ABSTRACT

The paper describes various factors which affect the design of a pumping system for a mining layout. Variation of the make and quality of mine water with respect to mine layout and developments are important factors to be considered in the design of a pumping system. The main pumping duties which can be assigned to a mine dewatering system are specified in terms of delivery rate, total head and the quality of mine water. The physical effects of undissolved solids on the wear and tear of the pump are outlined together with the possible solutions. Various inter-related design factors considered in the paper are standage capacity, water make, load factor, cost of minimizing friction losses, centralized pumping versus individual pumps delivering directly to the surface.

Types of pump available together with their operational characteristics have been discussed in relation to selection and optimization of mine pumping systems. Typical case histories are described that indicate the necessity for advanced planning in solving specific pumping problems.

INTRODUCTION

The most popular method of mine water control in underground mining is dewatering by pumps. The optimum design of mine pumping systems should be aimed to achieve effective mine dewatering together with high operational efficiency, low maintenance and overall costs. The pumping systems should be designed to deal with seasonal inflow fluctuations, mechanical and electrical breakdowns including power cuts and sudden increase in mine water inflow. Various factors which are taken into account for designing mine pumping systems are the variation of head requirements, mine water inflow quantities and quality in relation to mine layout and developments. The purpose of this paper is to examine the current practice of selection and optimization of mine pumping systems in order to achieve cost effective ground water control systems in underground mines.
CONSIDERATIONS FOR THE DESIGN OF PUMPING SYSTEMS

The selection and optimization of pumping systems is mainly concerned with relating a mine pump to its proposed duty. Various factors which are taken into account for the detailed design of mine dewatering systems are the quantity of mine water inflow, ground water quality, mine layout and developments. These factors will facilitate the determination of the pumping duties of the mine dewatering system throughout the lifespan of the mine.

Mine Water Inflow Quantities

Correct estimation of the ground water inflow quantity to the mine workings is of great importance in the design of the pumping systems. The factors affecting the mine water inflow to a mine are the hydrogeology of the rock surrounding the mining excavations, mine geometry, aquifer characteristics, ground water level, mining depths and structural discontinuities which will formulate flow channels of water to the mine workings. The quantity of water which can enter a mine workings can be attributed to surface hydrology, size and shape of source of water, recharge area and hydraulic characteristics of the intervening strata between the source of water and mine workings. The source of water may be:

i) surface accumulations such as lakes, rivers, seas, oceans,
ii) aquifers open or confined,
iii) bed separation cavities,
iv) solution cavities,
v) old mine workings.

Various techniques of predicting underground water inflow to a mine are available. These can be classified into two distinct groups viz analytical techniques and numerical techniques. Whichever technique is used, the predicted quantities should be taken as a first estimation of the ground water inflow and therefore, should be substantiated by a detailed monitoring programme during the initial stage of mining.

Modes of Water Inflow to Mines

Past experience indicates that there are four distinct modes of underground water inflow to a mine which has an important influence in designing pumping capacity. These inflow modes are:

- constant rates of inflow over a long period;
- occasional large inflows from a finite source of underground water;
- drainage of large solution cavities in Karst aquifers;
- water inflow through erosive protective layer.

a) Constant Rate of Inflow over a Long Period

This mode of flow is under free flow conditions which is characterized by dripping or seepage depending upon the inflow quantities. Mine development workings under an open aquifer or over a confined aquifer may experience this mode of flow.
b) Occasional Large Make of Water

Characterized by a high initial flow reducing to normal flow over a short period of time (Fig. 1). At an initial stage AB, the rate of water inflow increases rapidly as the head of water overcomes the resistance offered by the flow channels in the intervening strata, until a peak flow rate at C is observed. This flow rate is usually of a short duration and rapidly decreases until a normal flow rate consistent with strata permeability is obtained. This type of flow is normally observed when natural or induced mining fractures intercept a finite accumulation of water such as:

- bed separation cavities;
- solution cavity;
- old mine workings.

This type of flow is also observed when a protective layer or a pillar between an old working and the mine is eroded due to hydraulic pressure and induced mining stresses; for example, a barrier pillar between old workings and the present extraction panel in a steep seam conditions.

c) Large Solution Cavities

The water inflow from large caverns in Karstified rock (solution cavities in limestone) is usually a concentrated flow for a limited period followed by a decrease in inflow rates. The residual inflow rate from a dewatered Karst aquifer is only a fraction of the initial flow. The drainage control under such circumstances can be achieved by grouting from advanced boreholes, sealing the openings by underground dams whenever water is encountered and provision for large pumping capacities (example Driefontein [1] and Friedensville [2]). Figure 2 shows the variation of pumping rates over a 6 year period to dewater a Karst aquifer in West Driefontein mine, South Africa.
d) Water Inflow Through an Erosive Protective Layer

Mining in the vicinity of soft argilleceous strata or protective layer in a steep seam condition allows water to erode the existing or induced mining fractures and discontinuities, thus permitting water to flow through the barrier without offering any marked resistance to the water flow. The inflow in such circumstances starts with the roof convergence initiating the seepage at a low rate then followed by a high rate of inflow. The increase rate of inflow is accompanied by an increase in solid contents of water due to erosion of fractures and discontinuities until an equilibrium state, characterized by low rates of inflow and reduction in solid content has been reached.

The above discussion shows that the mode of water inflow has a great influence on the design capacity of main standage, peak pumping capacity and a sediment settler for a mine pumping system.

Seasonal Variation in Ground Water Inflow

About 30 percent of surface precipitation percolates into the rock mass and infiltrates to shallow mine workings through permeable and porous rocks, cracks, joints and faults in the strata. The permeability of surface rocks is high due to disintegration and the presence of open fissures and cracks due to shallow depths. Consequently, mine workings up to a depth of 100 m are usually wet and are subjected to profound seasonal variations in inflow quantities. The water inflow to shallow workings may either be synchronized with rainfall or delayed depending upon local hydrogeology. The data regarding seasonal variation in inflow rates may therefore, be obtained either by hydrological studies or from past experience of adjoining mines.
Mine Water Quality

The quality of mine water has a considerable influence on the durability and operational efficiency of a pumping system. The quality of effluents arising from coal mining is variable but major pollutants are suspended solids, dissolved minerals, chlorides, acidity and iron oxides.

Acid mine water may occur as a result of coal mining activities due to the oxidation of naturally occurring iron sulphides usually pyrite in the coal seam to sulphuric acid. Discharge of acidic mine water from abandoned mine workings to the present workings is still a serious problem in some mines.

Acid mine water often contains high concentrations of dissolved metals particularly in the form of ferrous sulphate and aluminium sulphate. When such water is oxidized in the presence of bacteria and fresh air hydrated ferric oxide and aluminium hydroxides are formed which have adverse ecological effects on surface streams.

The problems associated with low pH value and ferruginous water entails extensive maintenance of pumps and pipe columns due to corrosion and scaling effect on pumping equipments. Polluted water not only reduces the life of the pumping plant but also increases power requirements or reduces capacity of the pumping system.

The effects of suspended solid in the pumping plants are:

- wear of the wetted parts of the pump;
- increased power requirements due to pumping a high apparent viscosity fluid;
- formation of scale, thus reducing effective pumping capacities or increasing power requirements and discharge velocities.

Solid sediments in coal mining may originate from the erosion of rock material from the rockmass, mining operations, hydraulic stowing, percolation through caved workings and face. The pumping system therefore should be capable of dealing with large amounts of suspended solids.

Mine Layout and Developments

A detailed design of a mine pumping system should take into account the mine layout and developments over the entire life of a mine.

A projected plan of the mine over 5 to 10 years is necessary for collecting design data and making decisions.

- Estimated quantities of water inflow from various mining districts;
- decision regarding the requirements of a centralized pumping plant or small pumping plants at each district directly pumping to the surface;
- number and location of main and subsidiary pumps and their standage;
estimated head requirements for various pumps;
length, size and inclinations of various delivery ranges.

PUMPING DUTIES

The main pumping duties which a mine dewatering system is required to deal with are delivery rates, head requirements and the type of mine water.

Delivery rate depends upon the quantity and mode of water inflow, seasonal fluctuations and the selected load factor of the pump. It is important to ensure that the suction range capacity must exceed the delivery rate of the pump in order to avoid cavitation and therefore reduced delivery.

Head Requirements

The head requirement for a mine pump depends upon the suction lift, static delivery head, friction losses in the pump, friction losses in the suction and delivery pipes and the velocity head. Therefore, the first step in the design of pumping plant is the selection of size of the delivery range, its diameter, length and number of bends. This will help in estimating delivery rate, velocity head, friction head and static head of the pump, suction range requirements and hence the power requirements.

Type of water

In addition to the chemical effects of acid and ferruginous mine water and dissolved minerals on the wetted parts of the pumping installations, effects of undissolved solids and their physical effects on the pump should also be taken into account. For example, machines which depend for their performances on high relative speeds with a fluid containing abrasive solids can be expected to suffer considerable rates of wear. In such a situation there would be a limited number of possible solutions to the problem:

a) Accept the cost of considerable regular maintenance. Such a solution may be the most acceptable if the system is intended to be used only for a short period of time.

b) Take steps to remove or minimise the concentration of all offending material from the water. This would normally involve careful sump design and suction layout.

c) Use a pump constructed from specially selected materials. Certain manufacturers produce pumps with parts or linings which are easily changed and which are manufactured from a variety of materials such as hardened rubber, non-ferrous metals and hardened steels.

d) Select a type of pump which operates at relatively slow speeds and is capable of operation in these otherwise arduous conditions. This would normally mean the use of a 'positive displacement' type of pump.
Various Inter-related Factors

In order to determine the pumping duty of a mine dewatering system a number of design parameters should be considered before decisions relating to the overall pumping system are made:

1. The 'stand-by' (that is the period over which the pump is off load) to be made available in the sumps based on the simple relationship between the 'make' of water and the effective volume.
2. The 'load factor' at which pump is to be operated.
3. The fluid friction losses which can be tolerated versus the initial cost of minimizing these losses.
4. Whether the pumping station is accessible for maintenance and direct control or conversely remotely controlled submersible pumps requiring to be replaced for maintenance.
5. The use of a large single pumping unit as opposed to a number of smaller units which clearly improve the system's reliability.
6. In case of smaller pump units, the manner of operational control of the multiple unit station.

In almost all cases some of these issues are inter-related or limited by the factors outside the planner's control. Therefore, it may be necessary to optimise various factors so as to obtain the best compromise solution.

In connection with the above discussion, the sump capacity may be defined in two forms:

a) The working capacity between the normal low level at which the pumping would cease to the normal high level at which pumping will recommence. This capacity clearly governs the pumping cycle time. Short cycle times cause frequent switching and therefore unwelcome wear and tear on control gear. Cycle times of 10-24 hours can allow for pumping at off-peak periods to reduce power costs, providing the load factor i.e. pumping rate/make ratio is small enough to take advantage of this.

b) The sump may provide for excess capacity i.e. capacity above the normal high water level to give some margin of safety in the event of a breakdown.

The sump capacity described in (a) is dependent on the make of water and the off-load time and can be expressed by the following relationship:

\[
\text{Off-load time} = \text{cyclic time} \times (1 - \text{load factor}) \tag{1}
\]

The make of water = \( \frac{\text{sump capacity}}{\text{off-load time}} \) \tag{2}
The excess sump capacity is essential for a single pump installation but becomes less vital for the multi-unit pumping stations.

Sump Capacity in Relation to Pump Reliability

The ultimate limit to the excess capacity is usually determined by either the level at which the pumping plant itself becomes endangered or the level at which water may get back into lower parts of the mine, rendering the inbye district pumps virtually useless.

Submersible pumps clearly have a distinct advantage in the first respect but are equally susceptible to the latter. The withdrawal of a submersible pump from a deep mine shaft for repair or renewal and its subsequent reinstallation in shaft can be very time consuming (a few weeks) and therefore it may be essential to provide for considerable sump capacity. To do so invariably involves pumping from a lower level and this is, of course, very expensive in the long term.

Acessible pumps on the other hand can in the first place be better and regularly maintained and in the second place the time of repair in the event of breakdown is reduced; usually a matter of hours.

In a system using the accessible type of pumps it is usual and not unreasonable to use a few pumps (say at least 3), smaller in size including one standby unit for emergency situations. In this way idle capacity is kept to a minimum without sacrificing reliability.

SELECTION AND OPTIMIZATION OF MINE PUMPING SYSTEMS

Mine Pumping Sub-systems

In this context, the complete pumping system comprises drainage arrangement of raw water to sump, sediment settlers, suction and delivery ranges, pump and its monitoring and control unit. Each pumping sub-system maximizes the efficiency and economy of the whole pumping system.

Types of Pumps Available

Both 'positive displacement' and 'centrifugal' pumps have been in use since well before the end of the 19th century and although considerable advances have been made in design, construction, theoretical analysis and efficiency; the fundamental principles of operation remain the same. These very early mechanically operated pumps owed much of their development at the time to the needs of the mining industry. The largest positive displacement pump was installed in 1872 in the Friedensville Mine, Pennsylvania, USA having 2500 kW and capable of raising 1300 l/s from a depth of 80 m [2].

The positive displacement and centrifugal categories of pumps are still widely used and the main sub-divisions of these types with their applications in mining are listed below:

- Reciprocating pumps - piston, ram and diaphragm;
- Radial flow pumps - centrifugal, turbine and submersible pumps.
Reciprocating Pumps

The main types are piston, ram and diaphragm pumps. The simplest forms of piston and ram pumps are single acting and if driven through gearing by a crankshaft have a delivery pattern closely following a sinusoidal form. This causes considerable pressure fluctuations due to the accelerating forces on the fluid at the ends of the stroke. It is this more than any other single factor which imposes a strict limit on the speed at which they may be driven. The double-acting piston and the duplex ram pumps suffer from the same problem although for a given displacement, the same limited speed will provide twice the delivery rate. There is a considerable advantage in the above respects in using a 'three throw' ram pump since the acceleration component is halved. These fluctuating pressures may be reduced (and therefore the pump speed increased) by building fluid capacitance into the system in the form of an air vessel.

It can be readily shown that the dynamic pressure produced is given by:

\[ P_{d} = \rho a L \]  

where

- \( \rho \) = fluid density
- \( a \) = acceleration of the fluid column
- \( L \) = length of the column
- \( P_{d} \) = dynamic pressure

Normally, the acceleration can only be reduced either by the use of an air vessel and/or increasing the diameter of the range which is an expensive solution.

Performance of Reciprocating Pumps

i) Capability to deal with dirty mine water - As far as wear due to dirty water is concerned ram pumps are infinitely superior to the piston type. The essential difference is that whilst a piston must operate in cylinder with little clearance, a ram pump operates in a barrel which may have considerable clearance. The only sealing is by the gland through which the ram moves to occupy some of the space in the barrel and in so doing displacing its own volume. If a ram pump is arranged vertically then it is possible to pump heavily contaminated water without damage. Indeed if the porting and valves are large enough broken rock will readily pass through such a pump. In especially difficult applications the glands can be effectively protected from abrasion by bleeding clear water into them at a pressure greater than the pumping pressures.

Stable concentrated suspensions of erosive materials may be pumped using a diaphragm pump and such pumps are often used for slurry type fluids.

ii) Rating - All reciprocating pumps are subject to very limited delivery rates and typically upto 10 l/s (120 gpm). However, they are capable of developing pressures of upto 130 MN/m²
(20,000 psi). Reciprocating pumps are therefore invariably used where relatively small flows are required for high pressure duties.

iii) **Pumping efficiency in relation to operating characteristics**

   The pumping efficiency of reciprocating pump is often around 80% and may reach 90%. Provided the speed is maintained, the delivery will hardly change, irrespective of extreme changes in pressure. This follows from very small slip losses of the order of less than 5%. Such a characteristic is often thought to be of advantage in the process industries, but a constant volumetric flow rate can be helpful to the mining engineer having to deal with ferruginous water (Discussed in 'Case Histories').

iv) **Suction conditions** - Scaling up of pipes in ferruginous water is particularly troublesome in suction ranges since it can very rapidly lead to cavitation. For this reason every effort should be made in the design and layout of the suction range to facilitate easy and regular maintenance. This applies equally to the suction ranges of all types of pumps. It is worth noting that cavitation in a reciprocating pump can hardly continue unnoticed due to the noise produced, whilst in steady flow pumps this is not the case.

v) **Pump drives** - The traditional drives of reciprocating pumps, involving reduction gearing, leaves much to be desired by comparison with the simple direct drives to radial flow pumps. However, pumps are now available for difficult applications (sewage) with direct hydraulic drives from a standard oil-hydraulic power pack; producing a considerable saving in space and providing very wideranging control of both speed and pressure characteristics of the main pumps.

Radial Flow Pumps (Centrifugal and Turbine)

**Centrifugal Pumps**

These essentially comprise the single impellor pump commonly referred to as 'centrifugal' and multi-impellor pumps referred to as 'turbine'.

The 'centrifugal' single impellor pump may be either the 'single' or 'double' entry type, that is, water may enter from one or both sides of the impellor. The latter would be considered only for large flow rates and indeed the simpler design, construction and maintenance of the single entry centrifugal pump generally leads to its adoption. These single stage pumps can develop heads of 15 m at reasonable efficiency but if one is prepared to sacrifice the efficiency they can easily accommodate twice that load. For example, for a clear water pumping duty of 10 $\ell/s$ (120 gpm) and 36 m (120 feet) head the single impellor radial flow pump might require twice the power taken by a three-throw ram pump; although it would produce a much neater, simpler and cheaper installation.

For small delivery rates a reduced gap at the impellor outlet is desirable. However, for manufacturers and operational reasons, the outlet aperture cannot be unduly reduced. To help reduce the risk of
blockage especially at the impellor outlet the suction range inlet must be protected by a strainer of suitable screen size which must not reduce the total inlet area. Indeed such a strainer would normally provide for 3 to 5 times the suction range inlet area. Since such pumps are not self-priming a non-return valve is also required at the foot of the suction range and it is normal practice to combine the foot valve and strainer as an integral unit.

Turbine Pumps

The 'turbine' pump is in effect a number of centrifugal pumps arranged in series and with the impellors on the same shaft. The water is led from the outlet of each impellor along a guided path, which forms a diffuser, and into the 'eye' of the next impellor. Each of the 'stages' in these pumps develops its share of the total head, enabling very high pressures to be produced.

Performance of Turbine Pumps

The simplest version, a two-stage pump, could provide a very much higher efficiency than the small single-stage pump which was compared unfavourably earlier with the three-throw ram pump. However, it would be more expensive.

i) The number of stages will normally be determined to enable the pump to operate at the higher end of its efficiency range when developing the head imposed by static lift and friction. However unlike the positive displacement types all radial flow machines can, theoretically, operate anywhere between 'zero pressure and maximum volume' and 'maximum pressure and zero flow' with zero efficiency at two extremes.

Normally radial flow pumps do not possess serious overloading power characteristics.

ii) Suction conditions required for multi-stage pumps are exactly as for single-stage machines and both types should be started up with a closed delivery valve after priming has taken place.

Operating Point of Turbine Pumps

i) Selection of operating point - It should not be expected that a pump operator of a large plant should know how to precisely set a delivery valve to ensure optimum delivery conditions. Nor should it be expected that any given valve setting will always ensure or maintain the best system resistance for economic running since scaling of pipework will produce changes. For these reasons it is recommended that in addition to the usual stop valve fitted on the delivery a second 'control' valve be fitted which is opened to give the required system resistance and locked in that position. Thus for starting procedures only the usual delivery valve is used whilst the control valve will guarantee that the pump works at the required operating point.
A further issue concerning the operating point which is particularly relevant to mine dewatering installations concerns the stability of the pressure/discharge rate characteristic (p/\dot{V}) Reliability of the system usually dictates the use of a number of pumps in parallel and in such circumstances unstable characteristics can make load sharing between the units virtually impossible. Thus, a falling characteristic is desirable over the entire operating range of the pump. Naturally all pumps used in parallel would need to develop reasonably similar heads over the working parts (say middle third) of their respective delivery ranges.

Figure 3 clearly shows that when two pumps A and B are used in parallel they both deliver considerably less (\dot{V}_A, \dot{V}_B) than either of them used singly and that the decreases are related solely to the friction component of the duty curve and therefore the pipe friction losses should be minimized.

![Diagram showing reduction in performance of each pump when used in parallel](image-url)
iii) Effects of operating point on internal wear - Operating a pump either near to zero flow or near to maximum flow for prolonged periods can lead to internal damage. The internal flow patterns are clearly less disturbed when the pump is operating at a reasonably high efficiency since it is essentially high power losses dissipated within the impellor when efficiency is very low that causes the wear and tear. Such losses always occur at the extremes of the delivery range.

Optimization of Pump Operating Point to Minimize Power Costs

It can be appreciated that operating at the highest efficiency does not necessarily produce the lowest power cost in a mine dewatering system. Irrespective of the numerous forms of tariff charges, whether for a National Grid or private electricity supply, the minimum power cost will occur when the ratio

\[
\frac{\text{Units of power supplied}}{\text{Volume of water delivered}}
\]

is a minimum.

The analysis of the above ratio in terms of pump efficiency and head developed shows that the maximum efficiency condition cannot produce a minimum power cost.

A rigorous analysis of the final result indicates that 'minimum cost could theoretically occur at maximum efficiency if the pressure characteristic for that condition also showed a maximum value' but this would imply an unstable pump which should not be used.

The operating point of the turbine pump can be changed by regulating the rate of delivery. Since any mine dewatering installation will possess excess capacity, some flexibility is possible in the choice of the operating point for the pumps. One may operate a system at a higher delivery rate for a limited period of time or conversely choose to pump for longer periods at a reduced delivery rate.

Clearly this choice of operating point can be used to advantage by choosing the operating parameters to give optimum economy. It appears that most people assume that the optimum operating condition is that which takes place at maximum efficiency. Whilst such an operating condition will often approach minimum costs, the following analysis shows that this general belief is untrue. It is further suggested that for most pump characteristics cost is higher than that for maximum efficiency.

A complete picture of power cost can only be produced by plotting the curve or a function of it such as \( P/\eta \) or \( W/V \).

Let
\[
\begin{align*}
\dot{V} & \text{ be the volumetric flowrate} \\
P & \text{ be the pressure difference developed across the pump} \\
\dot{W} & \text{ be the input power to the pumping unit} \\
\eta & \text{ be the efficiency of the pumping unit}
\end{align*}
\]

and
\[
\eta = \frac{p\dot{V}}{\dot{W}}
\]

(4)
Consider a typical set of pump characteristic curves of pressure and efficiency as shown in Figure 4. Choose any point X along the base at a flowrate \( V \), and let the corresponding points on the pressure and efficiency curves be P and \( \eta \) respectively.

Draw a tangent to the curve at \( \eta \) to intersect the base at \( E' \).
Draw a tangent to the curve at P to intersect the base at \( P' \).

Thus the slopes at these points are:

\[
\frac{d\eta}{dV} = \frac{\eta}{XE'} \quad \text{and} \quad \frac{dP}{dV} = \frac{P}{XP'}
\]

Figure 4  Typical relationship between power, efficiency and costs relative to delivery rates

Power per unit volume must be a minimum for minimum power cost to remove a given 'make' of water.

Power per unit volume = \( \frac{\dot{W}}{V} = \frac{P}{\eta} \) from (4)

\[ \therefore \text{for minimum power cost } \frac{P}{\eta} \text{ must be a minimum value.} \]

\[
\frac{d}{dV} \left( \frac{P}{\eta} \right) = \frac{\eta dP - P d\eta}{\eta^2}
\]
when
\[ \frac{d}{dV} E' = 0 \]
\[ \frac{dP}{dV} = P \frac{d\eta}{d\eta} \]
\[ \therefore \frac{P}{XE'} = P \frac{d\eta}{d\eta} \]
\[ \therefore XP' = XE' \text{ and } P' \text{ must coincide with } E'. \]

Thus for minimum power cost the tangents to the pressure and efficiency curves must intersect at base line.

Also shown in Figure 4 is the 'optimum' flowrate at X, where the tangents to the operating points at P and E\n will intersect each other on x-axis. The curve P/\eta with \( \therefore \) respect to \( \therefore \) is also plotted and shows a relatively flat characteristic in the region of minimum cost which indicates that an approximate position of the operating points to the optimum values is quite satisfactory. It also shows that operating points to the right are comparatively less expensive than those to the left of the optimum values.

SYSTEMS APPROACH TO PUMPING PLANT DESIGN

Table 1 shows the logical relationship between the basic data, derived data, pump selection and power rating of a suitable mine dewatering system. It makes use of the basic data regarding sumpage, pumping periods, water quantity, water quality and total head. Table 1 indicates that some of the parameters are inter-related across the table and, therefore, can only purport to show a generalized approach. However, such an approach will make compromises inevitable

CASE HISTORIES

1) Scaling of Delivery Range with Ferruginous Water

In this connection, the authors recall a mine where the problem of scaling up due to pumping ferruginous water was solved by the use of a three-throw ram pump due to its constant delivery characteristic. It appears that initial scaling of the range produced an increased pipe velocity and that this in turn produced an increased scouring action on the deposits. Eventually a state of equilibrium appeared to develop when the rate of deposition was equated to the rate of scouring with no further depositions. Naturally, the friction losses were increased with consequential increase in power costs. It is likely that abrasive solids could be beneficial in such a situation.

In the same coalfield a mine using turbine pumps had to install extra large diameter shaft ranges and periodically renew them when they became heavily scaled.
Table 1

**SYSTEMS APPROACH TO PUMPING PLANT DESIGN**

<table>
<thead>
<tr>
<th>Basic Data</th>
<th>Consideration of:</th>
<th>Delivery Head:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sumpage</td>
<td>Normal operating capacity</td>
<td></td>
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<tr>
<td></td>
<td>Contingency capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delivery rates, size and length, friction factors, velocity head, lift</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greatest lift, temperature,’accel. (recip), possible scaling***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contingency capacity</td>
<td></td>
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<tr>
<td></td>
<td>Based on load factor</td>
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<tr>
<td></td>
<td>Delivery rate, size and length, friction factors, velocity head, lift</td>
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<tr>
<td></td>
<td>Power Factor</td>
<td></td>
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<td></td>
<td>Differential Power Tariffs</td>
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<tr>
<td></td>
<td>Consideration of:</td>
<td></td>
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<td></td>
<td>Average Make**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peak Values</td>
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<tr>
<td></td>
<td>Duration of Peaks</td>
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<td></td>
<td>Frequency of Peaks</td>
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<tr>
<td></td>
<td>Consideration of:</td>
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<tr>
<td></td>
<td>Dissolved solid concentrations e.g. acidity, salinity, alkalinity: causing corrosion and scaling***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Undissolved solids e.g. slurry with grit causing erosion, malfunction &amp; increased apparent viscosity</td>
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<tr>
<td></td>
<td>Total Head</td>
<td></td>
</tr>
<tr>
<td>Derived Data</td>
<td>Minimum Load Factor</td>
<td></td>
</tr>
<tr>
<td>Total Head</td>
<td>Number of pumps, Capacity of pump, Number of standby units</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Head</td>
<td></td>
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<tr>
<td>Selection</td>
<td>Sump Capacity</td>
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<tr>
<td>Pumping Capacity</td>
<td>Type of Pump Drive</td>
<td></td>
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<tr>
<td></td>
<td>Range Design</td>
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<tr>
<td>Rating</td>
<td>Delivery Rate (l/s)</td>
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</tr>
<tr>
<td></td>
<td>( \text{Efficiency (%)} )</td>
<td></td>
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<tr>
<td></td>
<td>Total Head (m)</td>
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<tr>
<td></td>
<td>( \text{Input Power} = \frac{\text{Vel.}}{\eta} ) or ( \frac{\text{Head}}{\eta} )</td>
<td></td>
</tr>
</tbody>
</table>
ii) Water Standage Capacity for a Mine Liable to Periodic Inrushes

The mine concerned was located in the north eastern corner of Assam, India in a hilly terrain covered by dense tropical forests. The rainfall in the area was prolific, often exceeding 5000 mm (200 inches) per annum, spread over a period of 10 months from November to August. The coal deposit is of tertiary origin and occurs in the form of a saucer shaped fold; two limbs of fold are dipping at 20° and 60° respectively. Two workable coal seams 6 m and 18 m thickness occur in the area.

Mining in this coalfield started in the late 1880's near the outcrops at the top of the hill and underground operations by adits were followed soon afterwards. The method of working was a variation of sub-level caving technique, four stopes being taken in a diagonal fashion at any one time.

Mine drainage was affected by gravity flow through adits and all extracted panels were sealed and drained through water seals in the dams. The subsidence trough due to extraction of thick and steep seams occurred over a vast area in hilly terrain which became inaccessible for maintenance during rainy seasons. These undrained subsidence troughs provided a large recharge area for old workings, consequently, providing large accumulations of underground water. However, the potential danger of large accumulations of water in old drained goaves were not realized by the management at the time.

Mining between zero and +19 level was ceased before 1950's. The present mining operation is concentrated between -4 level to -1 level. A protective pillar of 30 m (100 ft) was left between the present workings and the old workings. Incidentally, this practice resulted in sterilizing large reserves of coal.

Since the protective pillar against old workings on the rise side of a 18 m thick goaf was subjected to indirect mining, gravitational and hydraulic forces, it cannot offer protection against water inrushes indefinitely.

The protection against water danger was affected by the following factors:

- time required for collapse of the protective pillar was sufficient to consolidate present goaves;
- consolidation of caved carboniferous rock provided effective water barriers;
- regular inspection and maintenance of drains from old workings.

However, old workings did occasionally get punctured resulting in inrushes of water of variable intensity and duration. The mode of mine water inflow was similar to that shown in Figure 1 but lasted for a maximum period of 2-3 days. The quantities of water involved during inrushes was of the order of 8 Ml. The inrush water was desilted at 4 level and clear water was drained to 7 and 8 levels (main returns).
The normal peak make of water was 80 L/s and the pumping capacity 120 L/s at a load factor of 0.66. A spare pump together with a separate delivery range was available to deal with emergencies. The mine also had a standby power station for use in the events of power cuts. The capacity of the main sump situated vertically below the main pump house was sufficient for 48 hours standage. At the time of inrushes, any excess water was accommodated in number 8 level by building temporary dams of clay to provide a temporary reserve for inrush water (usually 250,000-450,000 L). This usually took about 7 days to dewater, clean and restore the workings.

During the period of November 1972 to September 1973 there were unprecedented non-stop rainfalls in NE Assam, during which old surface subsidence areas were inaccessible for the maintenance of surface drains. Consequently, vast volumes of old goaves became fully recharged and saturated. An inrush initiated during September/October 1973 of a very high intensity where the peak flow was maintained over a period of 3-4 months. Additional pumping capacities were installed in number 4 level near the intake end of the mine. Additional water was stored in a series of temporary dams in 7 and 8 levels. In spite of all efforts the 7 and 8 levels together with the pump house were abandoned.

This case example illustrates the importance of the study of the mode of mine water inflow together with peak intensity and duration of inflow in order to design main sump capacities and mine dewatering systems.

iii) Pumping Cost in Relation to Total Underground Power Cost

The mine concerned had water problems in two coal seams working 34 m and 64 m below a sandstone aquifer. The average depth of workings in the upper coal seam was 130 m and intervening strata between the aquifer and the coal seams was interbedded mudstone, shale and seat-earth. The aquifer itself was a brown to light yellow, fine grained often flaggy current bedded sandstone of variable thickness of 30-55 m. The aquifer has a very extensive surface outcrop in the area, more than 1.6 km wide in parts and some 10 km long. In addition, on the dip side towards the north there is a broad alluvial bed associated with the river Dearne. These provide a very high degree of recharge to the aquifer from the surface and account for the perpetual high pumping rate at the colliery.

The mine was worked by mechanised longwall caving systems, with a face length not exceeding 130 m. The subsidence control was provided by limiting the face length, adequate size of barrier pillars and strip packing of the face. The first general weighting would obviously cause fracture of impervious strata causing increase in flow of water to the mine. In the east and west side of the working shaft a 'make' of 25 L/s was encountered whilst at the south 45 L/s. This increase in the inflow rate at the south is associated with the increased thickness of the aquifer. The water began to hamper production especially at dip workings resulting in flooding of vast areas.
Because of continuous high make of water it was found necessary to establish a permanent pumping station with standby plants, bypass systems and duplicate shaft capacity. This enabled maintenance and repair work to be carried out without impeding pumping operations. Subsidiary pumping was necessary to feed water to the main sump. In places where these systems were not operative, it was possible as a temporary measure to discharge water into old workings. Altogether, 49 pumps were deployed to deal with water.

The total amount of water pumped from this colliery was 60 M& per week (130 gpm) and the ratio of water pumped to saleable coal raised was 6.5. The power consumed in pumping was 100,500 kWh per week which is equivalent to approximately 63% of the normal total underground power requirements.

It is in such circumstances that any reduction in pumping power cost, as suggested earlier, can produce considerable savings merely by making a slight change to the operating point of the pump.

CONCLUSIONS

A suitable mine dewatering system should satisfy the following objectives:

1. cope with the required duty under most adverse conditions;
2. reliable with minimum maintenance;
3. cost effective in relation to capital, manpower and power costs.

Capital, manpower and power costs should be followed in order to ensure that all the above aims are attained and the subsequent operational control of the system takes advantage of the means of minimizing power costs. In reality the above objectives will produce conflict in design and therefore, any solution must inevitably be a compromise.

Pumping power costs can represent a large proportion of the total power cost for a mine. It follows that even a modest improvement in the pumping cost can represent a considerable saving. Invariably mine pumps do not operate at a planned operating point for the pump and savings can be made in this area without entailing any additional costs.

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REFERENCES


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