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DISTRIBUTION OF WATER IN DEEP GOLD MINES IN SOUTH AFRICA

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ABSTRACT

Gold mines in South Africa use large volumes of water for cooling and other purposes underground. The mines are often at great depths, for example 3600 metres below surface level. Water piped down the shaft can therefore be at high pressures unless a system of pressure reducing dams or valves is installed. Modern practice is to utilize the high water pressures wherever possible. Examples of the use of water pressure include driving turbines for power generation, moving ore by means of high pressure jets and there is the future possibility of driving mining machinery using the water. The operation and analysis of water reticulation systems is complex owing to the complex distribution system and the number of possible operating conditions. Computer programs for the optimum design of such distribution systems and for the hydraulic analysis of such pipe flow systems have been compiled. The high pressures also pose problems in the design of pipework and equipment.

WATER REQUIREMENTS IN A TYPICAL SOUTH AFRICAN GOLD MINE

Gold mines in South Africa can utilize large amounts of water. The water is frequently recycled in order to conserve water resources and minimize pumping costs to the surface and at the same time prevent pollution due to discharge of used water. The water is used underground for a variety of purposes. The prime purpose for water underground was at one stage for dust suppression after blasting and during rock drilling.

An important use of water nowadays is for cooling purposes underground. The geothermal gradient in the South African goldfields is typically 12° centigrade per kilometre of depth. Virgin rock temperatures up to 65° centigrade have therefore been experienced. Previously air ventilation

was adequate in cooling the environment but now that mines are being sunk to greater depths the cooling capacity of the air is inadequate. Owing to the high specific heat of water and the fact that water is required underground for other purposes, the use of water for cooling is becoming common. In fact, owing to auto-compression, as air is circulated at greater depths underground very little cooling effect can be obtained. Water is therefore often used for cooling |1|. Water is cooled in refrigeration plants either underground or on the surface. Cooling towers are also used to precool the water before further chilling in the refrigeration plant. It is also possible that in the future ice will be sent underground for cooling as indicated in the Chamber of Mines Annual Report, 1981 |2|.

Mining takes place on a number of levels (see Fig. 1) and the hoisting capacity of the shaft is probably the main limitation on the area of working face in any particular mine. Large mines have typical cooling requirements of 20 000 kilowatts. That is the amount of heat to be removed during mining operations from any particular workings feeding one shaft. The amount of water to be circulated for this cooling duty may be calculated as follows. If the water is sent underground at $4^{\circ}C$ and returned at $28^{\circ}C$, that being the maximum temperature recommended, then

$$Q = 20\ 000kW/24^{\circ}C \times 4{,}18kWs/kcal$$

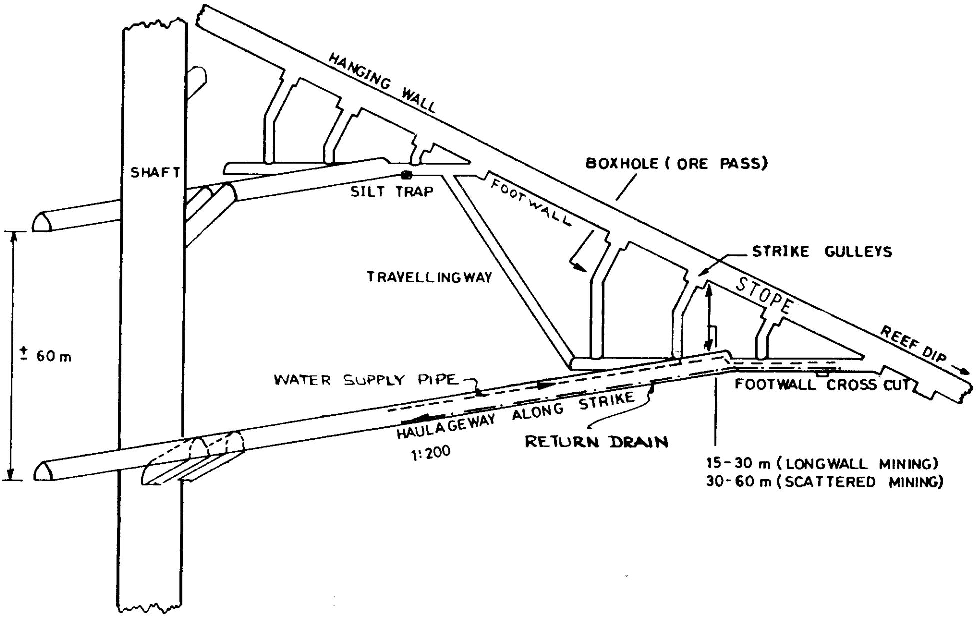
$$= 200\ell/s$$

This flow is typical for a deep level shaft and in fact is exceeded in many mines. Obviously the water requirement will be reduced if ice were used as the latent heat of fusion of ice will effectively reduce the specific heat. There are many problems associated with this possibility however and it is not pursued here |3|. The water used for cooling can also be used for other purposes.

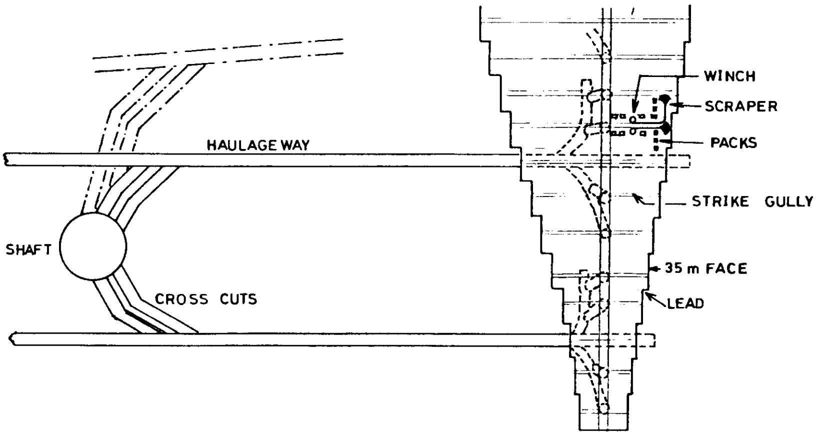
The mining operations also require water. Large masses of ore have to be moved once the rock is drilled and blast ed. An efficient method of moving the fine broken ore is by means of water jets. High pressures, up to 10 MPa have been used and this pressure is currently generated with pumps. Some mines are considering using a high pressure water column to supply these water needs. There is also the possibility of driving mining machines by means of the high pressure water although this idea is still in conception stage. On the other hand, a number of mines have installed hydroelectric turbines at the bottom or an intermediate stage of the shaft. About 40 pelton wheel turbines have been ordered by South African gold mines. Power outputs vary between 1000 and 5000kW.

WATER DISTRIBUTION PATTERNS

When mines were only sunk to a hundred metres or so below



DIAGRAMATIC ELEVATION OF WORKINGS.



PLAN

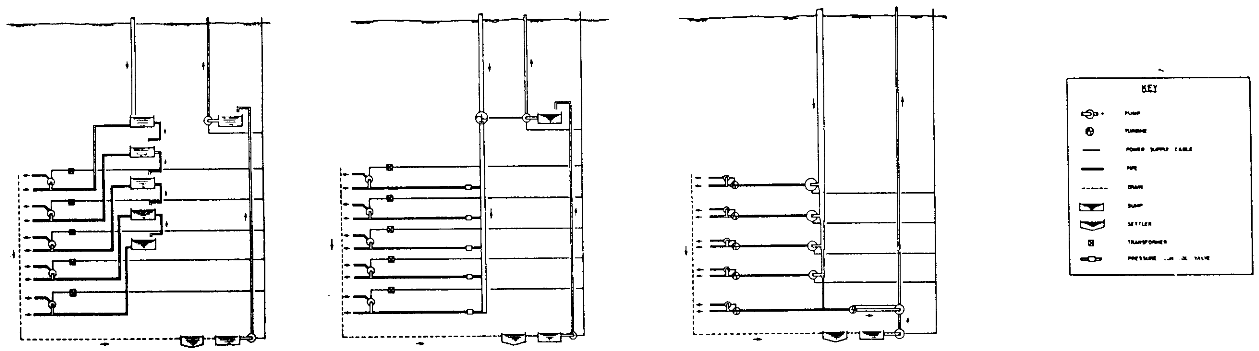
Figure 1: Development of a Typical Longwall Gold Mine

the surface the water used to be piped directly from a surface dam to the workings. As years passed, the upper ore-containing reefs were worked out and excavations followed the dipping reef. As mines became deeper it became necessary to break the pressures in order to operate safely. Water was cascaded from one dam to another at successively lower levels underground. A three-pipe system developed whereby water overflowed from one dam to another and was piped from one dam down two levels to supply the workings at the lower level. Figure 2 illustrates the successive generations in the distribution of water underground and as envisaged possibly in the future. It may be mentioned that the distance between mining levels depends on the angle of the gold-bearing strata or reef. Where the reef is steep the distance between levels may be 100 metres or more. Where reef dip is at a shallow angle then the distance between levels can be 30 to 60 metres. Thus the water pressure at the workings if supplied via the three-pipe or cascade system can vary. In fact the water is piped horizontally along the haulage ways and distributed up and down the working face so the pressure from any particular level may vary according to the elevation of the workings. Figure 1 illustrates a typical development of haulage ways, cross cuts and working stopes.

In many modern mines water is sent down the shaft and pressure is broken at a hydraulic turbine. The turbine can be used to generate electricity or to drive a pump to assist in returning water to the surface or to whatever level the refrigeration plant is located. Water can be taken off the shaft pipe at various levels and pressure-reducing valves can be used to constrain the pressures at the workings and to prevent danger to workers.

With the possibility of the use of the high pressure water at the workings, however, it may be necessary to extend high pressure piping down the shaft along the haulage ways to the workings. Pressure reducing valves may be required in some positions as not all users require the same pressure. In particular, if water is circulated through cooling coils and not sprayed onto the rock for cooling, then low pressures are recommended as these involve complex systems which would be extremely expensive if designed to operate at high pressures.

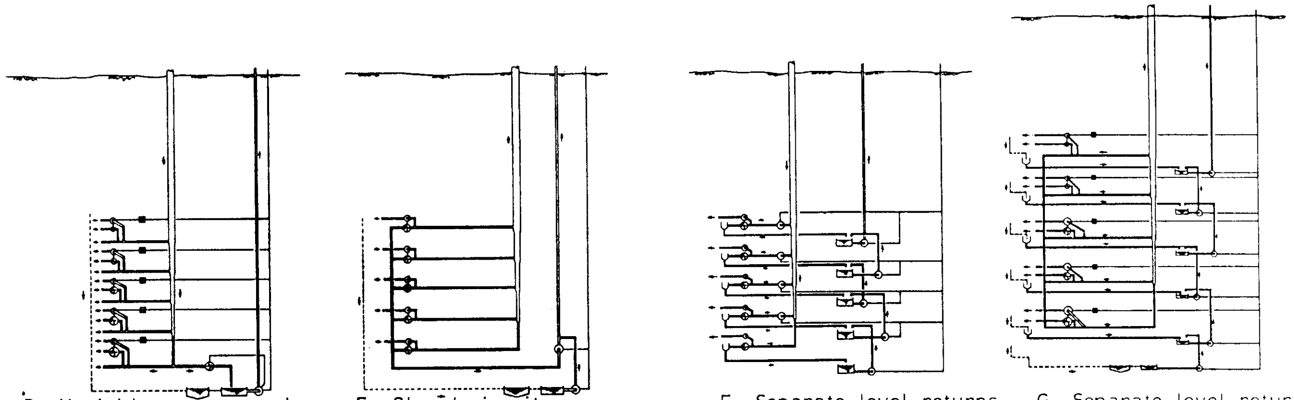
The possibility of closed water distribution circuits is therefore remote although careful investigations may reveal that water could be returned in a more efficient manner than at present at some mines. Most mines drain the workings at each level and send the water to the lowest level where it is purified by settling before being pumped back to the surface or to the refrigeration plant. The possibility of pumping the water back from individual levels is being considered although the cost of pumps and auxiliary equipment will increase. A number of possible water recirculation patterns is therefore illustrated in Figure 2.



A. Cascade System

B. Turbines & head control valves

C. Constant head and boosters



D. Variable power supply

E. Closed circuit

F. Separate level returns

G. Separate level returns

Figure 2: Alternative Supply Systems

It must be borne in mind that the diagram is a considerable simplification of the real system as invariably the water distribution pattern will develop on a day-to-day basis as the mine development proceeds. As different reefs are worked and faults and dykes frequently displace the reef in unexpected patterns, and the pay of the reef can vary considerably from point to point, the working pattern cannot be defined with great accuracy at the initial stage. It is therefore found that the water distribution pattern is extended and altered as mining proceeds.

COMPUTER STUDIES IN WATER DISTRIBUTION UNDERGROUND

A number of studies have recently been completed in the field of optimizing the distribution of water in gold mines. These are still at a fairly academic level and the application to new and existing gold mines will be a big task.

Optimization of pipe sizes

A study by Grosman |4| concentrated on the optimization of the distribution of water underground considering different water quality requirements for various uses. The water circulated underground is frequently of poor quality owing to pollution by sulphides and other minerals in the ore. The possibility of using different sources of water for different uses was therefore investigated. Although duplicate distribution networks may be required this method of water reticulation may be economic if high quality water is required for certain uses. In particular, if high pressure water is used for driving machinery or for oil-in- water emulsions then the possibility is real. Grosman used linear programming and non-linear programming for optimizing distribution patterns. He found that the cost of high quality water was enormous and should be avoided where possible.

Another study concentrated on the design of the vertical pipeline down the shaft of a typical gold mine. Bernstein |5| used dynamic programming to optimize the size of the vertical pipe considering various possible uses of the pressure underground. Not only did he consider the increase in temperature of water due to energy dissipation, but also the loss in possible power generation or use of water for driving machinery underground if pipes were too small. These results showed essentially that friction losses should be minimal in a typical system as the value of the power potential was so high in the face of rising electrical power costs. Both Bernstein and Grosman considered a steady-state system in order to simplify their analysis.

Simulation of water quality deterioration

Holton |6|, on the other hand, considered an unsteady state system. He simulated the water distribution in a typical gold mine using differential equations of storage and flow.

His study could incorporate two or more parameters. That is, he was not only able to study variations in flow rates but also variations in water quality. In particular his study may be used for optimum management of distribution systems in order to improve water quality. It is possible his study may be used for water temperature simulations as well.

In general the use of computers, particularly micro-computers, may prove a valuable tool in minimizing operating costs and improving the design of water distribution patterns underground. Future studies may introduce probability analysis for the design of extending distribution systems. That is, due to the unpredictable ore yields or cost of gold in the future the complete distribution pattern cannot be planned precisely beforehand but may have to be based on a most probable cost function.

HYDRAULIC ANALYSIS OF WATER DISTRIBUTION SYSTEMS

The water distribution system can also be treated as a typical pipe network subject to friction head losses and transient pressure variations. It is often a complicated task to determine the flow rates in different pipes which are linked in a network. The introduction of pressure breaking dams and pressure reducing valves complicates the issue. The head losses are also known to increase with time owing to the deterioration of the inner surfaces of the pipes. Corrosion and scaling can rapidly reduce the hydraulic capacity of the pipes although modern practice is to coat the piping with epoxy internally. Computer programs have been developed to analyse such systems.

Water hammer

In addition to the steady-state flow problem there is the problem of transient pressures generated by closing valves or operating pumps in the system. Water hammer pressures can be high owing to the high velocities in many of the pipes. The water hammer pressure which can typically be 150 metres pressure head per 1 metre per second of velocity may in fact be many hundreds of metres head if the flow in any pipe is stopped instantaneously. For safety reasons valves have to operate fairly rapidly although this is in contradiction to the requirement for minimizing water hammer pressures. Various possible operating conditions can therefore be studied using a computer simulation program. A so-called global hydraulic analysis program can be used to simulate any possible operating condition. In that way closing times of automatic valves can be selected from a number of trial simulations. High velocities, typically 5 to 10 metres a second, are also associated with pipes feeding turbines. The spear valve feeding a hydro-electric turbine can in fact be shut very quickly but the timing can be controlled and a desirable closing time can be recommended. Again the water hammer analysis program can be used to limit the pressure fluctuations and thereby minimize the cost of piping and valves.

The computer program is based on the method of characteristics |7|. The program has, however, a number of innovations. The pipe network can be very simply described by merely numbering the nodes at which various pipes join.

Any combination of pressure reducing valves or pumps can be specified as well as the opening and closing duration and time for the valves. The program is therefore able to recommend the maximum or minimum operating times.

The same program can be used to determine steady-state flows in an open distribution system. By specifying which valves are open in the global program and starting with any reasonable heads at the nodes then the hydraulic damping is sufficient to reduce the flows to practically steady-state conditions after a few iterations. Valves may then be closed after steady-state flows are attained. An important possibility has been studied in some mines using this principle. For example, the possibility of a burst in a high pressure pipe has been investigated and an automatic excess flow control valve closed when a high flow is detected. The entire burst and automatic shut-down procedure has been simulated with the program and the closing time of the automatic control valves thus specified. Alternatively water hammer protection methods can be used, such as release valves or accumulators |8|.

PIPES AND EQUIPMENT

Owing to the extreme pressures and the aggressive environment underground special equipment may have to be developed. The pressures are at the limits of present technology with respect to pipe auxiliary equipment. The high pressures can stress the pipe walls to their limits and higher grades of steel are being used each year. Owing to the difficulty of welding and normalizing the steel underground pipe jointing is a major problem. In particular since the pipe has frequently to be slung as laying proceeds, the positions of joints and elbows are frequently unknown. Therefore supports and fittings, such as elbows and tees, have to be readily available or fabricated in situ.

The protection of steel against corrosion is another problem. Owing to the humid warm environment and the high dissolved salt content of the water, pipes can frequently corrode through in a few years unless protected. Galvanizing has met with little success as has standard paint protection. Epoxy coatings are therefore being investigated as part of a major study into corrosion resistant coatings by the Research Organization of the Chamber of Mines. The addition of corrosion inhibition chemicals is often expensive and ineffective in the large distribution systems encountered. Lime is frequently added to increase the pH of the water and desalination of the water is being considered. The economic costs to the mining industry of corrosion are, however, enormous.

Valves for the control of the high pressure water are also expensive and cumbersome. Isolating valves are available but these should never be used for flow control at the pressures discussed. Control valves from the oil industry have been considered but the cavitation characteristics with water are likely to be more of a problem and it is possible that new valves will have to be developed in the future for the high pressures envisaged.

Centrifugal pumps can only operate at heads exceeding 1500 m if the motor speed exceeds 3000 r.p.m. Rapid wear is experienced at higher speeds owing to the poor quality water. It is therefore necessary to install a booster pump station at higher levels. Hydro-electric turbines are also limited in the head with which they can operate owing primarily to the high velocities at the periphery of the blades. It is possible that positive displacement machinery may have to be used with the high pressure water.

The high water pressures possible in deep level gold mines in South Africa therefore pose challenging problems to the industry and engineering profession in South Africa. The coordination by the South African Chamber of Mines Research Organization of the various engineering disciplines in environmental control, equipment design and hydraulic analysis, as well as water purification and materials science will be an exciting challenge. It is possible that new equipment and new uses for the high pressure water will develop with time and the gradual mechanization of the mining industry will be an added stimulus.

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REFERENCES

1. Whillier, A.H., 1980: Refrigeration applied in the cooling of mines. Intl. J. refrig. 3(6) pp.341-346.

2. Chamber of Mines of South Africa, 1981: Research and development Annual Report.

3. Sheer, T.J., 1983: Investigations into the use of ice for cooling deep mines. Proceedings of the 'FRIGAIR' Symposium, CSIR, Pretoria.

4. Grosman, D.D., 1981: Optimum Allocation of Mine Service Water Subject to Quality Constraints. MSc (Eng) dissertation, University of the Witwatersrand.

5. Bernstein, A.H., 1982: Dynamic Programming Optimization of Pipework in Deep Mine Shafts. MSc (Eng) dissertation University of the Witwatersrand.

6. Holton, M.C., 1982: A Computer Program for the Simulation of Water Reticulation Systems in Gold Mines. MSc (Eng) dissertation, University of the Witwatersrand.

7. Streeter, V.L., and Wylie, E.B., 1967: Hydraulic transients. McGraw Hill, N.Y.

8. Stephenson, D., 1981: Pipeline Design for Water Engineers. Elsevier, Amsterdam.