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MINE WATER - A RESOURCE FOR TRANSPORTATION OF ORES FROM UNDERGROUND MINES

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ABSTRACT

In underground mining a hydraulic hoisting system can increase the hoisting capacity without necessitating the sinking of new shafts. There is generally a considerable inflow of groundwater which has to be pumped out. When the mine dewatering installations are integrated with a hydraulic hoisting system, the cost of power needed to pump out the groundwater is excluded from the cost of hoisting, compared with other modes of transporting the solids to the surface. Different hydraulic systems are analysed and leading parameters such as, total energy consumption and underground water availability, are related systematically to representative solid to water mass ratios and pump efficiencies. The economical effectivness of integrating the mine dewatering and the hydraulic hoisting system is demonstrated and finally some schematic layout of applications are presented.

INTRODUCTION

There is an increasing international interest in the development of hydraulic transportation in underground mining. About 15 hydraulic hoisting applications have been taken into use within the last 15 years in Canada, China, Germany, U.S.A., and U.S.S.R. A recent installation in U.S.A. is in the Loveridge mine in West Virginia, see for example Alexander et al. (1984). Coal slurry is pumped underground from the mine face to a sump and then 260 m vertically to the surface. Finally, the slurry is pumped about 4 km in an overland pipeline to a preparation plant. The hydraulic hoisting is done by using seven centrifugal pumps in series in a vertical pipe with a diameter of 0.3 m. The maximum particle size in the pumped slurry is about 75 mm. The transportation water is decanted at the preparation plant and then recirculated to the mine.

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In underground mines there is generally a considerable inflow of groundwater which has to be pumped out. When the mine dewatering installations are integrated with a hydraulic hoisting system, the cost of power needed to pump out the groundwater is excluded from the cost of hoisting, compared with other modes of transporting the solids to the surface.

In the metal mining industry, conversion of fine particles into a slurry is often part of the normal processing of the ore, because the concentration process is mostly carried out by wet milling methods, where the ore lumps are grated into fine particle sizes, usually less than 0.2 mm. Therefore, from a system point of view, slurry transportation would be considered as a natural alternative, all the way from the working face to the final processing.

A hydraulic hoisting system is schematically compared with a shaft hoisting system in a conventional underground mine in Figure 1.

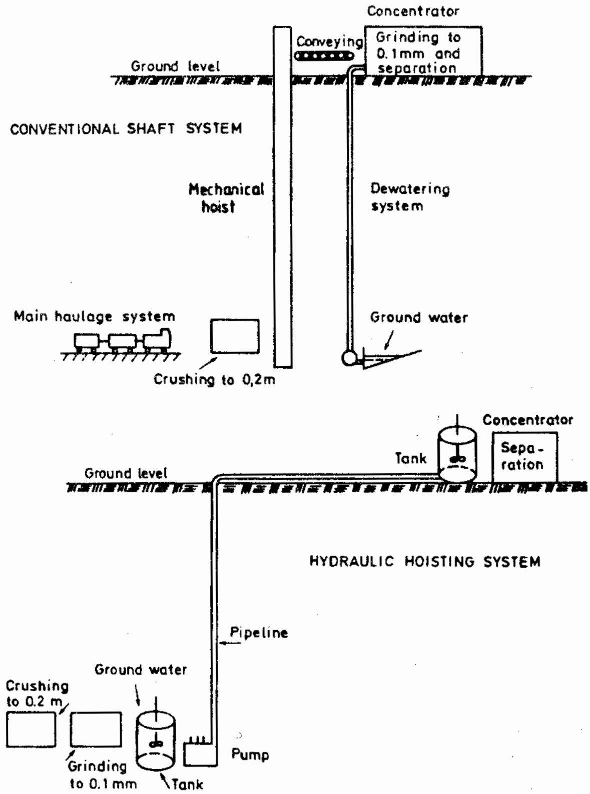

Figure 1. Schematic layout of a hydraulic hoisting system compared with a conventional shaft hoisting system in an underground mine.

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In conventional underground mining technology, the ore is comminuted to a rock size of about 0.1-0.2 m underground before being hoisted to the surface. From the storage bins the ore is transferred into skips for hoisting to the surface. The hoists are located in headframes directly above the hoisting shaft. Ore from the hoisting system is dumped into hoppers located in the headframe and then conveyed by belt, etc. to the preparation plant.

It follows from Figure 1 that hydraulic hoisting generally means that additional underground grinding and handling of the ore is necessary.

The chief advantage of hydraulic hoisting is that the hoisting capacity can be increased without necessitating the sinking of new shafts. A hydraulic hoisting system can also replace, or partly replace, a shaft hoisting system, and thus influence the load carrying capacity of the main haulage system. The small pipe shaft or borehole required can be sunk near the ore-bearing area and thus a more rational utilization of the existing underground horizontal haulage system is achieved.

The aim of this study is to demonstrate the feasibility of integrating the mine dewatering and the hydraulic hoisting system.

ANALYSIS

The flow of raw ore and mine water in a mechanical hoisting system and in a hydraulic hoisting system is schematically shown in Figure 2.

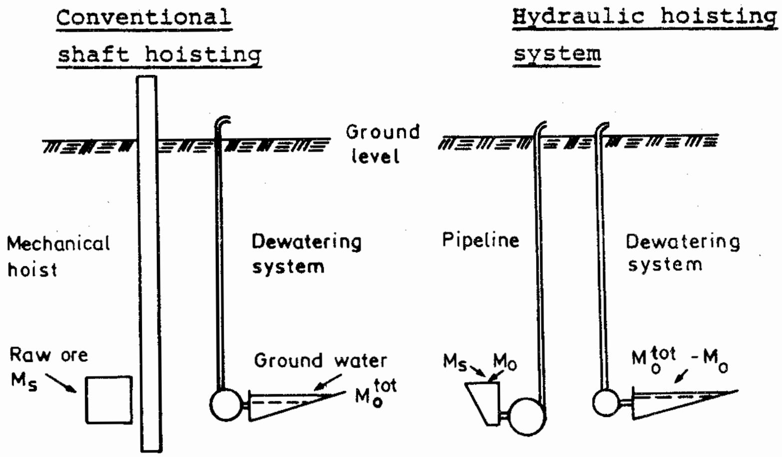

Figure 2. Flow of raw ore and mine water in a conventional shaft system and in a hydraulic hoisting system.

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In Figure 2 it is assumed that the total inflow of groundwater to the mine is $M_o^{Tot.}$ kg per sec. The water required to transport M_s kg of solid per sec. in slurry form is M_o kg per sec. In the figure the inflow of groundwater exceeds the water requirement in the hydraulic hoisting system. However, this is not always the case. Sometimes the leakage of water to the mine is small and water has to be recirculated if the mineral is to be hoisted hydraulically. Even if $M_o^{Tot.}$ exceeds M_o , this water is not always available for use in the hydraulic hoisting system. The variation with time of the inflow of groundwater, storage possibilities, and system restrictions are local factors which influence the portion of the groundwater which can be a useful resource in the hydraulic hoisting system.

In the hydraulic analysis, it was appropriate to define a "water availability factor", K . The factor expresses the portion of water in the hydraulic hoisting system, KM_o , which has to be pumped out of the mine, irrespective of the method of hoisting. Thus, $K = 1$ means that all water required in the hydraulic hoisting system can be taken from the mine dewatering system. $K = 0$ means that no mine water is available underground for use in the hydraulic hoisting system.

In an industrial application of vertical transportation of a solid-water mixture in a pipe, the operating velocity must be sufficiently high to maintain a continuous flow of solids at the discharge end. However, because of pipe wear and energy losses the velocity should not be unneccessarily high.

Important design factors, such as operating velocities and energy consumption, have been established through analysis and pilot-scale tests with ores and minerals taken from in-plant crushing and milling processing (Sellgren, 1979, 1982a). The results, which have been confirmed in other investigations as well as from industrial applications, were used in this study to determine the operating conditions in the hydraulic hoisting system.

The hydraulic analysis of integrating the mine dewatering system and the hydraulic hoisting system was presented in detail by Sellgren (1982b). It was found that the net energy requirement, e (kWh/tonne) , of transporting the ore hydraulically in an integrated system can be expressed with reasonable accuracy by the following characteristic equation in most practical applications.

$$e \approx H\, g\, M^{*-1}\, \eta^{-1}\, (1 + M^* - K\eta^*) \qquad (1)$$

H = total head in the mine dewatering system

g = acceleration due to gravity

$M^* = \frac{M_s}{M_o}$ mass ratio of solids and water

M_s = mass flow rate of solids

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$\eta^* = \frac{\eta}{\eta_o}$ slurry to water pump efficiency ratio
η = total efficiency of slurry pumps
η_o = total efficiency of water pumps

The interrelation of the parameters, e, M^*, η^*, and K can be structured in the following way:

$\eta^* > 1$, ie the efficiency of the slurry pumps exceeds the efficiency of the dewatering pumps. If $0 < K < \eta^{*-1}$, then the energy consumption per tonne of solids, e, decreases with increasing values of M^*. If a large amount of water is available underground, or more specifically, if $\eta^{*-1} < K < 1$, then e increases with increasing values of M^*. Finally, if $K = \eta^{*-1}$, then e is independent of M^*.

$\eta^* < 1$, ie the efficiency of the dewatering pumps exceeds the efficiency of the slurry pumps. The energy consumption, e, decreases with increasing values of M^* for all values of K.

$\eta^* = 1$, ie the efficiency of the slurry and dewatering pumps are equal. If $K = 1$, then e is independent of M, while e decreases with increasing values of M^* if $K < 1$.

DISCUSSION OF RESULTS

The results were represented in a generalized form comprising the leading parameters. Representative data are shown in Figures 3 and 4.

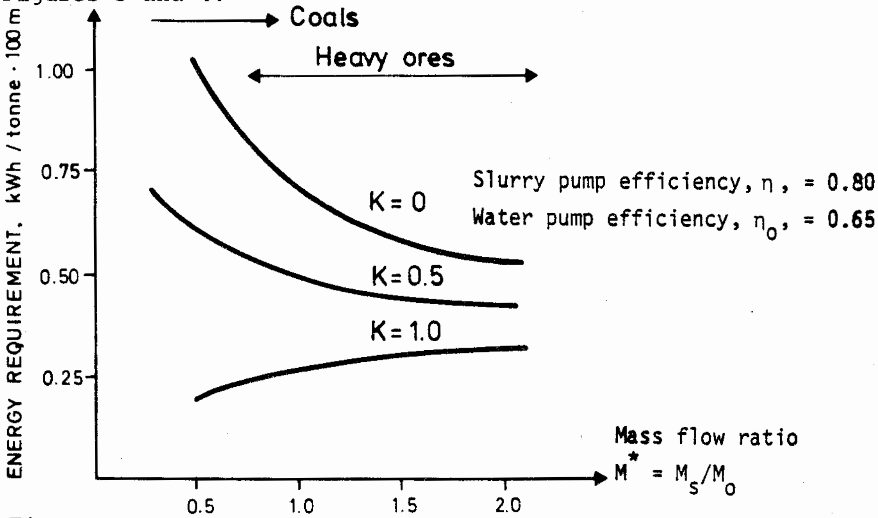

Figure 3. Net energy requirement in a hydraulic hoisting system based on high-efficiency slurry pumps. K is the amount of water needed which is available underground.

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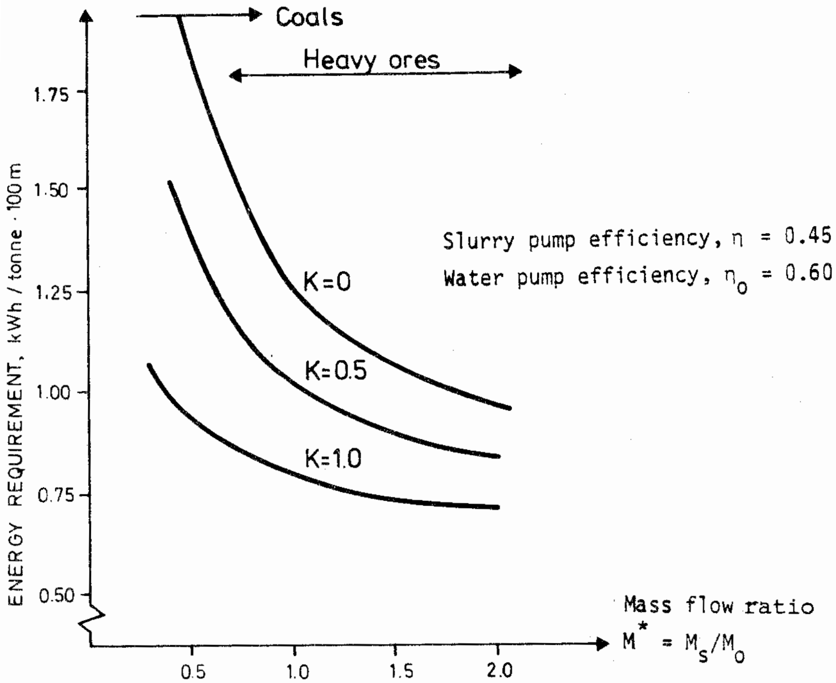

Figure 4. Exemplification of the net energy requirement in a hydraulic hoisting system based on centrifugal pumps.

Positive displacement pumps operating at pressures of 8-16 MPa are used in long-distance slurry transportation systems. The pumps are capable of pumping highly concentrated slurries at an efficiency of 75-85 %. However, the maximum particle size is limited to about 3 mm, due to narrow valve passages. With ores, present industrial experience is limited to particle sizes less than about 0.2 mm.

In recent years a considerable amount of work has been done on developing pumps, feeders, and injectors suitable for coarse particles, Wood et al. (1984). For example Fehn (1984) showed that coarse particles can be transported at very high concentrations in modified positive displacement pumps.

Centrifugal slurry pumps are used for pumping slurry at a relatively low pressure; however, pressures of up to 5 MPa have been employed in series installations. Therefore, hydraylic hoisting systems using centrifugal pumps are limited to shallow shafts because the number of pumps required in deep shafts would adversely affect the reliability. Particle sizes of up to 100 mm can be pumped in large units. Centrifugal pump clear-water efficiency is generally lowered by the presence of solids, ie the efficiency of a centrifugal pump unit in slurry service is normally in the range of 40-60 %.

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Mine dewatering is often carried out with fast-rotating high-head centrifugal pumps with efficiencies in the range of 65-75 %. In addition, submersible, wear-resistant, and rugged centrifugal pumps in series are used. Their efficiency is at maximum in the range of 50-60 %. Alternatively, positive displacement pumps are also used in mine dewatering operations.

According to Eq. (1) then, with $\eta^* > 1$, the most advantageous hoisting system comprises pumping of fine-grained solids with positive displacement pumps and where the water required is supplied by a mine dewatering system based on centrifugal pumps. Hydraulic hoisting with centrifugal pumps in a shallow shaft may represent the situations $\eta^* \gg 1$ in Eq. (1).

The curves in Figures 3 and 4 are representative for a large variety of industrial applications. The curves were developed for transportation of relatively coarse particles at an oprating velocity of 3 m/sec. Pumping, for example, of fine-grained iron ore concentrates at concentrations by volume in the range of 20-30 % at a velocity of 1.5 m/sec., may also be demonstrated by the curves; however, the energy consumption is slightly over-estimated (4-8 %).

The installed power required in a hydraulic hoisting system is obtained from Figures 3 and 4 with $K = 0$. For a given pump type, the investment cost is approximately proportional to the installed power, at least within a limited interval. Hence, it follows from Figures 3 and 4 that the capital cost decreases with increasing solids content in the slurry. The operating cost according to energy is determined by the possibility of using the water in the mine dewatering system, here expressed by the factor K.

The feasibility of hydraulic hoisting is demonstrated in two examples. The costs of capital and energy were based on the following assumtions. Delivery of one Mtonne of solids per year with 6 000 h of operation, a life of 10 years, and an interest of 16 % are assumed. The cost of energy is based on 0.15 Swedish Crowns (SEK)* per kWh and 6 000 h of operation a year:

Example 1
Iron ore concentrate (solids density = 4 700 kg/m^3).
Vertical pipeline length = 700 m.
Slurry pumping with a positive displacement pump (efficiency = 80 %).
Mine dewatering with high-speed centrifugal pumps (efficiency = 65 %).

Annual cost/tonne (SEK)	Solids concentration by volume 20 %	25 %	30 %
Capital:	0.76	0.68	0.62
Energy: (water availability factor K=1)	0.28	0.30	0.33

*) One SEK is approximately US$ 0.105 in March, 1985.

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Example 2

Coarse coal (solids density = 1 400 kg/m^3).
Vertical pipeline length = 300 m.
Slurry pumping with centrifugal pumps (efficiency = 45 %).
Mine dewatering with rugged centrifugal pumps (efficiency = 60 %).

Annual cost/tonne (SEK)

		Solids concentration by volume 20 %	25 %	30 %
Capital:		0.19	0.17	0.16
Energy:	(K = 0)	0.96	9.87	0.84
	(K = 1)	0.45	0.42	0.39

It follows from Example 1 that the cost of energy is approx. 0.30 SEK per tonne, if all water needed is available underground. This value is less than the cost of energy in a mechanical hoisting system. The capital cost of a conventional shaft system is estimated to be 3-5 times greater than that of a hydraulic system. Therefore, hydraulic hoisting is a very attractive alternative, for example, when the hoisting capacity of a mine is to be increased. Finally, Example 2 demonstrates the great economical potential of integrating the dewatering and hydraulic hoisting systems in a coal mine.

SOME IDEAS OF APPLICATIONS

Small or low-grade deposits are often not profitable if conventional mining and transportation methods are used. In the development of small deposits, transportable pumping and crushing units for hydraulic hoisting may be a useful solution. The concentration of the ore may take place at the mine in a mobilized plant, Figure 5.

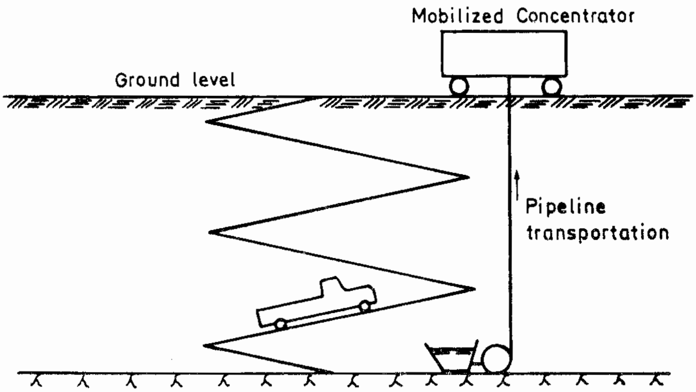

Figure 5. Hydraulic hoisting of ore in a small mine.

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A more detailed layout and typical data are shown in Figure 6.

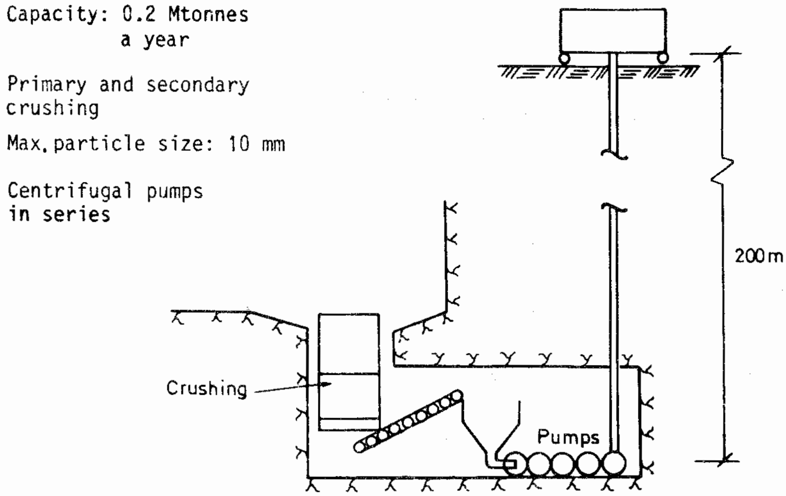

Figure 6. Layout of a hydraulic hoisting system in a small mine.

Hydraulic hoisting and overland transportation in pipes is believed to be a competitive way for rational utilization of a relatively closely located grouping of mines. With a minimum of surface buildings and transportation facilities ore will be pumped to a large central concentrator, which is greatly advantageous from an economic and environmental point if view, Figure 7.

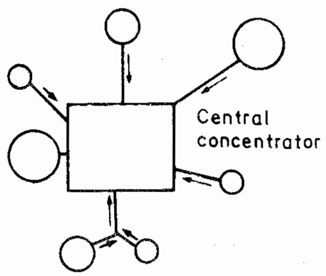

Figure 7. Hydraulic hoisting and haulage to a central concentrator from a group of underground mines.

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Principal layout etc. are shown in Figure 8.

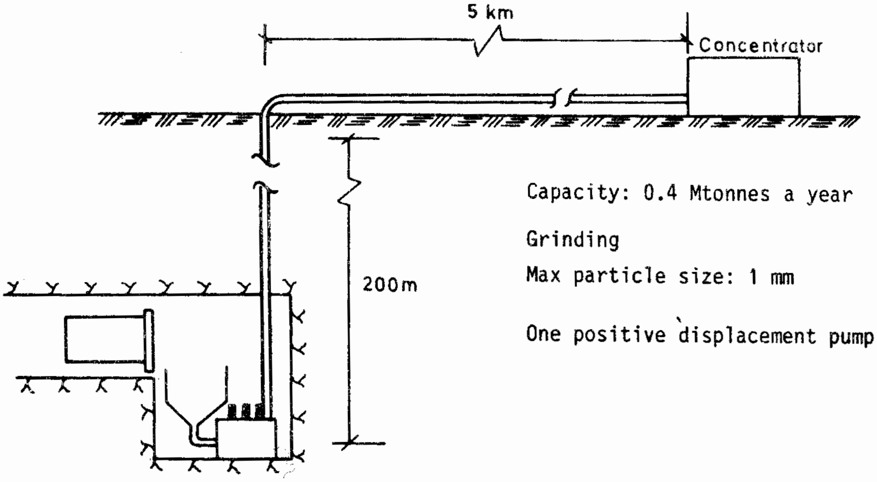

Figure 8. Slurry transportation to a central concentrator.

In the future, underground location of complete mineral concentrators may be the most rational solution, which also minimizes environmental impact on urban areas or ecologically sensitive areas. Besides, the present state-of-the-art in hardrock fullface techniques and continuous mining methods in softer minerals will gain the utilization of continuous hydraulic transportation from working face to surface (Figure 9).

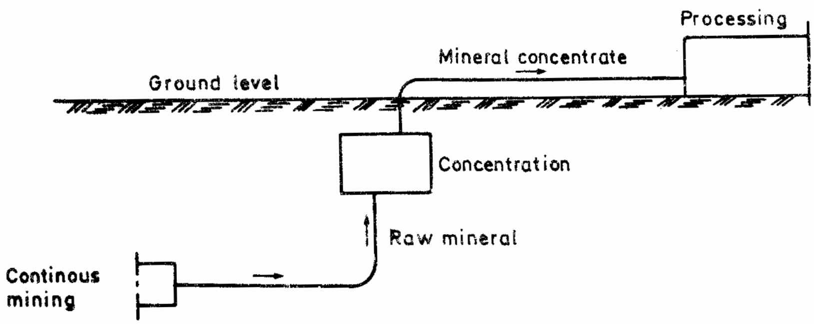

Figure 9. Continuous mining and long-distance pipeline transportation to processing plant.

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CONCLUSIONS

Conversion into a slurry is often a part of the normal processing of ores and industrial minerals. Therefore, hydraulic hoisting of these products shall be seen as a system in which parts of the mining and processing operations are included.

In underground mines there is generally a considerable inflow of groundwater which has to be pumped out. Integration of mine dewatering installations with a hydraulic hoisting system provides an efficient way of using the groundwater. The effectiveness is strongly dependent on the pump efficiencies and the water availability underground.

For example, in a fully integrated system, the cost of energy for pumping fine-grained iron ore is less than the cost of hoisting it mechanically. In addition, the capital cost of a hydraulic system is much lower than that of a conventional shaft system.

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