SELECTION AND OPTIMIZATION OF MINE PUMPING SYSTEMS

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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 import-
ant 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 frict-
ion 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 fluc-
tuations, 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 varia-
tion 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 hydro-
geology of the rock surrounding the mining excavations, mine geometry,
aquifer characterisitcs, 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 estima-
tion 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 under-
ground 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
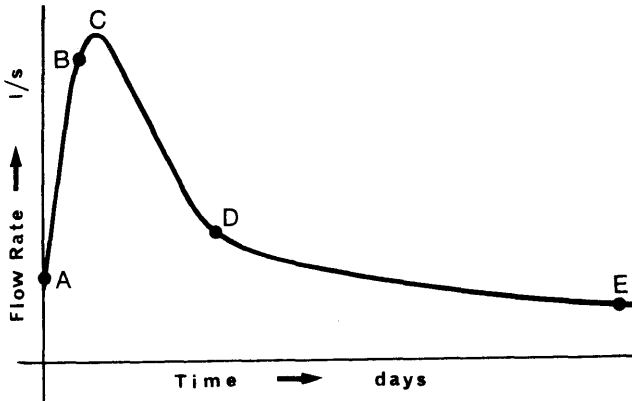consistent with strata permeability is obtained. This type of flow is

Fig. 1 Mode of ground water flow with respect to time

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 under-
ground 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
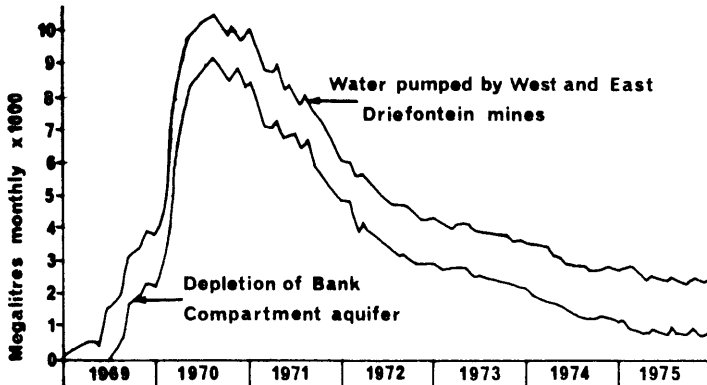dewater a Karst aquifer in West Driefontein mine, South Africa.

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Fig. 2 Variation of pumping rates to dewater a Karst Aquifer
        (After Wolmarans et al, 1978 [1]

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 capa-
city 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 permeabi-
lity of surface rocks is high due to disintegration and the presence
of open fissures and cracks due to shallow depths. Consequently,
mine workings upto 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.

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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 abondoned 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 ferrugerious 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;

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- 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 ferruoginous 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.

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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:

- the 'standage' (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.

- The 'load factor' at which pump is to be operated.

- The fluid friction losses which can be tolerated versus the initial cost of minimizing these losses.

- Whether the pumping station is accessible for maintenance and direct control or conversely remotely controlled submersible pumps requiring to be replaced for maintenance.

- The use of a large single pumping unit as opposed to a number of smaller units which clearly improve the system's reliability.

- 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 planners 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:

$$\text{Off-load time} = \text{cyclic time} (1 - \text{load factor}) \qquad (1)$$

$$\text{The make of water} = \frac{\text{sump capacity}}{\text{off-load time}} \qquad (2)$$

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 invariable 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.

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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:

$$P_d = \rho \, a \, L \tag{3}$$

where
ρ = 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/m^2

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(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 ℓ/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

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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.

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ii) Pressure volume eharacteristics for pumps operating in parallel -
A further issue concerning the operating point which is particu-
larly relevent 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 character-
istics can make load sharing between the units virtually impos-
ible. 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 ($\dot{v}A_2$, $\dot{v}B_2$) than
either of them used singly and that the decreases are related
solely to the friction component of the duty curve and therefore
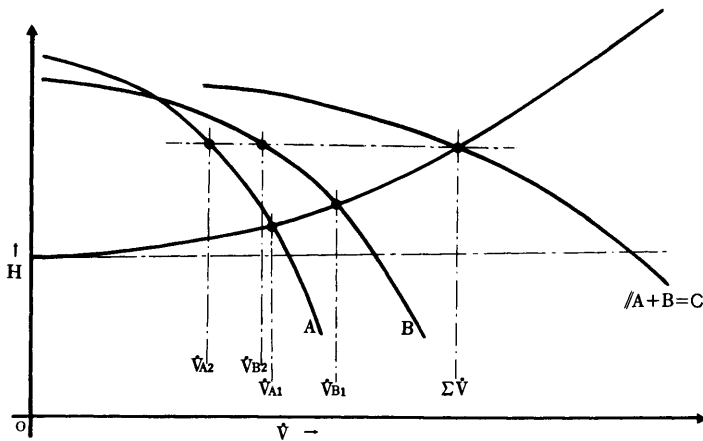the pipe friction losses should be minimized.

Figure 3 Reduction in performance of each pump when used in
          parallel

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iii) <u>Effects of operating point on internal wear</u> - 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
$\dfrac{\text{Units of power supplied}}{\text{Volume of water delivered}}$ 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 maxi-
mum efficiency.

A complete picture of power cost can only be produced by plotting the
curve or a function of it such as P/η or $\dot{W}/\dot{V}$.

Let
$\dot{V}$ be the volumetric flowrate
P be the pressure difference developed across the pump
$\dot{W}$ be the input power to the pumping unit
η be the efficiency of the pumping unit

and $\qquad \eta = \dfrac{P.\dot{V}}{\dot{W}}$ \hfill (4)

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Consider a typical set of pump characteristic curves of pressure and efficiency as shown in Figure 4. Ch..ose any point X along the base at a flowrate $\dot{V}_x$ and let the corresponding points on the pressure and efficiency curves be P and η respectively.

Draw a tangent to the curve at η 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:

$$\frac{d\eta}{d\dot{V}} = \frac{\eta}{XE'} \quad \text{and} \quad \frac{dP}{d\dot{V}} = \frac{P}{XP'}$$
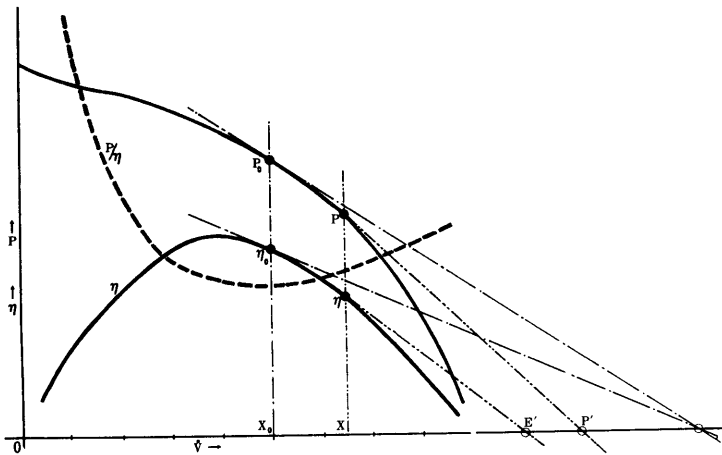

Figure 4   Typical relationship between power, efficiency and costs relative to delivery rates

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

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

∴ for minimum power cost $\frac{P}{\eta}$ must be a minimum value.

$$\therefore \quad \frac{d\left(\frac{P}{\eta}\right)}{d\dot{V}} = \frac{\eta\frac{dP}{d\dot{V}} - P\frac{d\eta}{d\dot{V}}}{\eta^2}$$

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when

$$\frac{d\,(\frac{P}{\eta})}{dV} = 0$$

$$\eta\frac{dP}{dV} = P\frac{d\eta}{dV}$$

$$\therefore \eta\frac{P}{XP'} = P\frac{d\eta}{XE'}$$

∴XP' = XE' and P' 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_o where the tangents to the operating points at P_o and η_o will intersect each other on x-axis. The curve P/η with respect to $\dot{V}$ 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

i)   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.

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Table 1

SYSTEMS APPROACH TO PUMPING PLANT DESIGN

	Sumpage	Pumping Periods	Quantity	Quality	Head
Basic Data	Consideration of: Normal operating capacity Contingencies capacity based on Load Factor Delivery Rate & Makeup** & Settling Requirements*	Consideration of: Max, Demand Continuity of Supply Power Factor Differential Power Tariffs	Consideration of: Average Makeup** Peak Values Duration of Peaks Frequency of Peaks	Consideration of: Dissolved solid concentrations e.g. acidity, salinity, alkalinity: causing corrosion and scaling*** Undissolved solids e.g. slurry with grit causing erosion ⟩ malfunction & increased apparent viscosity	Delivery Head: Based on delivery rates, Range size and length, friction factors, velocity head, lift Suction Head: Based on: size, length and fitting greatest lift, temperature, accel. (recip), possible scaling***
Derived Data		Minimum Load Factor	Number of pumps, Capacity of pump, Number of standbye units	Settling requirement* Material of Construction	Total Head
Selection		Pumping Capacity	Type of Pump Drive		Range Design
Rating		Delivery Rate ($\dot{V}$)		'Unit Efficiency (η)	Total Head (ΣH)

$$\text{Input Power} = \frac{\Delta b \cdot \dot{V}}{\eta} \quad \text{or} \quad \frac{\dot{m} g \Sigma H}{\eta}$$

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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 occured over a vast area in hilly terrain which became inacces-
sible 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).

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The normal peak make of water was 80ℓ/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
powercuts. 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 unpre-
cedented 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 rechar-
ged 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.

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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 Mℓ 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:

.   cope with the required duty under most adverse conditions;
.   reliable with minimum maintenance;
.   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.

ACKNOWLEDGEMENTS

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