a value lying in the range of 0.20 to 0.35 may be selected (Laubscher,1973). The volumetric hoisting concentration of coal, C_v, may be calculated from

$$C_v = \frac{C_v'}{1 + \dfrac{900\, C_v' V_s' \pi D^2}{Q_c}} \tag{3.7}$$

3.2.4 Power required

The actual power required for a hydraulic hoisting installation for two types of systems has been included in the following components (Chapus and others, 1962;

Leeman and Laubscher, 1970; Laubscher, 1973):

1. The power required to overcome the friction head loss in the water supply pipeline, P_1 (kW), is given by

$$P_1 = \frac{\rho_w Q_w g H_d}{3600 \times 10^3} \tag{3.8}$$

where Q_w is total required water of the system (m^3/h),

H_d is friction loss in water supply pipeline, according to the Darcy-Weibach equation, H_d is given as follows:

$$H_d = \frac{f_2 V_f^2 H_f}{2 g D_f}$$

f_2 is Darcy-Weibach friction factor for the water supply pipes (m), which can be obtained from the well-known Reynolds number versus friction factor curves (see Figure 3.2). Using this figure, the Reynolds number of the pipe (N_R) and relative roughness (R) are given by (Warring,1984)

$$N_R = \frac{D V}{\mu} \tag{3.9}$$

$$R = \frac{k}{1{,}000 D} \tag{3.10}$$

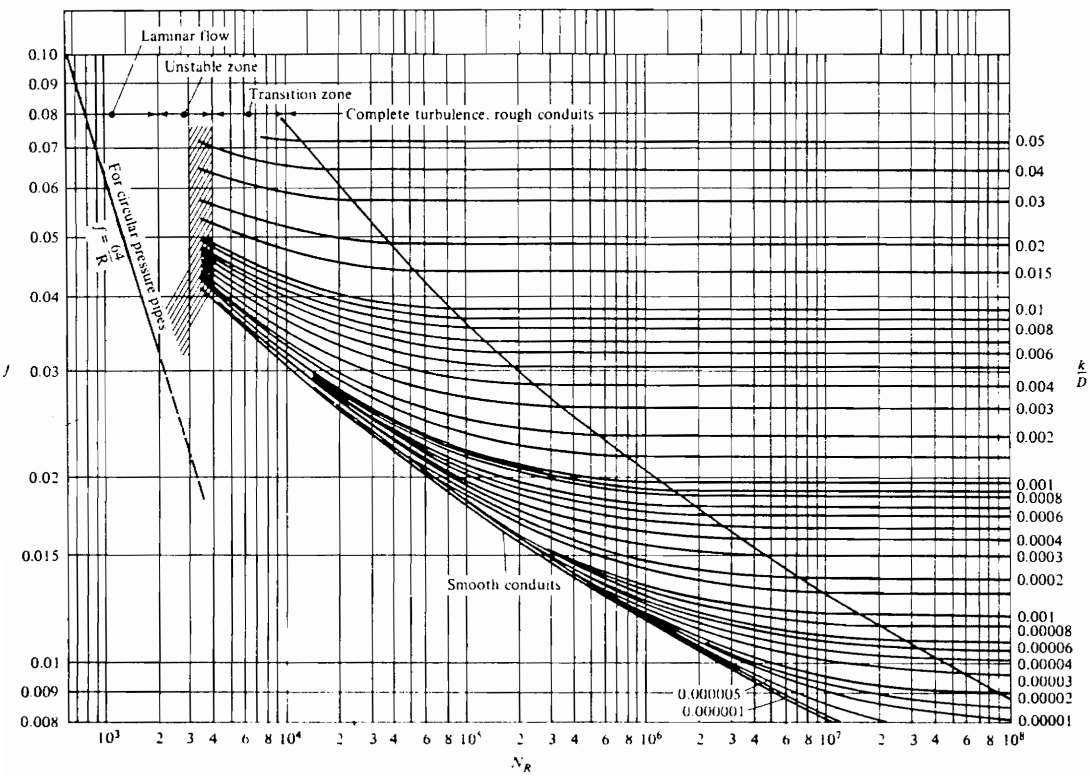


Figure 3.2 Friction Factors for Pipes

(After Warring, 1984)

where ρ_w is density of water equals 1 t/m^3 in this study,

μ is Kinematic viscosity of water varies with temperature, the range is 74 x 10^{-8} to 74 x 10^{-7} m^2/s (Kostuik, 1966),

H_f is length of water supply pipeline (m) (for the open system: $H_f = L_1$, for the circulating system: $H_f = H_2 + L_1 + L_2$),

V_f is velocity of the supply water (m/s),

D_f is diameter of the water supply pipeline (m),

$V_f = 0.75$ V and $D_f = 0.75$ D are assumed in this study.

2. The power required to overcome the friction head loss of the coal-water slurry in the uplift pipeline or horizontal pipeline, P_2 (kW), can be calculated from the following equation:

$$P_2 = \frac{f_1 \rho_s Q_s H V^2}{7200 D \times 10^3} \tag{3.11}$$

where f_1 is Darcy-Weibach friction factor for the uplift pipes and can be obtained same to f_2,

ρ_s is density of the coal-water slurry (t/m^3),

H is the sum of the vertical and horizonal length of the slurry pipeline (m) and $H = H_2 + L_1 + L_2$.

3. For the open system, the power required to lift the coal-water slurry in the uplift pipeline, P_3 (kW), is given by

$$P_3 = \frac{\rho_s Q_s g H}{3600 \times 10^3} \tag{3.12}$$

where ρ_s is the density of coal-water slurry (t/m_3) and expressed as

$$\rho_S = \rho_w [1 + C_v (S - 1)]$$

For the circulating system, the power required to lift the coal up the height H_2 in the upflow pipeline, P_3 (kW), is given by

$$P_3 = \frac{\rho_c Q_c g H_2}{3600 \times 10^3} \tag{3.13}$$

4. The power required to overcome the static head of the displaced water, which is set free by the feeder, P_4 (kW), is given by the following expression:

$$P_4 = \frac{\rho_w Q_c g H}{3600 \times 10^{-3}} \tag{3.14}$$

5. The power required to overcome the friction loss in the displaced water pipeline, P_5 (kW), can be calculated as follows:

$$P_5 = \frac{\rho_w Q_c g H_{dw}}{3600 \times 10^3} \tag{3.15}$$

where H_{dw} is friction loss in water supply pipeline (m), according to the Darcy-Weibach equation, H_{dw} is given as follows

$$H_{dw} = \frac{f_3 V_{dw}^2 H_{dw}}{2 g D_{dw}}$$

f_3 is Darcy-Weibach friction factor for the water supply pipes, which can be obtained using the same method for f_2 in section 3.2.4,

V_{dw} is velocity of the displaced water (m/s), which may be given by

$$V_{dw} = \frac{Q_c}{900 \pi D_{dw}^2} \tag{3.16}$$

where D_{dw} is internal diameter of the displaced water pipeline (m),

if V_{dw} is selected from Table 3.2, D_{dw} can then be obtained from equation 3.16.

Table 3.2 Recommended Delivery Flow Velocities

Pipe Bore		Water		Light Oils		Boiling Liquids		Viscous Liquids	
mm	inches	m/sec	ft/sec	m/sec	ft/sec	m/sec	ft/sec	m/sec	ft/sec
25	1	1.00	3.5	1.00	3.5	1.00	3.5	1.00	3.5
50	2	1.10	3.6	1.10	3.6	1.10	3.6	1.10	3.6
75	3	1.15	3.8	1.15	3.8	1.15	3.8	1.15	3.7
100	4	1.25	4.0	1.25	4.0	1.25	4.0	1.25	3.8
150	6	1.50	4.7	1.50	4.7	1.50	4.7	1.50	3.9
200	8	1.75	5.5	1.75	5.5	1.75	5.5	1.75	4.0
250	10	2.00	6.5	2.00	6.5	2.00	6.5	2.00	4.5
300	12	2.65	8.5	2.65	6.5	2.65	6.5	2.65	4.5
	over 12*	3.00	10.0						

* General formula: pipe diameter (inches) = √(gal/min)/20
Source: Warring, 1984.

6. The power requirements (P_4 and P_5) are used in the calculation of the lock-hopper feeder and the displaced water must be directly pumped to the surface.

7. The power required to introduce the coal-water slurry at the bottom of high pressure pipeline (in Figure 2.13, after a hoisting cycle, each chamber is left filled with coal-water slurry which must overflow while loading dry coal again, therefore, an amount of this overflow slurry is same as the loaded coal by use Lock-Hopper feeder will be introduced into upflow pipeline by the additional power; for the Hydro-Hoist feeder, the slurry will be introduced into feeder from coal-water mixing tank), P_6 (kW), is given by the following equation:

$$P_6 = \frac{\rho_s Q_c g H}{3600 \times 10^3} \tag{3.17}$$

8. The power required to overcome the shock and velocity head loss in upflow and water supply pipelines, P_8 (kW), may be assumed as a 15% of the total above required power.

The total theoretical power required for the hydraulic hoisting system, P_t (kw), is dependent upon the configuration used for the hydraulic hoisting system.

The hydraulic efficiency (η_H) of a hydraulic hoisting system can be calculated as follows

$$\eta_H = \frac{P_t}{P_a} \qquad (3.18)$$

where P_a (kW) is actual power required for the hydraulic hoisting system.

In order to obtain the overall efficiency of the installation of the supplementary hydraulic hoisting system, the hydraulic efficiency needs multiplied by the mechanical efficiency of the system equipment.

IV. SUPPLEMENTARY HYDRAULIC HOISTING SYSTEMS

The purpose of this study is to investigate the feasibility of the hydraulic hoisting system as a supplementary system in order to increase the production capacity of existing coal mines where maximum production is constrained by existing mechanical hoisting systems. In these coal mines, although the present conditions are quite different for the installation of supplementary hydraulic hoisting systems, a major factor is whether the mine possesses enough mine water to be used for the supplementary system, since this factor will be used to determine the configurations of the system.

In the configuration of the supplementary hydraulic hoisting system, there are essentially two major variations to be considered in the basic design of the system. The variations are an open system and a circulating system. The open system requires only one length of pipe extending from the shaft bottom to the surface with all pumping facilities located within the mine. For this system, the mine water as a transport media is coming from the existing dewatering system within the mine. The circulating system consists of two pipelines. The transport water is pumped from some type of receptacle down the pipe to the shaft bottom; on this level the coal to be transported is introduced into another pipeline and carried back to the surface by water. The coal is separated from the water on the surface and the black water is then recirculated.

It is obvious that if the mine is operating with a full pumping rate and dewatering installations, an open supplementary hydraulic hoisting system can be installed to increase the capacity of the existing mechanical hoisting system; on the other hand, the circulating system will be adopted for the same objectives. In this chapter, both the open and circulating types of supplementary hydraulic hoisting systems will be discussed.

4.1 Open Hydraulic Hoisting Systems

The open hydraulic hoisting system is defined as a combination of the present dewatering system and a supplemental coal feeding system. Therefore, in an open system, the different types of pumps in the dewatering installations and feeding system will be operated in parallel, where the combined performance characteristics can be found by adding the capacities. In this combined system, if a centrifugal pump in the dewatering system will be paralleled to the positive displacement pump of the feeding system, the characteristic curve of the combined pump will be the same as the centrifugal pump curve, but the capacity will be the sum of two discharges.

The size distribution of the run-of-mine coal is 6.3 mm and -6.3 mm, about 28.89

to 38.15% (Leonard,1979). In practical applications, this percentage in the coal production is generally higher than the expected capacity of the supplementary hydraulic hoisting system for the existing coal mines. Therefore, the particle size of the pumping coal solids will be smaller than 6.3 mm, which can be considered as fine solids in this study. The coal solids will be mixed with water to the required concentration and introduced to the existing dewatering pipeline by the coal-water feeder. In the combination of the existing dewatering and supplementary feeding systems, the feeder will be used to supply a highly concentrated coal-water slurry into the pipeline in which the high-pressure water stream dilutes the slurries and hoists them to the surface. For this reason, the feeders may include injection systems, Mars pumps, Jupiter pumping systems, Hitachi slurry hydro-hoists, positive displacement pumps, rotary and lock-hopper type feeders. The principles and operations of this equipment are presented in Chapter 2.

4.1.1 Layout of Open Hydraulic Hoisting Systems

The layout of the open hydraulic hoisting system in the coal mine is dependent upon existing conditions. In this study, the layout of the feeding system in the open system will be considered since the high-pressure water stream system is assumed to be present in the coal mine. The overall general layout of the open hydraulic hoisting system is schematically shown in Figure 4.1.

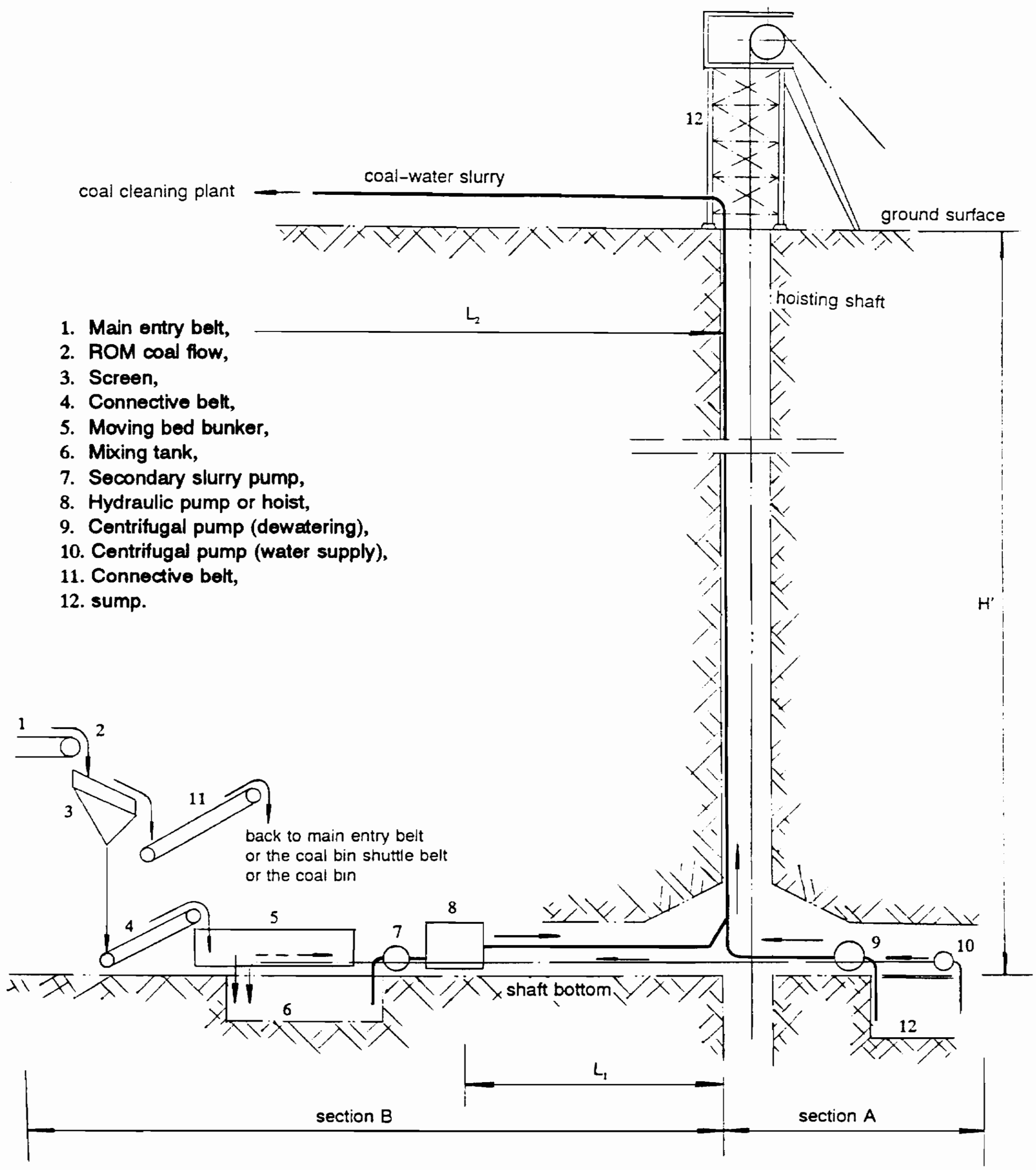


Figure 4.1 Layout of the Open Hydraulic Hoisting System

Section A of Figure 4.1 illustrates the mechanical hoisting and dewatering system in the coal mine. The dewatering installations will be integrated with supplementary hydraulic feeding systems to carry the coal solids by the high-pressure water stream to the surface. However, the mechanical hoisting is still used to hoist a great portion of the coal production. The horizontal pipeline on the surface is newly installed to deliver the coal-water solids to the coal cleaning plant from the top of the uplift pipeline.

Section B of Figure 4.1 is the supplementary hydraulic feeding system. The screen is used to separate coal size and supply the finer coal (-6.3 mm) to the hydraulic feeder. The screen can be installed at any convenient place between the front and the end of the main entry belt. A connecting slope belt receives the finer coal solids from the screen and then delivers them to the hydraulic feeder, coal-water mixed tank, finer coal bin, and moving-bed bunker. Another connecting slope belt or screw conveyor delivers the coal from the bin or bunker to the hydraulic feeder.

The coal and water can be mixed in the feeder or mixing tank depending upon the type of feeder. The horizontal pipelines in sections A and B are used for the mine water supply and the coal-water slurry delivery.

In the layout of the supplementary hydraulic hoisting system, the first consideration is the availability of existing equipment and tunnel layout. Next, the position of the major equipment of the feeding system should be arranged in order to reduce excavation of the additional space needed for the installation of the supplementary equipment.

4.1.2 Existing Dewatering Systems

In underground coal mines, there is usually a considerable inflow of ground water which must be pumped to the surface. A dewatering system, consisting of pumps, pump motors, starters, controls, electrical supplies, a pump station, and pipelines, should be installed. In the dewatering system, the pumps are the chief elements. There are basically two types of pumps to be used which must be fully understood. The reciprocating pump is the most efficient for relatively small capacities, high heads, and automatic operation; however, it is a high maintenance device because of its valve action. The centrifugal pump is by far the most popular for mine pumping, since it can handle large quantities of water and can be staged (connected in series) to operate against extremely large heads.

The dewatering system moves the water from a point in the mine to the surface. Energy is introduced into the system via the pump to overcome the total dynamic water heads, H_t (m), is given by

$$H_t = H_S + H_f + H_{sh} + H_v \tag{4.1}$$

where H_s is total static head representing difference in elevation between the level of water at the source to the point of discharge (m),

H_f is frictional head produced by resistance of water flowing in the pipes (m), calculated by the empirical formula as

$$H_f = \frac{f_w \, L V_w^2}{D} \tag{4.2}$$

where L is length of the pipeline (m),

D is diameter of the pipeline (m),

V_w is velocity of mine water (m/s),

f_w is Darcy-Weisbach friction factor of the water supply pipeline (obtained by the same procedure in section 3.2.4),

H_{sh} is shock losses due to changes of water flow produced by fittings and given by

$$H_{sh} = f_t f_w \, V^2 \tag{4.3}$$

where f_t is the table factor of the equivalent length of the straight pipe for different fittings, given in Table 4.1 (Warring, 1984),

Table 4.1 Equivalent Straight Lengths of Fittings

Fittings	Factor	Fittings		Factor
Flash sharp-edged entry	20-25	Tee:	Straight through	10
Slightly rounded entry	10-12		Side outlet, sharp angled	50-55
Flush bell-mouth entry	4		side outlet, radiused (swept tee)	20-25
Sharp entry projecting into liquid	35	Branch piece, straight through		10
Bell-mouth entry projecting into liquid	10	Branch piece, flow to branch		45
Foot-valve with strainer	100	Branch piece, flow from branch		22
Round elbow	45	Bell-mouth outlet		9
Short radius bend	30-35	Sudden enlargement		45
Medium radius bend	15	Taper, divergence angle above 60°		45
Close return bend	100	Taper increase or reduces with		22
Less than 15° divergence angle	1			

Note: Equivalent Length = Table Factor X Pipe Diameter in Same Length Unit as Diameter.
Source: Warring, 1984.

H_v is velocity head of water moving at a given velocity in the equivalent head through which it would have to fall to acquire the same velocity (m). However, this is so small that it is ignored in the calculations.

In the dewatering system, the theoretical minimum amount of power required for a pump to drive the water, P_{wt} (kW), is expressed as

$$P_{wt} = \frac{Q_{wl}\,\rho_w\, g H_t}{3600 \times 10^3} \tag{4.4}$$

where Q_{w1} is volume flow rate of mine water to be pumped out, (m^3/h).

The brake power, P_{wb} (kW), is an amount of power which must be delivered to the input shaft of the pump and can be obtained from

$$P_{wb} = \frac{P_{wt}}{E} \tag{4.5}$$

where E is efficiency of the pump as a decimal.

4.1.3 Design of Open Hydraulic Hoisting Systems

The open hydraulic hoisting system in this study is a combined system in which a supplementary feeding system is integrated in the mine dewatering installations. The open hydraulic hoisting system is schematically show in Figures 4.2 to 4.4. The following data for the design of a hydraulic hoisting system need to be collected from the existing coal mine:

T is expected capacity of the supplementary hoisting, metric million tons per year (MMTPY),

Q_{w1} is existing pumping rate of the mine (m^3/h),

P_{wb} is brake power required of one pipeline (kW),

D is diameter of dewatering pipes (m),

H is hoisting depth (m),

L_1 is horizontal distance of the feeding pipeline in the mine (m),

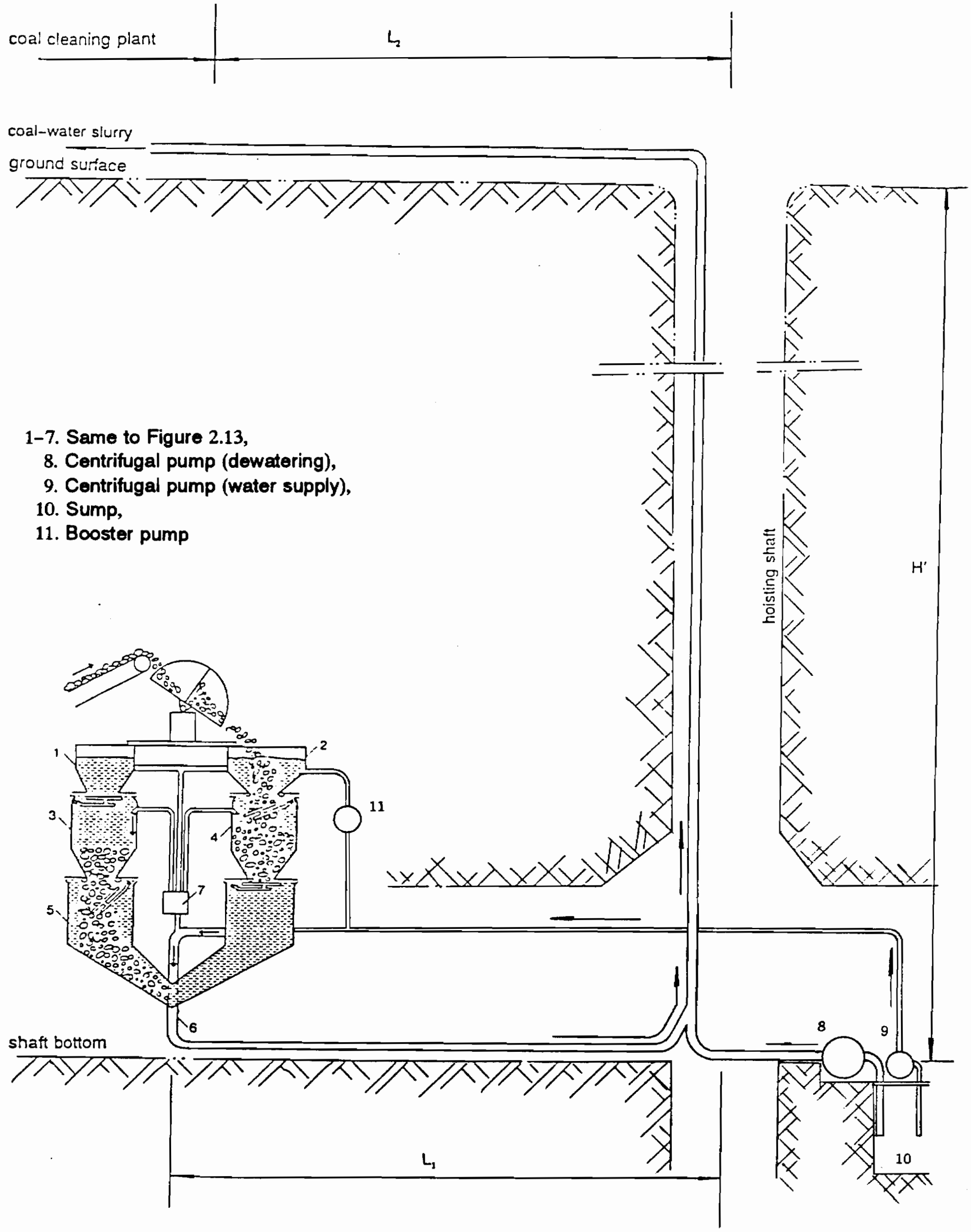


Figure 4.2a Schematic Arrangement of the Lock-Hopper and High-Pressure Water Stream Hoisting in the Open System

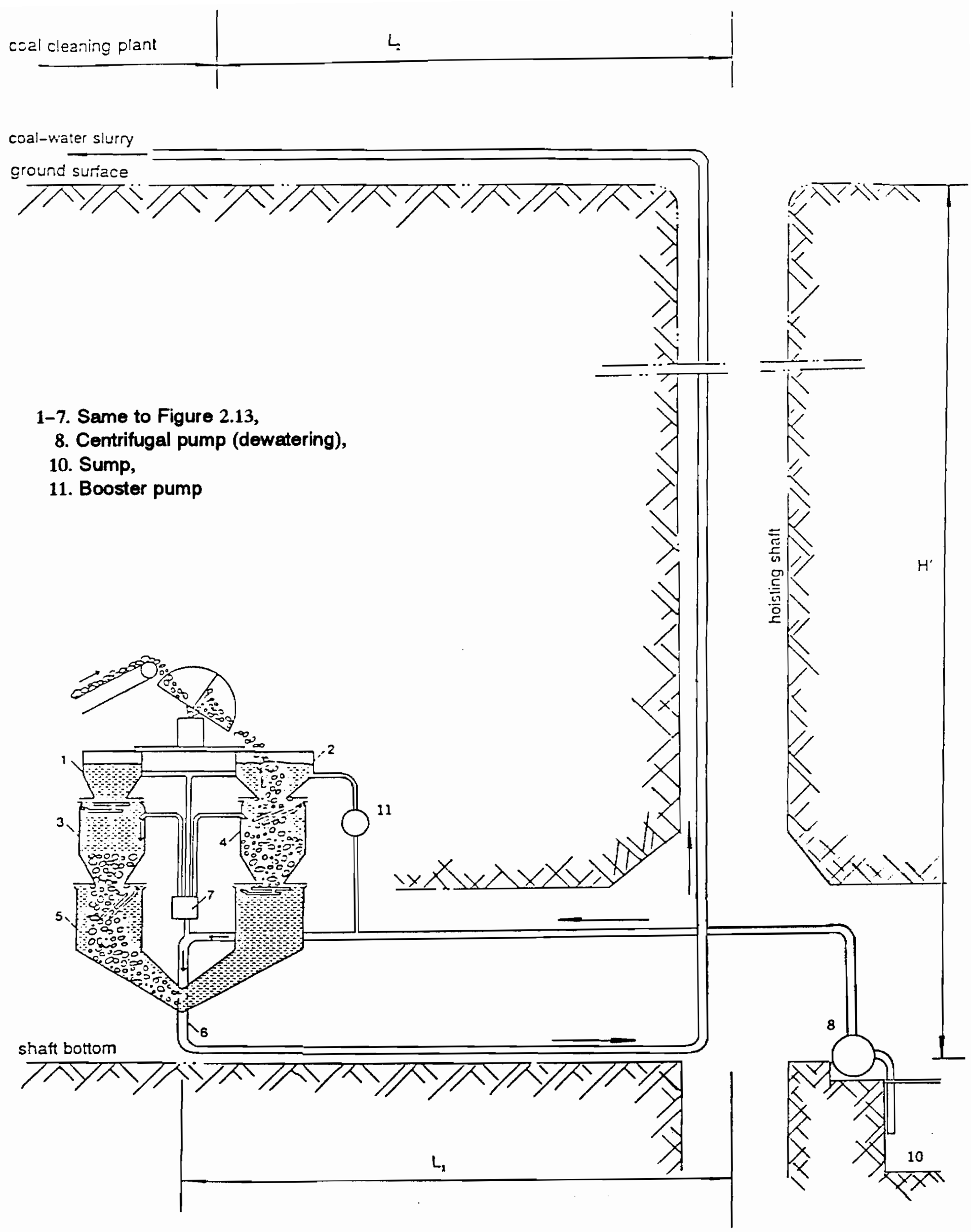


Figure 4.2b Schematic Arrangement of the Lock-Hopper and High-Pressure Water Stream Hoisting in the Open System

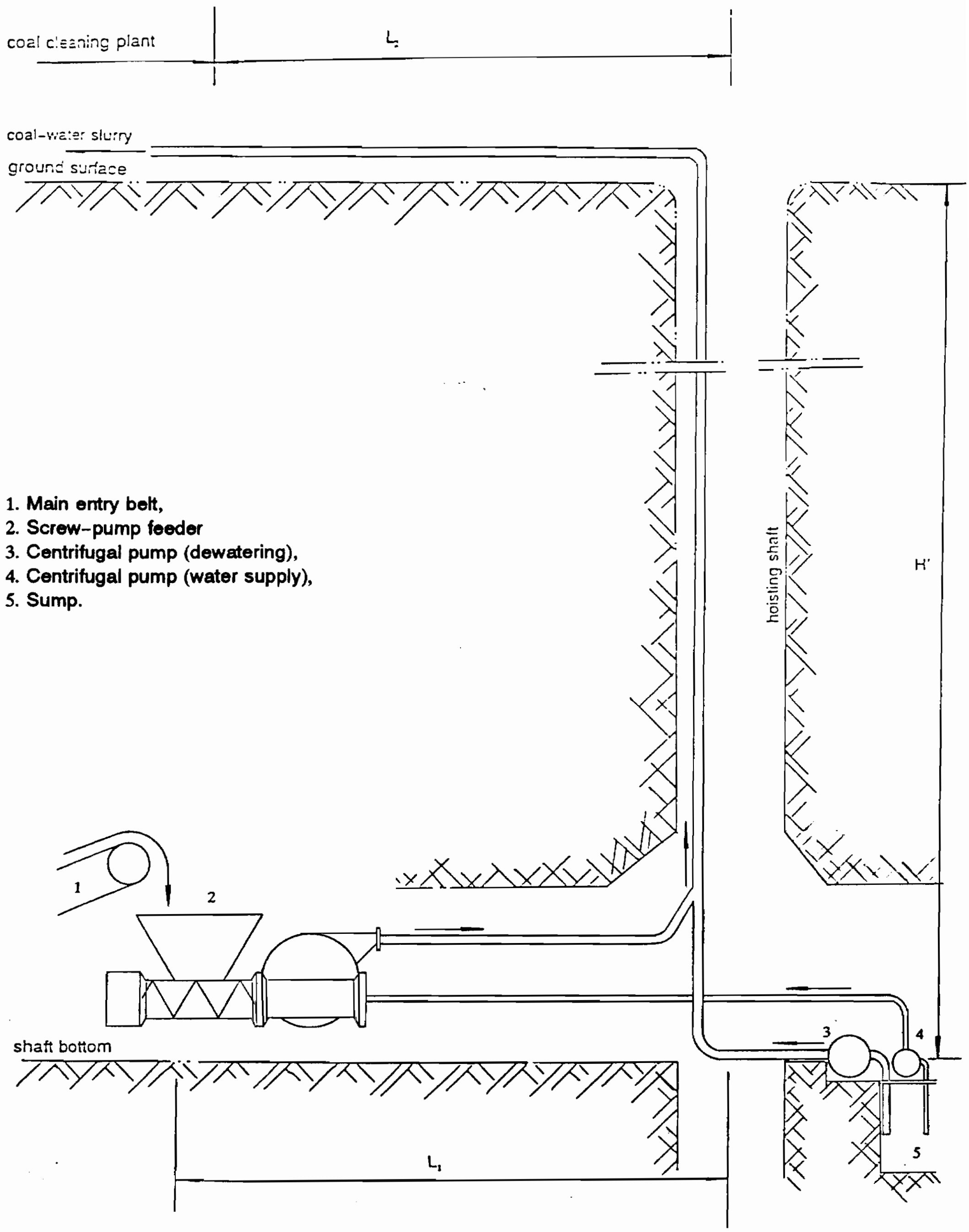


Figure 4.3 Schematic Arrangement of the Screw-Pump and High-Pressure Water Stream Hoisting in the Open System

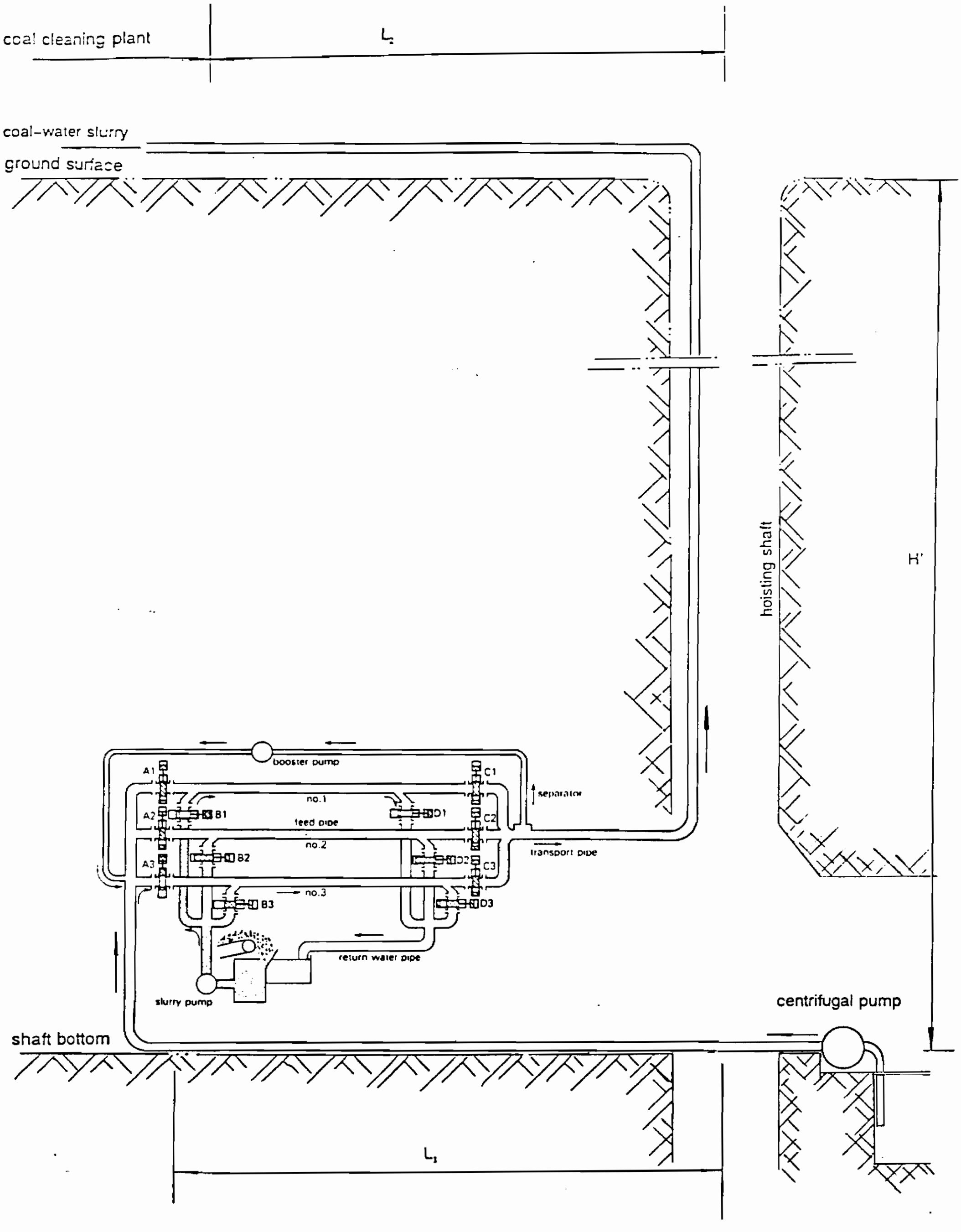


Figure 4.4a Schematic Arrangement of the Hitachi Hydrohoist in the Open System

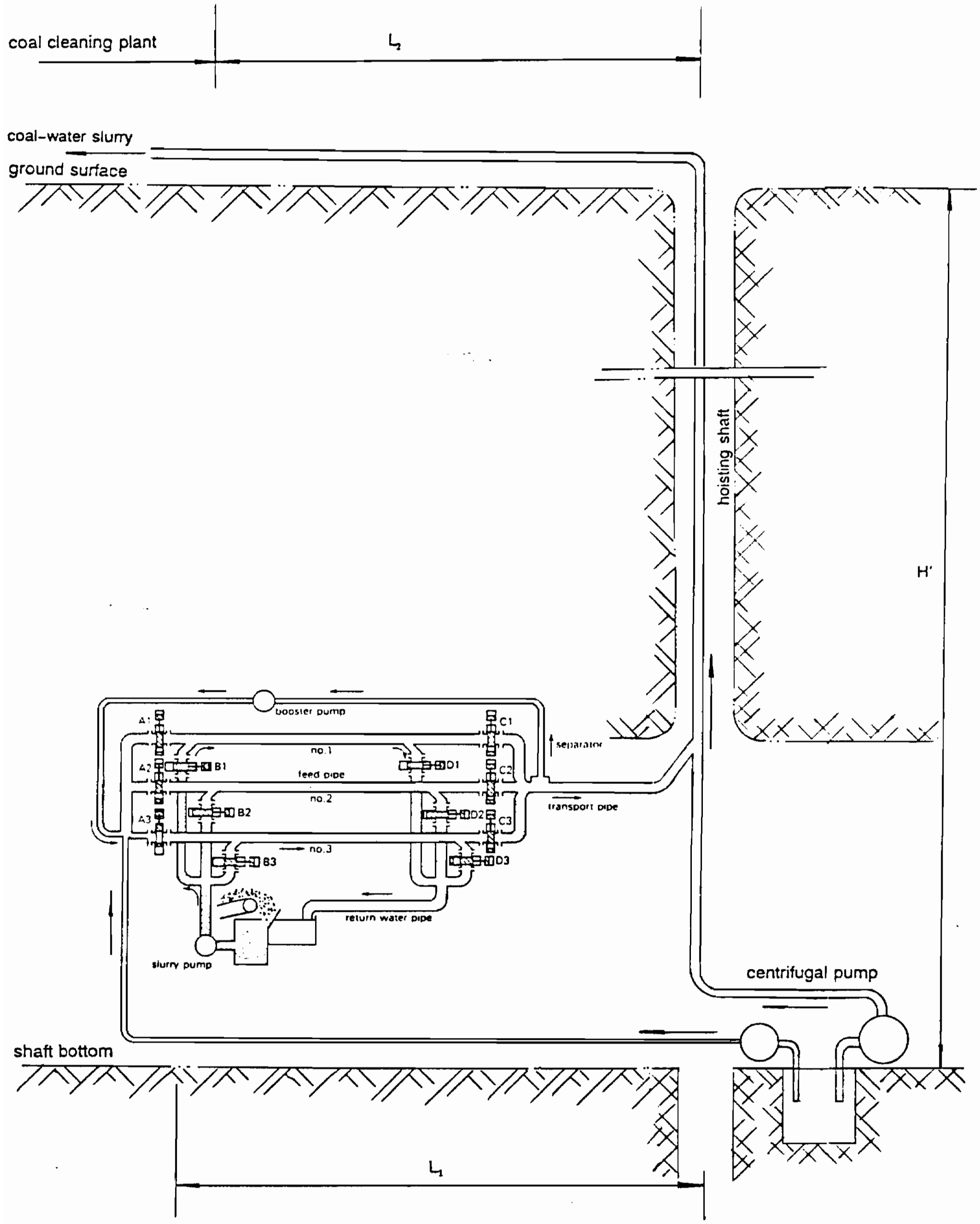


Figure 4.4b Schematic Arrangement of the Hitachi Hydrohoist in the Open System

L_2 is horizontal distance between coal cleaning plant and shaft top (m),

d_n is weighted mean nominal diameter of run-of-mine coal (mm),

S is specific gravity of run-of-mine coal (t/m^3).

According to the conditions given above, the calculations for the design of the hydraulic hoisting system can be done by the following procedures

Calculation for the uplift pipeline:

1. The volume flow rate (Q_c) of coal solids that will be pumped to the surface through the existing uplift pipeline is given by equation 3.1. If the number of uplift pipelines is greater than one, and if one pipeline can't satisfy the requirements of the expected capacity of the supplementary hydraulic hoisting, other uplift pipelines can be paralleled as an uplift pipeline for the following calculation. In this case, the diameter of the uplift pipeline, D, is approximately equal to the equivalent diameter of the paralleled uplift pipeline and can be calculated from

$$D = \sqrt{\frac{4nA}{\pi}} \tag{4.6}$$

where A is the cross-sectional area (m^2) of one uplift pipeline, and n is the number of uplift pipelines which will be paralleled for use in the hydraulic hoisting system.

2. The volumetric hoisting concentration (C_v) of coal solids in the shaft uplift pipeline can be calculated using equation 3.7 where the volumetric spatial concentration (C_v') settling velocity of coal solids (V_s) and the hindered settling velocity (V_s') of a particle in the bed are selected and calculated from sections 3.2.2 and 3.2.3.

3. The mean velocity (V) of the coal-water slurry in the shaft uplift pipeline is determined by equation 3.5. This value should be greater than 2.5 V_s (Laubscher, 1973), and if this condition is not fulfilled, other parameters for C_v may have to be adopted and the above calculations for C_v need to be repeated.

4. The volume flow rate (Q_w) of the water in the coal-water slurry of the shaft uplift pipeline is given by equation 3.3. If the volume flow rate of mine water (Q_{w1}) is less than Q_w, the circulating type of supplementary hydraulic hoisting systems will be installed.

5. The total theoretical power required to drive the coal-water slurry from the shaft bottom to the surface coal cleaning plant at a rate of Q_s through the shaft uplift pipeline and surface horizontal pipeline in the open system (P_{to}) is now given by the following equation:

$$P_{to} = (P_1 + P_2 + P_3 + P_6) \times 1.15 \qquad (4.7)$$

where P_1 is Power required to overcome the friction head loss of the water in water supply pipeline and given by equation 3.8 (in which $H = L_1$),

P_2 is power required to overcome the friction head loss of the coal-water slurry in the shaft uplift pipeline and surface horizontal pipeline and given by equation 3.11 (in this equation $H = H' + L_1 + L_2$),

P_3 is the power required to pump the coal-water slurry through the uplift pipeline to the coal washing plant and is given by equation 3.12 (in which $H = H' + L_1 + L_2$),

P_6 is power required to introduce the slurry into the high pressure pipeline in feeding station by using Lock-Hopper feeder and given by equation 3.17 (in which $H = H'$),

the shock and velocity head loss of the system is assumed as 15% of the total above required power components.

Supplementary power required for the open hydraulic hoisting:

Since the existing high-pressure water stream can be used for the open hydraulic hoisting system to lift the coal from the feeding station in the mine to the cleaning plant on the surface, the power required for these dewatering installations can be excluded from the total required power of the supplementary hoisting system.

4.2 Circulating Hydraulic Hoisting Systems

To increase the production capacity of a mechanical hoisting system for an existing coal mine, the circulating hydraulic hoisting system as a supplementary system can be used in a mine where mine water is not sufficient to transport the coal solids in an expected capacity to the surface.

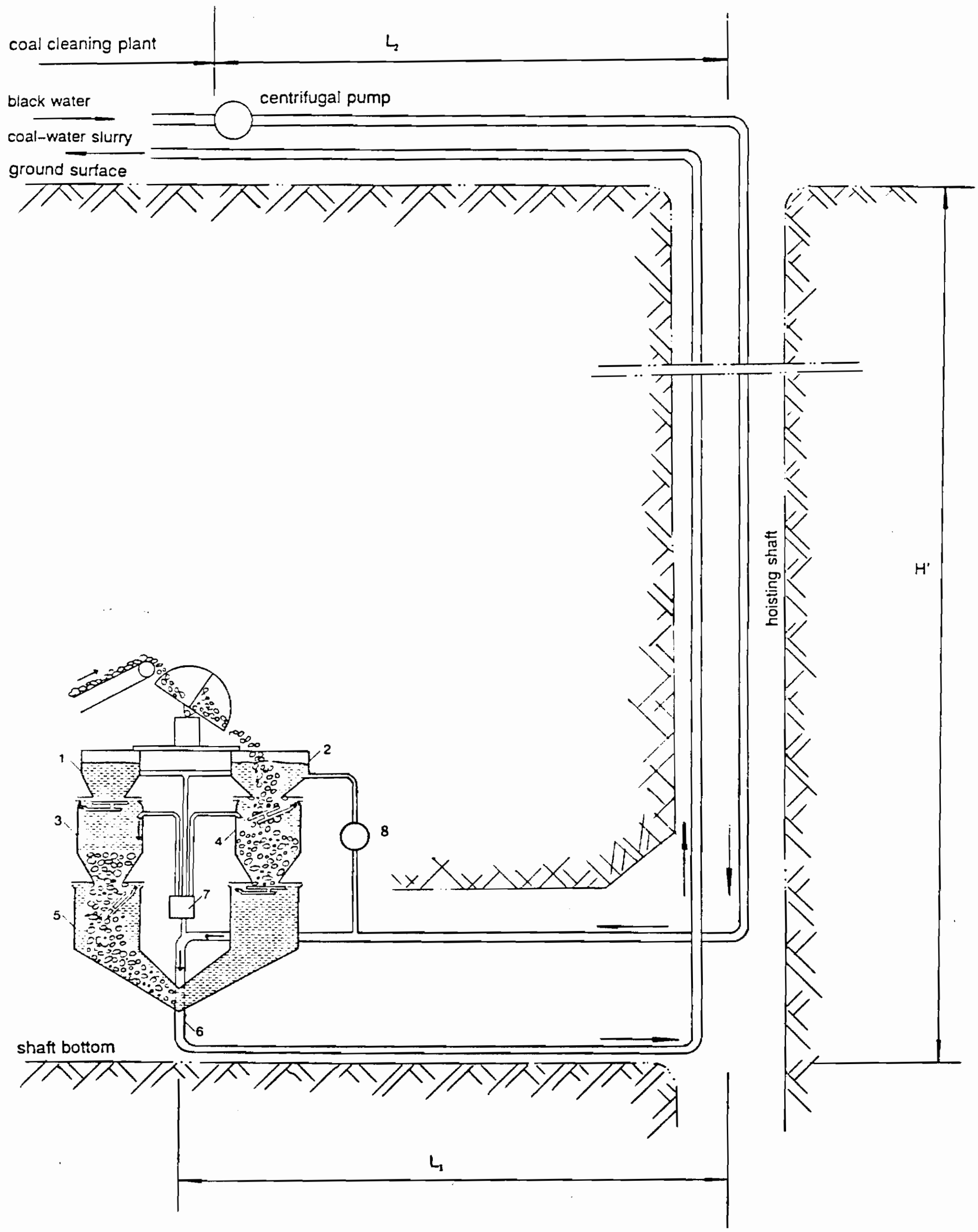
When the total inflow of ground water to the mine is not enough to satisfy the water requirement of hydraulic hoisting systems, all the present ground water and the dewatering system still need to be considered as a proper subsystem to be used in the hydraulic hoisting system. Under this circumstance, the difference between the water required for the hydraulic hoisting and the total inflow of ground water will be supplemented by a recirculating system. Therefore, the dewatering equipment in the mine can be used to produce a high-pressure water stream for hoisting, or as a water supply to the feeder, and is dependent on the difference in the amount of water.

In the following discussions, the coal mine has no ground water available as a transport media resource. This will be a specific example to be considered in the design of the circulating hydraulic hoisting system.

4.2.1 Layout of Circulating Hydraulic Hoisting Systems

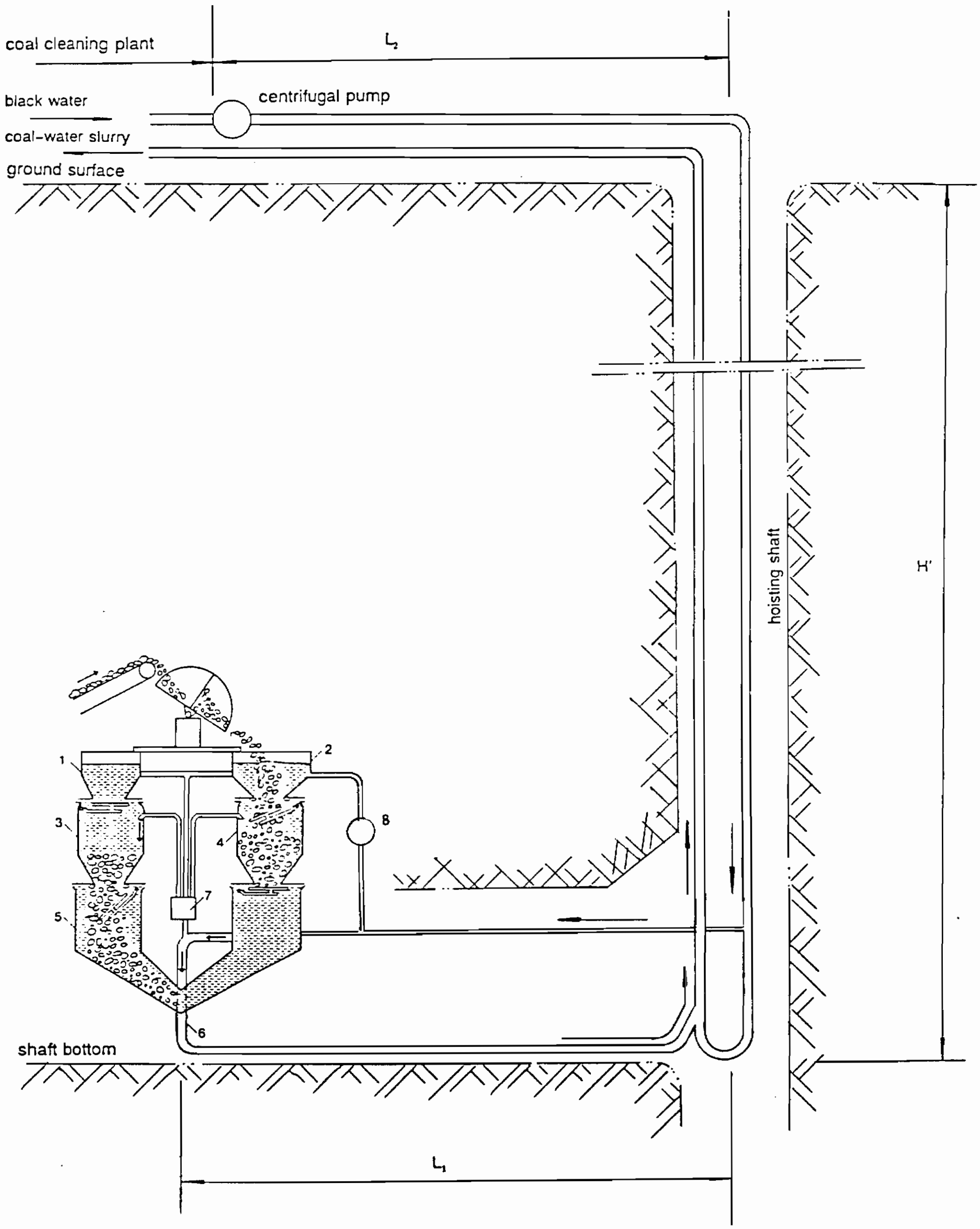
The installation of the circulating hydraulic hoisting system in an existing coal mine assumes that all water required must be taken from the recirculating system of the transport water. The overall layout of the circulating hydraulic hoisting system is schematically shown in Figures 4.5 to 4.7.

The circulating hydraulic hoisting system consists of a centrifugal pump, dewatering or decanting devices, transport pipeline, screen, temporal storage bunker, and connecting belts, etc. In this model, the layout of the screen, temporal storage bunker, and connecting belt is similar to the open system. One side of the circulating pipeline is used to lift the coal-water solids to the surface, and the other side is used to deliver the high-pressure water to the feeding station. The centrifugal pump is situated on the surface to produce the high-pressure water stream. The water stream runs down through the water pipeline to the coal feeding station in the mine. Here a lock-hopper, Hitachi hoist, or screw-pump feeder is used to introduce the coal solids or coal-water slurries into the high-pressure pipeline. The coal is then entrained through the uplift side of the pipeline to the surface. The coal is separated from the water by dewatering or decanting devices at the coal cleaning plant, and the separated water and



1-7. Same to Figure 2.13, 8. booster pump.

Figure 4.5a Schematic Arrangement of the Lock-Hopper and High-Pressure Water Stream Hoisting in the Circulating System



1-7. Same to Figure 2.13, 8. booster pump.

Figure 4.5b Schematic Arrangement of the Lock-Hopper and High-Pressure Water Stream Hoisting in the Circulating System

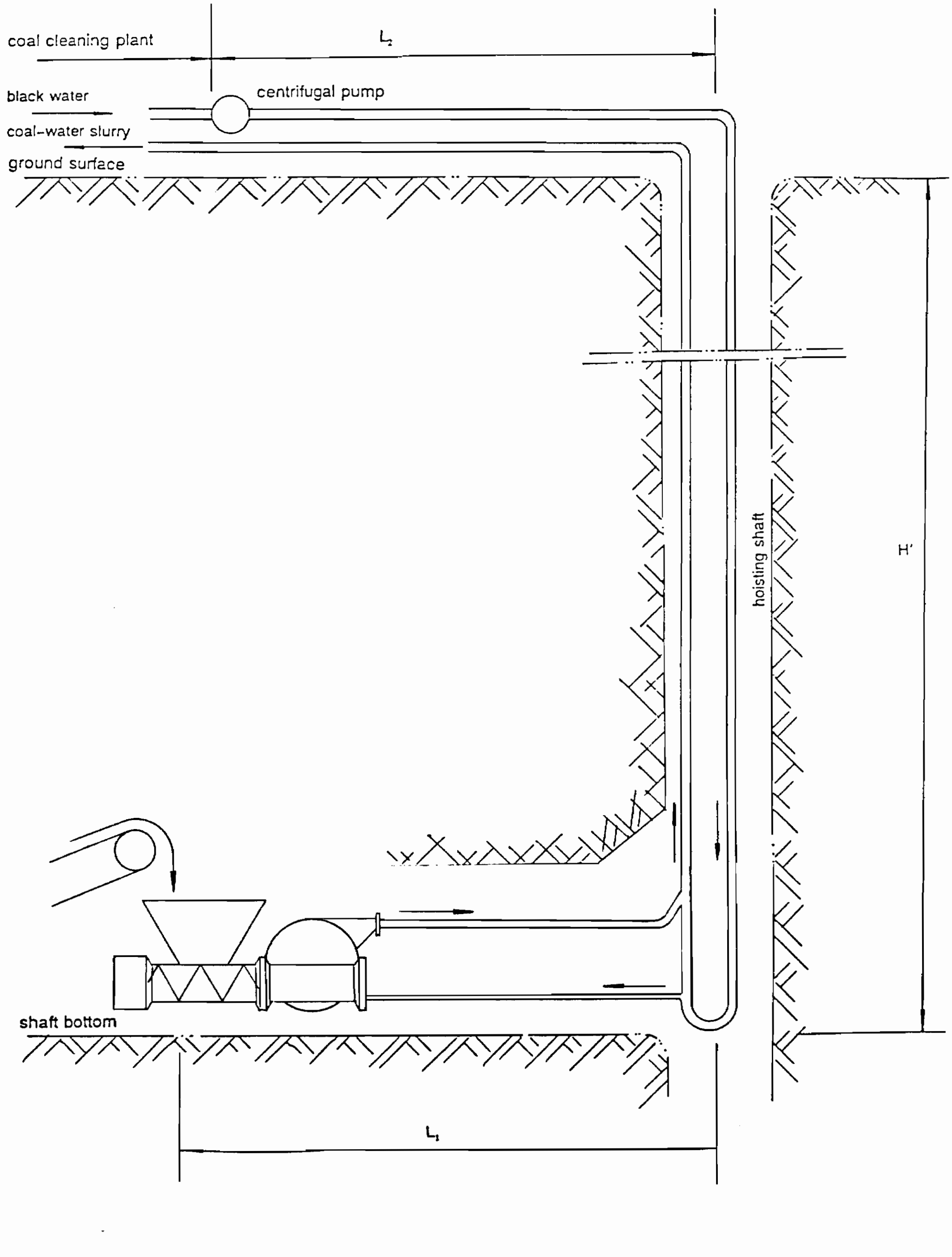


Figure 4.6 Schematic Arrangement of the Screw-pump and High-Pressure Water Stream Hoisting in the Circulating System

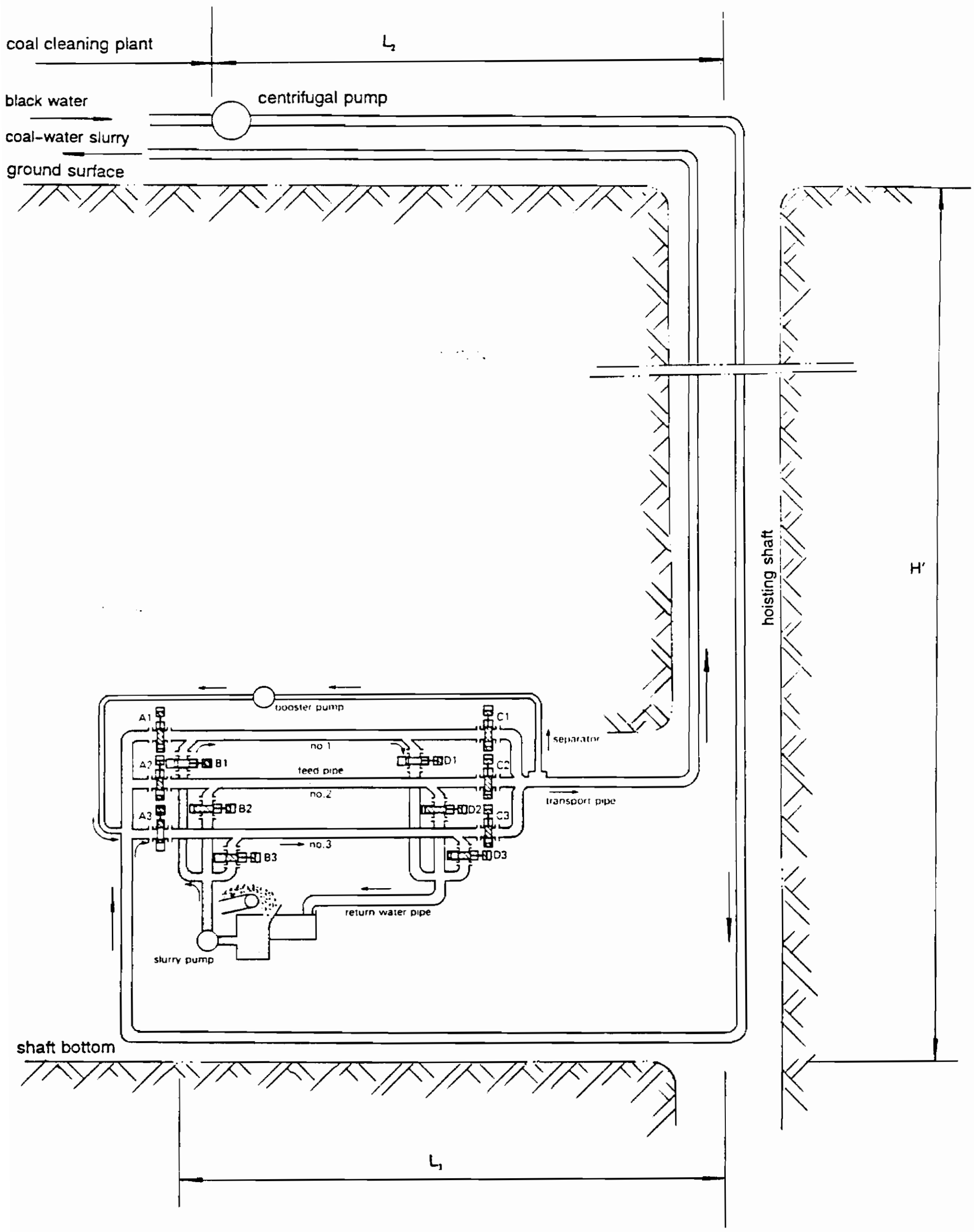


Figure 4.7a Schematic Arrangement of the Hitachi Hydrohoist in the Circulating System

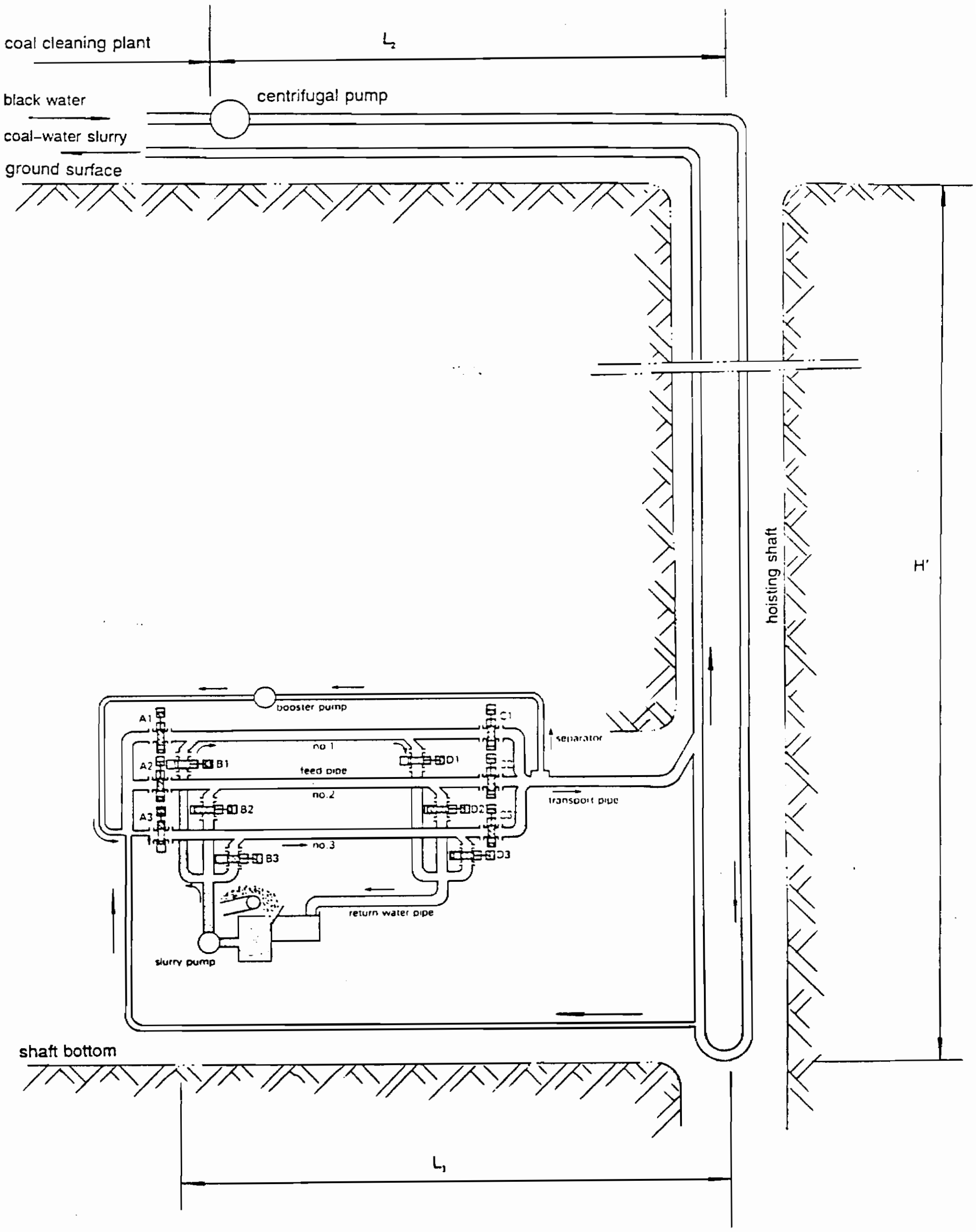


Figure 4.7b Schematic Arrangement of the Hitachi Hydrohoist in the Circulating System

some replenished water are then recirculated.

For the circulating hydraulic hoisting system, the sizes of the lock-hopper feeder (see Figure 2.13) and screw-pump feeder (see Figure 2.9) are smaller and self-mixing. Therefore, the new space required is less than for Hitachi hoist feeders. However, Hitachi hoist feeders may be suitable for the feeding station or coal cleaning plant if there are located far away from the mine hoisting shaft. In this study, when the Hitachi hoist is chosen, the high-pressure pump is still installed on the surface to reduce equipment and improve operating conditions.

4.2.2 Design of Circulating Hydraulic Hoisting Systems

In this study it is assumed that the circulating hydraulic hoisting system as an independent system will be installed in the existing coal mine where no ground water can be used as a transport media of the supplementary hoisting system. From the coal mine data, the expected capacity of the supplementary hoisting, hoisting depth, distance between coal cleaning plant and hoisting shaft top, distance between the feeding station and the hoisting shaft bottom, and weighted mean nominal diameter of run-of-mine coal can be collected and used for the design of a supplementary hoisting system. The carrying capacity, velocity, concentration, and power required for the circulating hoisting system can be calculated by using equations 3.1 to 3.17 in Chapter III; and other calculations are shown as follows:

Total theoretical power required of circulating systems

The total theoretical power required to lift the coal-water slurry from the feeding station in the mine to the coal cleaning plant on the surface by the circulating hydraulic hoisting system (P_{tc}) is dependent upon the feeder type.

When the lock-hopper feeder is used in the hoisting system (see Figure 4.5a; in this case, the feeding station is located near the hoisting shaft bottom), the total theoretical power required (P_{tc}) can be calculated by the following expression

$$P_{tc} = (P_1 + P_2 + P_3 + P_6) \times 1.15 \tag{4.8}$$

where P_1 is Power required to overcome the friction head loss of the water in water supply pipeline and given by equation 3.8 (in which $H = H' + L_1 + L_2$),

P_2 is power required to overcome the friction head loss of the coal-water slurry in the shaft uplift pipeline and surface horizontal pipeline and same as open systems,

P_3 is the power required to pump the coal-water slurry through the uplift pipeline to the coal washing plant and is given by equation 3.13 (in which $H = H' + L_1 + L_2$),

P_6 is power required to introduce the slurry into the high pressure pipeline in feeding station by using Lock-Hopper feeder and same as open systems, the shock and velocity head loss of the system is assumed as 15% of the total above required power components.

4.3 Efficiency and Optimum Pipe Diameter of the Supplementary System:

The hydraulic efficiency, η_H, of the Supplementary hydraulic hoisting system is given by equation 3.18 as follow:

$$\eta_H = \frac{P_t}{P_a} \tag{4.9}$$

The diameter of the slurry pipeline is given by:

$$D = \sqrt{\frac{Q_s}{900\,\pi\,V}} \tag{4.10}$$

Optimum pipe diameter for the maximum hydraulic efficiency of circulating systems can be obtained by differentiating η_H with respect to D and equating the result to zero as the following equation:

$$\frac{d\eta_H}{dD} = \frac{d(\frac{P_t}{P_a})}{dD} = 0 \tag{4.11}$$

4.4 Other Considerations of Supplementary Hydraulic Hoisting Systems

For the supplementary hydraulic hoisting system, the separation and temporary storage of the expected particle size and amount of coal from the main entry belt may require use of the screen and bunker equipment. In this section, this equipment will be discussed briefly.

4.3.1 Screens

In supplementary hydraulic hoisting systems, the screen is a mechanical process that will be used to separate the size of -6.3 mm finer run-of-mine coal from the main entry belt. The high-speed mechanical screen is suitable for this size requirement and is recommended by Fuerstenau (1973). The capacity of screens can be estimated for use in this study by the following equation:

$$T_s = \frac{Tf_t}{P_c} \tag{4.12}$$

where T_s is total feeding required (ton/hr) of the run-of-mine coal by the screen,

T is expected capacity (ton/hr) of the supplementary hydraulic hoisting,

P_c is percentage of the expected capacity of the hydraulic hoisting to the total production capacity of the existing mechanical hoisting and the supplementary hoisting system, given by

$$P_c = \frac{T}{T_c + T} \tag{4.13}$$

where f_t is modifying factor can be calculated as follows (Fuerstenau, 1973):

$$f_t = f_e + f_f + f_w + f_d \tag{4.14}$$

where f_e, f_f, f_w, and f_d are efficiency factor, fines factor, wet screening factor and type of deck factor, respectively, given in Table 4.2.

Table 4.2 Modifying Factors for the Screen

Efficiency Factor (f_e)		Fines Factor (f_f)		Wet Screening Factor (f_w)		Type of Deck Factor (f_d)	
95%	1.00	10%	0.55	-20 mesh	1.25	Square	1.00
90%	1.25	20%	1.70	-10-+20 mesh	2.0-3.0	rectangular (ton-cap)	1.10-1.15
85%	1.50	30%	0.80	-0.5-+4 mesh	3.0-3.5	long-slot (tyler rod)	1.15-1.20
80%	1.75	40%	1.00	-1 in.-0.5 in.	1.5-2.0	Rod-deck (right-angle)	1.30
75%	2.00	50%	1.20	+1 in.	1.25	Rod-deck (slot parallel)	1.40
		60%	1.40				
		70%	1.80				
		80%	2.20				
		90%	3.00				

Source: Warring, 1984.

4.3.2 Temporary Storage Bunker

With a supplementary hydraulic hoisting system to improve productivity, the mine can adopt a temporary storage bunker to reduce the production down time from mechanical hoisting and outbye haulage systems. During mining operations, the mining faces, outbye haulage, and mechanical hoisting are entirely dependent upon each other. If any part of the transport system is inoperable, the entire system is forced to cease operation. The utilization of the bunker system will allow the supplementary hydraulic hoisting to continuously lift the coal, which is coming from the bunker, during periods when the mechanical hoisting or outbye haulage system is down or inoperable.

The bunker size and the production rate will determine the period of the down time of the transport system. Therefore, the capacity of the bunker can be designed from collected data of the maximum production rates and the mechanical hoisting and outbye haulage system of the existing coal mine. According to the existing layout conditions in the mine, the temporal storage can be selected of the moving bed, moving car, and bin bunker.

V. FEASIBILITY DEMONSTRATION BY EXAMPLES

The feasibility study of using supplementary hydraulic hoisting systems in existing coal mines is demonstrated by examples. In these examples, two mines with two hypothetical situations, abundant mine water versus no mine water, are analyzed. The cost evaluation of supplementary hydraulic hoisting systems is particularly important to demonstrate whether this supplementary system can improve the economics of mine operations.

5.1 Data Collections:

The maximum production capacities of the two hypothetical mines are 1.5 and 5 million metric tons per year (MMTPY); however, their existing production capacities are 1.2 and 4 MMTPY because of the limitation of the mechanical hoisting systems. For this reason, the mine operators are planning to use hydraulic hoisting systems to increase production capacities.

Some assumed data for the supplementary system are shown in Table 5.1. In this table, the two cases, abundant mine water with dewatering installations and no mine water are considered.

Table 5.1 Assumed Data for Design of Supplementary Hydraulic Hoisting Systems

Parameters	Existing Production Capacity of Coal Mines			
	1.2 MMTPY		4 MMTPY	
	Full Water	No Water	Full Water	No Water
Opening Date Remaining Life (year, Y)	1980 7		1980 7	
Expected Increase in Capacity by Supplementary System (MMTPY)	0.3		1	
Distance Between Mine and Coal Cleaning Plant (m)	500		500	
Distance of Pumping Station from Shaft Bottom (m)	500		500	
Size Distribution of Coal	25% less than 3.2 mm		25% less than 3.2 mm	
Average Diameter of coal to be Pumped (mm)	2		2	
Present Minimum Pumping Rate (m^3/h) Present Maximum Pumping Rate (m^3/h)	71 142	0 0	235 470	0 0
Total Pumping Static Head (m)	305		305	
No. of Existing Pumps in the Mine Motor Power, Each Pump (kW) Capacity, Each Pump (m^3/h) Total Head, Each Pump (m)	3* 85 71 330	0	3* 80 235 328	0
No. of Existing Pipelines in the Shaft Pipe Diameter (inside, mm)	2 175	0	2 250	0
Operation of Supplementary Systems: Days Per Year, Shifts Per Day, and Hours Per Shift	220, 3, 8		220, 3, 8	

* Two of the three pumps are connected as parallel and another one is spare;
MMTPY: Million Metric Tons Per Year.

5.2 Technical Design and Equipment Selections of Supplementary Systems:

According to the assumed and collected data for the above two mines, the design of supplementary hydraulic hoisting systems can be completed by using the derived formulas and procedures presented in Chapter III and Chapter IV.

The open system has been used in mines with abundant mine water and dewatering installations. The circulating system has been used no mining water and no dewatering installations exist. In both systems, the total power of supplementary systems in the following calculations required 15% more power to overcome shock and velocity head losses. A Lock-Hopper feeder (shown in Figure 2.13) has been used for hydraulic hoisting systems in this design in order to introduce coal into the upward pipeline. An example of calculations for the basic design of supplementary systems is given below. Some calculated results of the supplementary system for use in the four cases are shown in Table 5.2.

1. An example of calculations for a hoisting system with a capacity of 300,000 tons per year as follows:

   a). Basic design parameters for the open and circulating hydraulic hoisting systems are given below:

   hoisting capacity of the supplementary system: T = 300,000 t/yr, hoisting depth: H_2 = 305 m,

distance between feeding station and the shaft bottom: L_1 = 500 m,

distance between shaft top and coal cleaning plant: L_2 = 500 m,

a weighted mean particle diameter of the coal: d_n = 2 mm,

the coal particle drag coefficient: C_D = 2,

a specific gravity value of the coal: S= 1.5 t/m^3,

concentration of coal-water slurry: C_v = 0.35,

the volumetric spatial concentration of the coal-water slurry: C_v' = 0.3,

density of the water: ρ_w = 1 t/m^3,

density of the coal: ρ_c = 1.5 t/m^3,

density of the coal-water slurry: ρ_s = 1.175 t/m^3,

internal diameter of the upflow pipeline: D = 0.175 m,

Darcy-Weibach friction of upflow pipes: f_1 = 0.0165,

internal diameter of the water supply pipeline: D_f = 0.15 m,

Darcy-Weibach friction factor of water supply pipes: f_2 = 0.0185,

the volume flow rate of coal hoisted by the hydraulic hoisting system:

$$Q_c = \frac{T}{S(220 \times 3 \times 8)}$$

$$= \frac{300000}{1.5 \times 5280}$$

$$= 38 \; m^3/h$$

the volume flow rate of water hoisted by the hydraulic hoisting system:

$$Q_w = \frac{Q_c(1 - C_v)}{C_v}$$

$$= \frac{38 \times (1 - 0.35)}{0.35}$$

$$= 71 \ m^3/h$$

the volume flow rate of coal-water slurry:

$$Q_s = Q_c + Q_w$$

$$= 38 + 71$$

$$= 109 \ m^3/h$$

the velocity of coal-water slurry in the upflow pipeline:

$$V = \frac{Q_c}{900 \, \pi \, D^2 \, C_v}$$

$$= \frac{38}{900 \times 3.1416 \times 0.175^2 \times 0.35}$$

$$= 1.25 \ m/s$$

the velocity of the water in the water supply pipeline:

$V_f = 0.75 \ V = 0.75 \times 1.25 = 0.94$ m/s,

the friction head of water supply pipeline (the Darcy-Weibach equation):

for the open system ($H_f = L_1$):

$$H_d = \frac{f_2 V_f^2 H_f}{2gD}$$

$$= \frac{0.0185 \times 0.94^2 \times 500}{2 \times 9.81 \times 0.15}$$

$$= 2.77 \ m$$

for the circulating system ($H_f = H_2 + L_1 + L_2$):

$$H_d = \frac{0.0185 \times 0.94^2 \times (305 + 500 + 500)}{2 \times 9.81 \times 0.15}$$

$$= 7.25 \ m$$

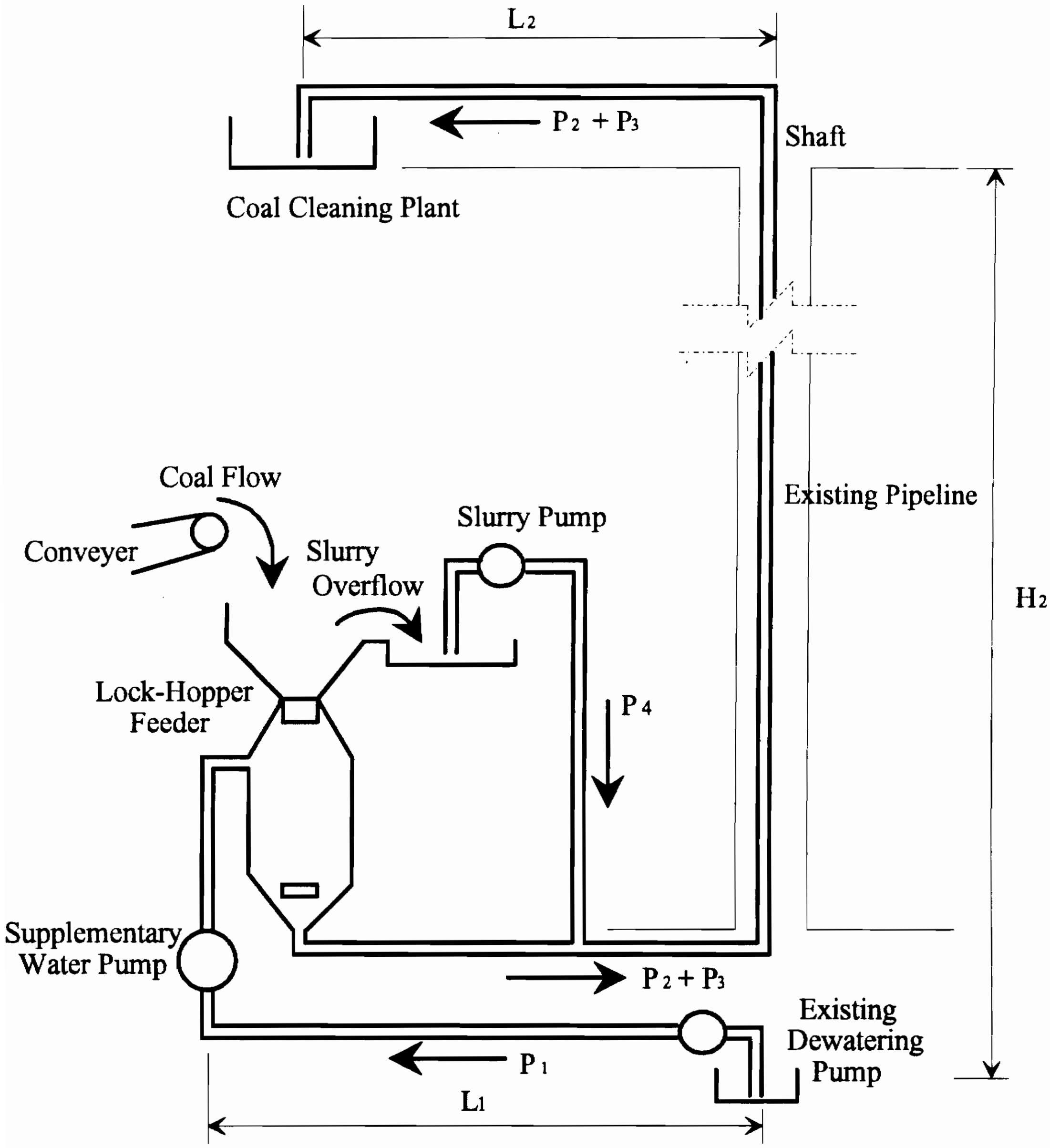
b). The required power of the open hydraulic hoisting system (see Figure 5.1):

P_1, the power required to overcome the friction head loss in the water supply pipeline (given by equation 3.8):

$$P_1 = \frac{\rho_w g H_d Q_w}{3600 \times 10^3}$$

$$= \frac{1 \times 1000 \times 9.81 \times 2.77 \times 71}{3600 \times 10^3}$$

$$= 0.54 \ kW,$$



P_1: power required for the friction head loss in the water supply pipeline,
P_2: power required for the friction head loss in the uplift pipeline,
P_3: power required for hoisting the slurry in uplift pipeline,
P_4: power required for introducing overflow slurry into the high pressure-pipeline.

Figure 5.1 Schematic Arrangement of the Open Hydraulic Hoisting System

P_2, the power required to overcome the friction head loss of the coal-water slurry in the uplift pipeline (given by equation 3.11):

$$P_2 = \frac{f_1 H \rho_s Q_s V^2}{7200 D \times 1000}$$

$$= \frac{0.0165 \times (305 + 500 + 500) \times 1.175 \times 1000 \times 1.25^2 \times 109}{7200 \times 0.175 \times 10^3}$$

$$= 3.42\ kW,$$

P_3, the power required to lift the coal-water slurry into the uplift pipeline (given by equation 3.12):

$$P_3 = \frac{\rho_s Q_s g H}{3600 \times 10^3}$$

$$= \frac{1.175 \times 1000 \times 109 \times 9.81 \times 305}{3600 \times 10^3}$$

$$= 106.45\ kW,$$

P_6, the power required to introduce the overflow slurry in the feeding station into the upflow pipeline (given by equation 3.17):

$$P_6 = \frac{\rho_s Q_c g H}{3600 \times 10^3}$$

$$= \frac{1.175 \times 1000 \times 38 \times 9.81 \times 305}{3600 \times 10^3}$$

$$= 37.11\ kW,$$

P_s, power required to overcome the shock and velocity head losses in the upflow and water supply pipeline is assumed as 15% of the above total required power:

$$P_s = 0.15 \times (P_1 + P_2 + P_3 + P_6)$$

$$= 0.15 \times (0.536 + 3.42 + 106.45 + 37.11)$$

$$= 0.15 \times 147.516$$

$$= 22.13 \text{ kW},$$

P_t, total theoretical required power of the open supplementary hydraulic hoisting system:

$$P_t = P_1 + P_2 + P_3 + P_6 + P_s$$

$$= 0.54 + 3.42 + 106.45 + 37.11 + 22.13$$

$$= 169.65 \approx 170 \text{ kW}.$$

c). The required power for the circulating system (see Figure 5.2):

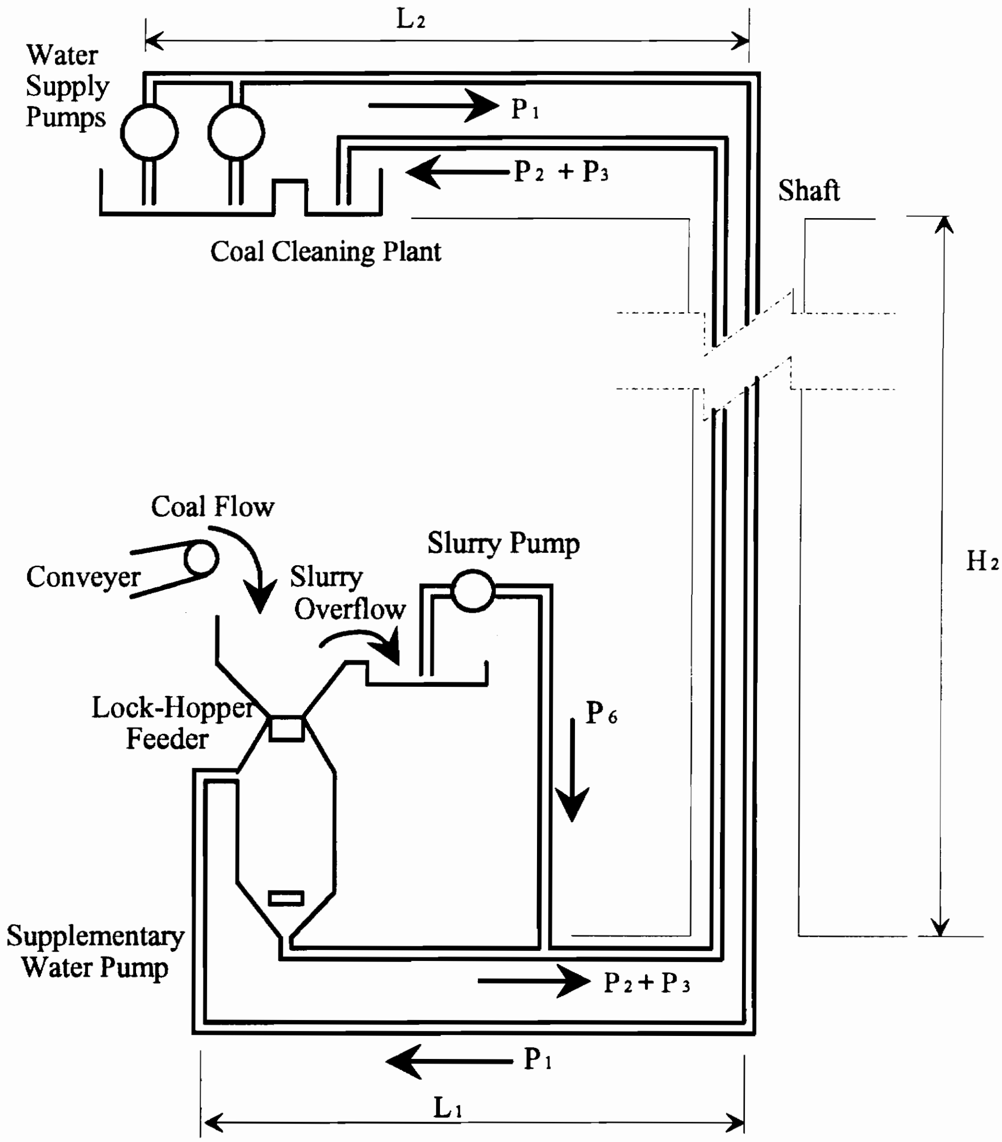
P_1, the power required to overcome the friction head loss in the water supply pipeline (given by equation 3.8):

$$P_1 = 1 \times 1000 \times 9.81 \times 7.25 \times 71 / 3600 \times 1000$$

$$= 1.40 \text{ kW},$$

P_2, the power required to overcome the friction head loss of the coal-water slurry in the uplift pipeline:

$$P_2 = 3.42 \text{ kW (same as the open system)},$$



P_1: power required for the friction head loss in the water supply pipeline,
P_2: power required for the friction head loss in the uplift pipeline,
P_3: power required for hoisting the in uplift pipeline,
P_6: power required for introducing overflow slurry into the high-pressure pipeline.

Figure 5.2 Schematic Arrangement of the Circulating Hydraulic Hoisting System

P_3, the power required to lift only coal in the uplift pipeline (given by equation 3.13):

$$P_3 = \frac{\rho_c \times Q_c \times g \times H}{3600 \times 10^3}$$

$$= \frac{1.5 \times 1000 \times 38 \times 9.81 \times 305}{3600 \times 10^3}$$

$$= 47.37\ kW,$$

P_6, the power required to introduce the overflow slurry from the feeding station into the upflow pipeline:

P_6 = 37.11 kW (same as the open system),

P_s, power required to overcome the shock and velocity head losses in the upflow and water supply pipeline:

P_s = 22.13 kW (same as the open system),

P_t, total theoretical required power of the circulating supplementary hydraulic hoisting system:

$$P_t = P_1 + P_2 + P_3 + P_6 + P_s$$

$$= 1.40 + 3.42 + 47.37 + 37.11 + 22.13$$

$$= 111.43 \approx 112 \text{ kW}.$$

2. Using the same method in the above procedures, the basic design for supplementary hydraulic hoisting systems with a hoisting capacity of 1,000,000 tons per

year can be calculated, and the results are shown in Table 5.2.

Table 5.2 Calculation Results of Hydraulic Hoisting System Design

Parameters	Existing Production Capacity of 1.2 MMTPY		Existing Production Capacity of 4 MMTPY	
	Open System	Circulating System	Open System	Circulating System
Expected Production Increase by Using Supplementary Hydraulic Hoisting Systems (MMTPY)	0.3		1	
Hoisting Depth (m)	305	305	305	305
Total Water Required (m^3/h)	71	71	235	235
Concentration of Coal-Water Slurry in Uplift Pipeline	0.35	0.35	0.35	0.35
Velocity of Coal-Water Slurry in Uplift Pipeline (m/s)	1.25	1.25	2	2
Existing or Designed Diameter of Pipelines (interior, m) No. of Pipe Columns to be used for the Hydraulic Hoisting System	0.175 1	0.175 1	0.25 1	0.25 1
P_1, Power Required to Overcome Friction Loss in Water Supply Pipeline (kW)	0.54	1.40	2.95	6.97
P_2, Power Required to Overcome Friction Loss in Upflow Pipeline (kW)	3.42	3.42	17.21	17.21
P_3, Power Required to Lift Coal-Water Slurry (or coal in circulating systems) in Upflow Pipeline (kW)	106.45	47.37	352.30	157.41
P_6, Power Required to Introduce Coal-Water Slurry into the High-Pressure Pipeline (kW)	37.11	37.11	123.31	123.31
P_8, Power Required to Overcome shock and Velocity Head Losses in the Pipeline (kW)	22.13	22.13	74.37	74.37
P_t, Total Power Required for Supplementary Hoisting Systems (kW)	170	112	570	380

According to the above results for the system basic design, equipment for supplementary hydraulic hoisting systems can be selected as follows.

For the supplementary system in this study, the maximum capacity of Lock-Hopper feeders is 100 tons per hour for a hoisting capacity of 0.3 MMTPY and 200 tons per hour for a hoisting capacity of 1 MMTPY. Centrifugal (multi-stage turbine) pumps and stroke piston slurry pump are selected for pumping the water and the overflow slurry in the supplementary hydraulic hoisting system (see Figures 5.1, 5.2, and Table 5.3). The capacity of the bunker is 400 to 800 tons. The screen can accept coal up to 200 mm and handle the coal at the rate of 200 to 1,000 tons per hour. The capacities of belt conveyors will be selected accordingly. The required power of screen, bunker, conveyers, and others is assumed as 75 kW for hoisting 0.3 MMTPY system and 185 kW for hoisting 1 MMTPY.

Table 5.3 Pumps used in Supplementary Hydraulic Hoisting Systems

Items	Hoisting Capacity of Supplementary Systems			
	0.3 MMTPY		1 MMTPY	
	Full Water	No Water	Full Water	No Water
Required Power (after considered mechanical efficiency of 0.75) of the Hydraulic Hoisting Systems (kW)	227	149	760	507
No. of Existing Pumps is integrated into the Systems Motor Power, Each Pump (kW) Capacity, Each Pump (m^3/h) Head for Pumping Water, Each Pump (m)	1* 85 71 330	0	1* 280 235 328	0
No. of Additional Pumps installed in the Mine Motor Power, Each Pump (kW) Capacity for Pumping Water (or Overflow Coal-Water Slurry), Each Pump (m^3/h) Head for Pumping Water (or Overflow Coal-Water Slurry), Each Pump (m)	2* 85 71 (38) 330 (410)	1** 55 (38) (339)	2* 280 235 (127) 328 (404)	1** 185 (127) (341)
No. of Additional Pumps installed on the Surface Motor Power, Each Pump (kW) Capacity for Pumping Water, Each Pump (m^3/h) Head for Pumping Water, Each Pump (m)	0	2*** 55 36 420	0	2*** 185 120 424
No. of Pumps connected in Series Motor Power, Each Pump (kW) Capacity of Series Pumps for Pumping Coal-Water Slurry (m^3/h) Head of Series Pumps for Pumping Coal-Water Slurry (m)	2 85 109 344	0	2 280 362 362	0

* One of the two additional pumps works with one existing pump in series; second one is a slurry pump introduces slurry into the high-pressure pipeline.

** This additional pump is installed to introduce slurry into the high-pressure pipeline.

*** Two pumps are installed on the surface and work in parallel.

The efficiency of hydraulic pump and supplementary hydraulic systems can be calculated by using equations 3.18 and 3.19 in Chapter III and shown in Table 5.4. The maximum efficiencies of circulating hydraulic hoisting systems can be obtained by the method of optimum pipe diameter described in Chapter IV.

Table 5.4 Efficiencies of the Pump used for Supplementary Hydraulic Hoisting Systems2

Parameters	Existing Production Capacity of 1.2 MMTPY		Existing Production Capacity of 4 MMTPY	
	Open System	Circulating System	Open System	Circulating System
Theoretical Required Power of the Hydraulic Hoisting System (see Table 5.2) (kW)	170	112	570	380
Actual Required Power of the Hydraulic Hoisting System (see Table 5.3) (kW)	3×85	3×55	3×280	3×185
Efficiency of Pumps	0.67	0.68	0.68	0.69

5.3 Cost Estimations of Supplementary Hydraulic Hoisting Systems:

Capital Investment costs of the supplementary system: Estimating capital investment costs of supplementary systems, as determined in this study, is based on the price of similar equipment quoted in the publications of previous projects and telephone quotations from manufacturers. The estimated capital costs of the equipment including construction, installation, and controls are shown in Table 5.5.

Table 5.5 Estimating Capital Costs of the Supplementary Hydraulic Hoisting Equipment (dollars, 1993)

Items	Estimating Costs ($)
* Lock-Hopper Coal Feeders	100,000-140,000
** Slurry Pumps	65,000-120,000
* Water Pumps	10,000-15,000
* Pipes:	
150 mm Diameter per 100 m	6,000
175 mm Diameter per 100 m	7,000
200 mm Diameter per 100 m	8,000
250 mm Diameter per 100 m	10,000
*** Temporary Storage Bunkers	60,000 - 100,000
* Belt Conveyer Assembly	100,000
*** Screens	26,000 - 43,000
Underground Construction and Installations	300,000
Contingencies (15%)	100,000 - 200,000

Sources: Hartman and Reed, 1973; Klumpar and Slavsky, 1985; Wilson-Snyder Pumps, 1992; Stamler Corporation, 1992; Hewitt Robins Company, 1992 (* 1973, ** 1985, and *** 1992 cost figures updated by using producer price indexes shown in Table 5.6).

Table 5.6 Purchasing Power of the Dollar: 1973 to May, 1993

	Annual Average as Measured by			Annual Average as Measured by	
Year	Producer Prices	Consumer Prices	Year	Producer Prices	Consumer Prices
1973	2.193	2.251	1984	0.964	0.961
1974	1.901	2.029	1985	0.955	0.928
1975	1.718	1.859	1986	0.969	0.913
1976	1.645	1.757	1987	0.949	0.880
1977	1.546	1.649	1988	0.926	0.846
1978	1.433	1.532	1989	0.880	0.807
1979	1.289	1.380	1990	0.839	0.766
1980	1.136	1.251	1991	0.822	0.734
1981	1.041	1.096	1992	0.820	0.722
1982	1.000	1.035	1993	0.806	0.704
1983	0.984	1.003	1994		

source: U.S. Bureau of Labor Statistics, Monthly Data in U.S. Bureau of Economic Analysis, Survey of Current Business, 1993.

Annualized capital costs calculated by the straight-line depreciation method by assuming 7 years of remaining life and zero salvage value. Fixed costs, which include taxes and insurance are assumed to be 5% of capital investment.

Operating Cost: The estimated annual operating cost of the supplementary hydraulic hoisting system consists of the following components:

Direct costs of the production and maintenance labor is assumed as $0.1 million per year (MDPY);

Power cost is assumed as $0.05/kW;

Annual operating supply cost consists of repair parts, lubrication, and hydraulic oil costs. This cost can be assumed as 15% of the total capital cost.

Estimation of Costs: According to the above given technical data, estimated cost of supplementary hydraulic hoisting systems can be calculated as follows:

1. Open systems used for hoisting capacity of 0.3 MMTPY with full water and dewatering installations in the mine:

a). System Equipment and Complete Costs:

Lock-Hopper Feeder	1 unit	$100,000
Slurry Pump	1 unit	$65,000

Water Pump	1 unit	\$10,000
Pipe (D = 175 mm)	1,500 m	\$90,000
Bunker	1 unit	\$60,000
Belt Conveyers	150 m	\$100,000
Screen	1 unit	\$30,000
Underground Construction		\$300,000
Contingencies		\$100,000
Total		**\$855,000**

Based the above data,

Estimated capital investment cost: $C_{co} = 0.855$ million dollars (\$M),

Fixed cost: $C_{fo} = 0.05\ C_{co} = 0.05 \times 0.855 \approx 0.043$ M\$,

Total capital investment cost: $C_{to} = C_{co} + C_{fo} = 0.855 + 0.043 = 0.898$ \$M,

Annualized capital investment cost: $C_{aio} = C_{to} \div Y = 0.898 \div 7 = 0.128$ \$M.

b). The annual operating costs can be estimated as follows:

Direct costs of production and maintenance labor is assumed as: $C_{do} = 0.1$ \$M,

Power cost: $C_{po} = P_o \times 0.05 \times 220 \times 3 \times 8 \times 10^{-6} = 3 \times 85 \times 0.000264$

$= 0.067$ \$M,

Annual other operating cost: $C_{oo} = 0.15 \times C_{to} = 0.15 \times 0.898 = 0.135$ \$M, Total annual operating cost: $C_{aoo} = C_{do} + C_{po} + C_{oo} = 0.1 + 0.067 + 0.135$

$= 0.302$ $M.

c). Total annual hoisting cost: $C_{tao} = C_{aio} + C_{aoo} = 0.128 + 0.302 = 0.43$ $M.

d). Hydraulic hoisting cost in dollars per ton of the additional coal:

$C_{pto} = C_{tao} \div T = 0.43 \div 0.3 = 1.43$ $/t.

2. The same procedures can be used to obtain the results for system design for the other cases studies shown in Table 5.7:

Table. 5.7 Cost Estimations of Supplementary Hydraulic Hoisting Systems ($M)

Items	Existing Production Capacity of 1.2 MMTPY		Existing Production Capacity of 4 MMTPY	
	Open System	Circulating System	Open System	Circulating System
Lock-Hopper Feeder (quantity × unit price = costs)	1 × 0.100 = 0.100	1 × 0.100 = 0.100	1 × 0.140 =0.140	1 × 0.140 = 0.140
Slurry Pump (quantity × unit price = costs)	1 × 0.065 = 0.065	1 × 0.065 = 0.065	1 × 0.120 =0.120	1 × 0.120 = 0.120
Water Pump (quantity × unit price = costs)	1 × 0.010 = 0.010	2 × 0.010 = 0.020	1 × 0.015 =0.015	2 × 0.015 =0.030
Pipe (an unit = 100 m) (quantity × unit price = costs)	5 × 0.006 =0.030 10 × 0.007 =0.070	13.5×0.013=0.081 13.5×0.017=0.095	5×0.008 =0.040 10×0.010 =0.100	13.5×0.008=0.108 13.5×0.010=0.135
Bunker (quantity × unit price = costs)	1 × 0.060 = 0.060	1 × 0.060 = 0.060	1 × 0.100 =0.100	1 × 0.100 = 0.100
Belt Conveyers	0.100	0.100	0.100	0.100
Screen (quantity × unit price = costs)	1 × 0.030 = 0.030	1 × 0.030 = 0.030	1 × 0.040 =0.040	1 × 0.040 = 0.040
Underground Construction	0.300	0.300	0.300	0.300
Contingencies	0.100	0.100	0.200	0.200
Capital Investment (C_c)	**0.865**	**0.951**	**1.155**	**1.273**
Fixed Cost: ($C_f = 0.05\ C_c$)	0.043	0.048	0.058	0.064
Total Capital Investment ($C_t = C_c + C_f$)	**0.908**	**0.999**	**1.213**	**1.337**
Annualized Capital Investment ($C_{ai} = C_t \div Y$)	**0.130**	**0.143**	**0.173**	**0.191**
Assumed Annual Direct Costs (C_d)	0.100	0.100	0.100	0.100
Annual Power Costs ($C_p = P \times 0.05 \times 220 \times 3 \times 8 \times 10^{-6}$)	170 × 0.000264 = 0.045	165 × 0.000264 = 0.044	560 × 0.000264 = 0.148	555 × 0.000264 = 0.147
Annual Other Operating Costs ($C_o = 0.15\ C_t$)	0.135	0.148	0.182	0.201
Total Annual Operating Cost ($C_{ao} = C_d + C_p + C_o$)	**0.280**	**0.292**	**0.330**	**0.448**
Total Annual Hoisting Cost ($C_{ta} = C_{ai} + C_{ao}$)	**0.410**	**0.435**	**0.503**	**0.639**
Cost in Dollars per Ton of the Supplementary System	**1.37**	**1.45**	**0.51**	**0.64**

Y = years of remaining life of the mine;
P = actual required power of supplementary hydraulic hoisting systems (kW).

5.4 Analysis of Results:

The above results of technical design and cost estimations indicate that hoisting cost varies between \$0.51 and \$1.45 per tons (in 1993 dollars) of coal hoisted by supplementary hydraulic hoisting systems depending upon hoisting capacity, availability of mine water and hoisting depth.

It is expected that the additional coal hoisted by the supplementary system will cost less to mine than the present reduced capacity mining cost because most of the existing coal production facilities will be used for this additional production. If the annualized fixed cost of the hydraulic hoisting system is excluded, the total annual fixed cost of the mine will almost be the same whether the mine is operating with a reduced capacity or full capacity. In other words, this additional production will cost less to mine because of the differences in unit fixed cost. This cost differential between the existing and increased production rates may vary from mine to mine depending upon their fixed and variable cost components. Figure 5.3 illustrates cost saving for the system for various cost differentials.

For example, if the cost differential for the additional production is \$2 per ton, a circulating system of 300,000 tons per year capacity will result in \$2 - \$1.45 = \$0.55 cost saving per addition ton of coal mined and transported by the supplementary system. For the same cost differential, an open system of 1,000,000 tons per year capacity will produce \$2 - \$0.51 = \$1.49 per addition ton of coal.

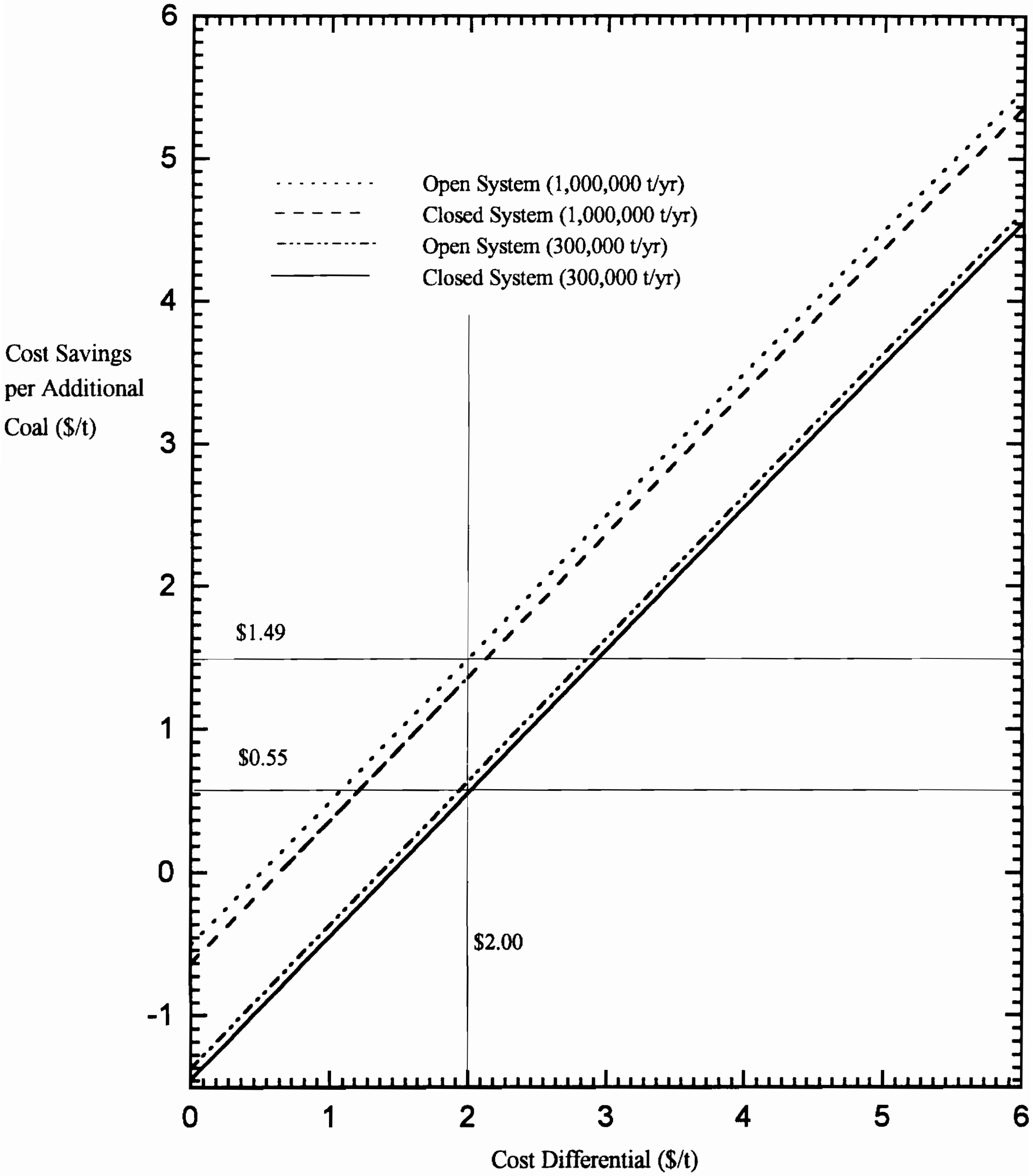


Figure 5.3 Cost Savings as a Function of Cost Differentials

VI. CONCLUSIONS

6.1 Summary

In this thesis, a technique for hydraulic hoisting has been applied to develop a methodology for increasing existing mechanical hoisting capacity of coal mines. After an engineering design, the hydraulic hoisting system is integrated with the existing mechanical hoisting system and dewatering installations. For this supplementary system, available mine water determines which of two system variations, open or circulating, will be used to contribute about 20-30% increase in the mine production capacity.

To ascertain the feasibility of supplementary hoisting systems, estimation of the capital investment for the supplementary systems and operating costs of existing dewatering systems were examined. These were incorporated in an economic analysis of the example systems presented in this study. Thus, the implementation of the technical design and cost estimations were developed for the feasibility study of the supplementary hoisting systems. The models, functions, and indices were given explicitly with respect to each case in the examples. A procedure was developed to assess and predict the feasibility of the supplementary hydraulic hoisting system.

6.2 Conclusions

From the results obtained and described in this study, the following conclusions can be drawn:

Hydraulic hoisting is one of the most promising supplementary systems for increasing existing mechanical hoisting capacity. The theory of hydraulic hoisting is well understood and such a supplementary system may be easily combined with various mechanical hoisting systems existing in coal mines.

The major advantage of this supplementary system is that existing mechanical hoisting capacity can be increased at comparatively low costs and without changing of the existing mechanical hoisting or sinking new shafts. These often become very expensive and require a long time to achieve.

The methodology presented in this thesis will facilitate analysis of the economic feasibility of a supplementary hydraulic hoisting system. The potential for the applications of a supplementary system is evident. As a design tool, the models, functions, and indices are derived for the actual and theoretical power required to pump coal-water mixtures up a vertical and horizontal piping network for open and circulating systems. From these models, functions, and indices, the flow data, hydraulic efficiency and optimum pipe diameter are obtained. Also, these models can be used as an assessment tool for the economic valuation of supplementary hydraulic hoisting systems.

The case studies indicate that the actual required power of the supplementary system for a given hoisting capacity may be determined according to the availability of mine water. For the open system, although the actual required power is larger than the circulating system, about one third of this required power can be saved by using of the existing dewatering pump.

The cost analysis of supplementary systems shows that the open systems, compared with circulating systems, will decrease the total capital investment cost from \$86,000 to \$118,000 and decrease the total annual hoisting cost of additional production from \$25,000 to \$136,000 because the present mine water and dewatering installations can be integrated with supplementary hydraulic hoisting systems.

According to the results, the most critical parameters are the capacity of the supplementary system and savings in mining costs because of the increased production capacities. If the capacity of the supplementary system is one million tons a year, then the system becomes economical if this additional one million tons of coal can be mined about \$0.51 per ton less expensively. Larger savings in mining costs can make a smaller capacity hoisting system an economically viable alternative. The on-going calculations do not consider cost of mechanical hoisting corresponding to the additional tonnage since this additional production will not be hoisted mechanically. Inclusion of this cost with the total cost may further enhance attractiveness of the supplementary system.

6.3 Recommendations for Further Research

For the application of supplementary hydraulic hoisting systems, much work can be done by extending the approaches developed in this thesis. The following two areas are identified for additional study.

One source states that steel pipe wear during a twenty-year anticipated life time can be expected to range from 3 to 6 mm (Cabrera, 1979). Obviously, this will be a problem for the supplementary hydraulic hoisting system. Therefore, further research efforts should be aimed at the wear factors in order to reduce the cost of maintenance and to increase operational availability of the system. These efforts include several measures such as optimum design of the velocity, concentration, coal solid size, and throughput capacity of the coal-water flow in order to reduce pipe wear.

Another area requiring further research is extensive investigations of new hydraulic hoisting equipment. This would allow optimal equipment selection for a site specific elevation and route distance requirement, required capacity, operational characteristics, initial capital investment, and operational and maintenance costs for the various applications of supplementary hydraulic hoisting systems.

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