Gravity-fed water systems in mines

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SYNOPSIS

South African mines often experience significant losses in production because of recurring shortages of water at work places as the result of underground dams running dry. Similar shortages have occurred during fire-fighting operations, and now, with the use of cold service water to aid in the cooling of mines, it is even more necessary that such shortages should be prevented.

This paper draws attention to the primary cause of such water shortages, and an outline is given of some of the fundamental hydraulic principles that must be followed in the design of gravity-fed water-supply systems on mines.

SAMEVATTING

Suid-Afrikaanse myne ondervind dikwels betekenisvolle verliese in produksie vanweë herhaalde watertekorte by werkplekke omdat ondergrondse damme opdroog. Dergelike tekorte het al tydens brandbestrydingswerk voorgekom en met die gebruik van koue dienswater om met die verkoeling in myne te help is dit tans nog meer noodsaaklik om sulke tekorte te voorkom.

Hierdie referaat vestig die aandag op die primêre oorsaak van sulke watertekorte en gee in hooftrekke 'n paar van die grondliggende hidroulikabeginsels wat by die ontwerp van watervoorsieningstelsels met swaartekragtoevoer in myne toegepas moet word.

Introduction

It is common for South African mines to experience significant losses in production because of recurring shortages of water at work places as the result of underground dams running dry. Similar shortages have been experienced during fire-fighting operations. Now, with the advent of cold service water to aid in the cooling of mines, it is becoming even more necessary to prevent shortages of water.

Usually, such shortages are attributed to the small diameters of pipes carrying the water down the shaft. However, in most instances it is not the size of the pipes in the shaft that is at fault (in fact they are often too large), but rather that the piping arrangement for getting the water from the dams into the vertical pipes in the shaft is hopelessly inadequate. The reason for this is that the construction of the dams and of the pipes leading from the dams does not always follow sound hydraulic practice.

Sound practice for conveying water down pipes in shafts requires proper recognition of the following principles.

(a) The water tends to flow down the pipe at such a velocity that the frictional loss of head just balances the available vertical head. Thus, the speed of the water increases until the friction head loss (expressed as metres of water gauge per metre length of pipe) approaches sin ϕ, where ϕ is the angle of inclination of the shaft. For vertical shafts, sin $\phi=1$, and the limiting velocity occurs when the frictional head loss is 1 m of water per metre length of pipe. (Further discussion in this paper will refer only to vertical piping systems.)

(b) Any restriction in the approach pipe leading to the shaft will tend to cause a negative gauge pressure in the pipe column. In other words, the water flowing down a vertical pipe tends to draw water into the approach pipe.

(c) When the pressure in the approach pipe is subatmospheric (that is, when the gauge pressure is negative), there is a tendency for air to be drawn into the pipe through a vortex at the entrance to the pipe.

(d) If the absolute pressure anywhere in the pipe column approaches the saturation pressure of the water (5 kPa at a water temperature of 33 °C, 1 kPa at 7 °C), some of the water at that position will vaporize, with a large increase in volume. An instant later, this water and steam will have entered a zone where the pressure is slightly higher than the vapour pressure, and the vapour will condense instantaneously with a consequent inrush of water to fill the 'hole' created by the condensing vapour. This phenomenon, which can be heard easily at some distance from the pipe, is known as cavitation and can cause very high pressure surges in pipelines, often fracturing the pipes. It also severely restricts the flow-rate of water in the pipe.

(e) To avoid any possibility of negative gauge pressures, the approach pipe system leading from the dam to the shaft must be designed so that the available head of water in the dam is able to accelerate the water to the required velocity and to overcome frictional losses in this pipe at least as far as the shaft. This requires that the diameter of the approach pipe leading from the dam to the shaft should be considerably greater than the diameter of the pipe down the shaft. It also requires that a tapered inlet be provided at the entrance to the pipe so as to avoid a *vena contracta* at this point, since the velocity of the water in the *vena contracta* is about 40 per cent greater than the nominal velocity of the water in the pipe.

(f) Care must be taken that pipe sections on different elevations leading to the shaft are sized on the basis of the available upstream head of each section, and not on the basis of the total head for the entire pipeline.

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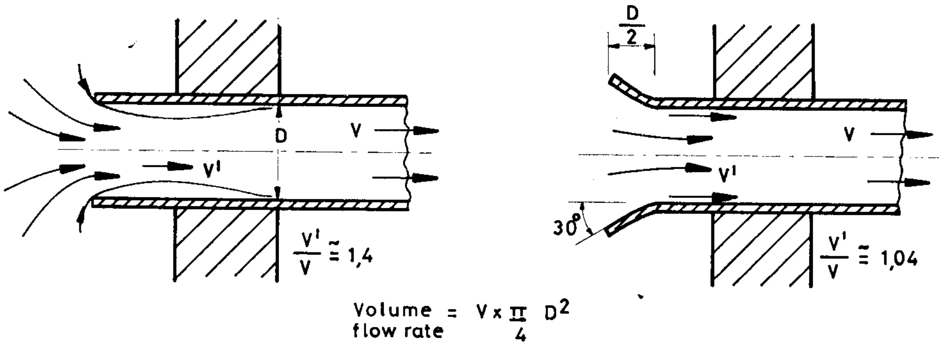


Fig. 1—Effect of shape of pipe inlet on the vena contracta

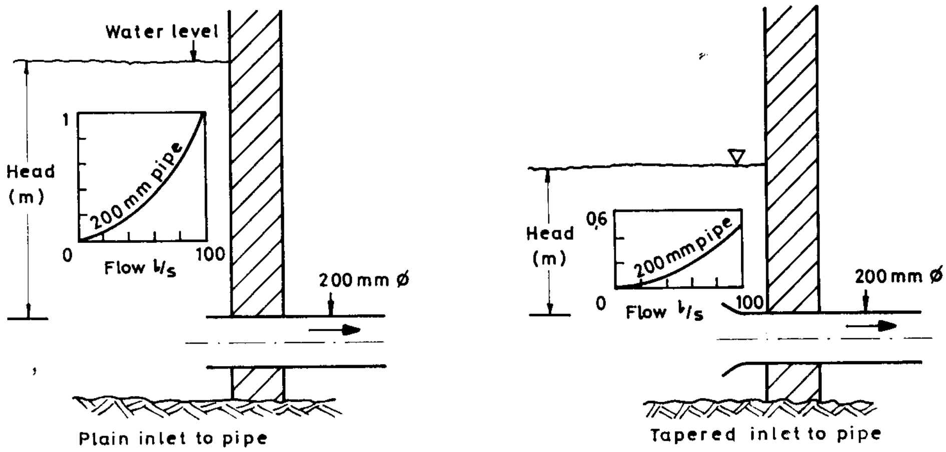


Fig. 2—Minimum water depth (above top of pipe) to achieve the flow-rates indicated

Estimation of Water-flow Capacities

A useful rule-of-thumb guide to the sizing of pipes is that the water flow-rate in litres per second at a nominal velocity of 2 m/s is equal to the square of the pipe diameter expressed in inches. Thus, a 100 mm (4 inch) pipe will carry 16 l/s, while a 200 mm (8 inch) pipe will carry 64 l/s, both at 2 m/s.

Effect of the Vena Contracta

If the water flows at a rate of 100 l/s from a dam through a 200 mm pipe in which the entrance shape is as illustrated in Fig. 1, the nominal velocity in the pipe would be $(100/1000)/(\pi/4\times 0{,}2^2)=3{,}18$ m/s, and the head necessary to accelerate the water to this velocity, $(V^2/2g)$, would be $3{,}18^2/(2\times 9{,}79)=0{,}52$ m. Thus, if air is not drawn into the pipe, the depth of water in the dam would have to be more than 0,52 m above the *top* of the pipe. This is illustrated in Fig. 2.

If the pipe does not have a shaped inlet, the water velocity at the *vena contracta* would be about 40 per cent greater than the nominal velocity, or 4,45 m/s, and the corresponding head, $V^2/2g$, necessary to accelerate the water to this velocity would be 1,01 m. Thus, in this case the depth of water in the dam to avoid air being drawn into the pipe would have to be at least 1,01 m above the top of the pipe.

It is well known that, during periods of heavy demand for water in mines, the levels of dams fall to a few centimetres above the pipe inlets, so that the rate of water flow is reduced considerably, resulting in shortages of water. The problem is not that the water is drawn too rapidly from the dams, but rather that the feeding of water into the dams is too slow because of inadequate design of the inlet opening in the pipes all the way up the shafts, often starting at the main supply dam at the top of the shaft.

The calculations above indicate that, for the example considered and for a straight inlet to the pipe, the water level must remain at a height greater than about 1 m above the top of the outlet pipe if full flow is to be maintained to the lower levels. Thus, the effective storage or surge volume in the dam is reduced considerably, being only the volume of water above this 1 m level to the top of the dam wall. It will be apparent therefore that, with the usual design of pipe inlets, the useful storage volume in mine dams is considerably smaller than the total volume of water, being unfortunately closer to half the total volume of water in the dam.

The shape of the tapered inlet is not very critical, provided that it gives a *smooth transition* on the inside. A typical inlet cone might have a 30° slope, and a diameter 30 to 40 per cent larger than, or even double, that of the pipe itself.

Benefits of a Goose-neck Inlet

Better use can be made of the total volume in storage dams if a tapered goose-neck inlet is provided to all the pipes going out through the dam wall. This is illustrated in Fig. 3, where, for the example shown, the flow of 100 l/s could be maintained with the level of water only 135 mm above the goose-neck inlet pipe.

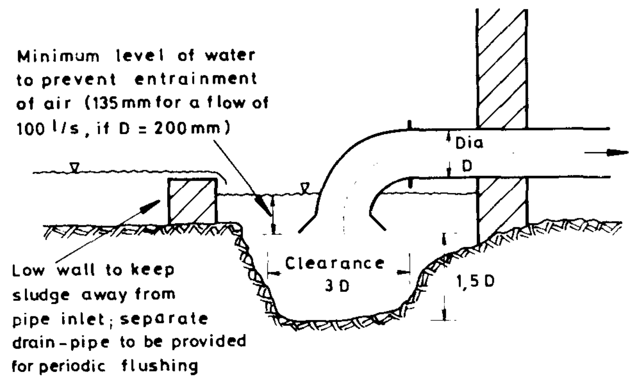


Fig. 3—Benefit of a tapered goose-neck inlet

In the case illustrated, where the maximum diameter of the tapered inlet is assumed to be 1,4 D, the velocity of the water at this point is $3{,}18/(1{,}4)^2 = 1{,}62$ m/s, giving a velocity head, $V^2/2g$, of 0,135 m.

It must be emphasized that, because of turbulence, wave action, and possible swirling, in practice air would be drawn into the pipe somewhat before the level of the water had dropped to the value indicated. However, the point to emphasize here is that, with a tapered goose-neck inlet, almost the entire volume of the dam could be utilized for surge capacity, and full flow could be maintained in the outlet pipe at practically all times.

The provision of a simple sludge trap in the form of a low-level wall inside the dam, as illustrated in Fig. 3, should be noted.

Design for Peak or Average Flow

The decision as to whether to design for peak flow or 24-hour average flow or some intermediate value depends on the size of the dams at the various levels. The average water demand can be determined most easily from pumping records, and it is usually safe to assume that peak flow-rates will not exceed two to three times the average flow-rate.

When refrigeration is to be used to cool the service water, it is desirable that the storage volume of dams should be equivalent to at least one-third of the total amount of water used per day, in order to even out the loads on the refrigeration plant. Thus, it is important to utilize the full volume of dams.

Prevention of Swirl

Swirl will seldom be a problem if tapered goose-neck inlets are used. However, if swirl is detected in dams, it can be suppressed fairly easily such as by the use of short, vertical sheetmetal grid plates arranged horizontally above the inlet pipe.

Necessary Head

In order to avoid negative gauge pressures in the pipeline, and hence to avoid surging, cavitation, swirl, and air entrainment, it is essential that the available head at the dam is sufficient to overcome friction losses in the pipeline leading to the shaft, and also to accelerate the water to the terminal velocity in the pipe going down the shaft. A useful guideline is that the diameter of the pipe leading from the dam to the shaft should be at least twice the diameter of the pipe going down the shaft.

The approximate terminal velocity and corresponding flow-rate of water going down pipes in vertical shafts is as indicated in Table I. As there are few shaft systems at present using more than 150 l/s on the 24-hour average, it would appear that pipes of 150 mm diameter down shafts should suffice if the capacity of the dams is sufficient to meet peak demands. Indeed, in many mines 100 mm pipes would suffice in the shafts, provided that they were fed from the dams through 200 mm approach pipes and provided the dams had adequate surge capacity.

TABLE I

TERMINAL FLOW IN VERTICAL PIPELINES

Nominal pipe diameter, mm	Approximate terminal velocity, m/s		Corresponding flow-rate, l/s	
	New pipe	Old pipe	New pipe	Old pipe
50	6	4	12	8
100	10	6,7	80	54
150	12	8	216	144
200	15	10	480	320

Regulation of Flow

Any attempt to regulate the flow down the shaft by throttling at the inlet will result in severe surging as a result of cavitation, unless the pipe is vented. The flow of water down pipes in shafts should preferably be regulated either

(a) by means of a valve at the bottom of the pipe, in which case the pipeline must be designed to withstand the full static head, or
(b) by means of an *on–off* control at the top of the pipe, together with an air vent to allow air to enter the pipe when the water flow is shut off, in which case the outlet at the bottom of the pipe column must be open at all times unless the pipeline is designed to withstand the full static head.

In the case of an *on–off* control at the top of the pipe column with the bottom end open at all times, there can be only two stable flow situations. One is with zero flow, and the other with full flow at the terminal velocity. The flow in such a pipeline must hence be intermittent, with the relative duration of the *on* and *off* periods depending on the average demand for water at the bottom end of the pipeline.

Because of the increase in resistance of a pipeline with time (due to scaling or roughening as a result of corrosion), the relative duration of the *on* periods will increase steadily during the life of the pipeline. Thus, in the case of a mine requiring a 24-hour average flow of 100 l/s and provided with a 150 mm pipeline controlled from the top end, the *on* periods will constitute about 100/216=46 per cent of the total time when the pipe is

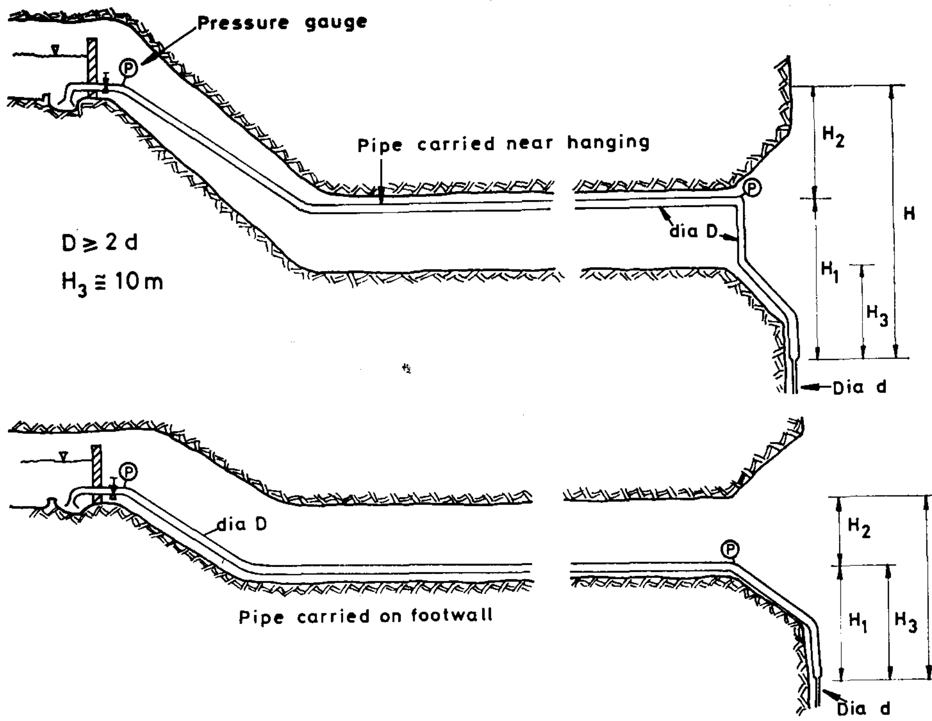


Fig. 4—Height of underground dam to ensure full flow of water

new, whereas, as the pipe ages, the *on* periods will increase towards about 100/144=69 per cent of the time. The feed to the shaft pipe would have to be designed to provide water at the rate of 216 l/s (for a 150 mm pipe, see Table I) without the development of negative gauge pressures in the pipeline.

Returning again to the example of a 150 mm pipeline down the shaft, the terminal velocity in the pipe when new will be about 12 m/s. The corresponding velocity head, $V^2/2g$, is 7,35 m, so that, referring to Fig. 4, the minimum value of the head, H_3, above the entrance to the 150 mm pipe must be 7,35 m if negative gauge pressures are to be avoided. If the diameter, D, of the supply pipe from the dam is 300 mm, the head loss in this pipe at a flow-rate of 216 l/s would be about 3 m per 100 m length. If the length of this 300 mm pipe, including the short portion down the shaft, is 150 m, the frictional head loss in the pipe would be H_2=4,5 m, and the total head, H, (see Fig. 4) necessary to ensure no negative pressures in the pipeline would be 7,35+4,5= 11,85 m. It should be evident from this example that dams must be developed at a level somewhat above that of the station footwall, so as to avoid the need for pumps to transfer the water out of dams to the shaft.

In practice it will be found that slight negative heads (up to a few metres) do not cause surges, giving a small safety factor in these calculations. Furthermore, as a further safety precaution, the measurement of the head H is taken from the bottom of the dam without allowance for the depth of water.

This example, and other similar calculations, lead to the rule-of-thumb recommendation that the diameter of the supply pipe leading from the dam to the shaft should be at least twice the diameter of the pipe down the shaft, and that, before joining the smaller shaft pipe, it should extend down the shaft for a distance of about 10 m below the station footwall. (Referring to Fig. 4, the diameter, D, should not be less than $2d$, and the distance H_3 should not be less than 10 m.)

Over-sized Shaft Pipes

When pipes down shafts are over-sized in relation to the pipes feeding water to them, several practical difficulties arise. For example, in pipelines in which the flow is regulated from the top, severe surging occurs unless a continuous bleed of air is allowed into the pipe at the top. This continuous bleed of air results in accelerated corrosion of the pipelines internally because of the ready availability of oxygen in the warm, damp environment. Such corrosion not only shortens the useful life of such pipes but also causes frequent blockages at places in the pipe circuit where scale and debris can accumulate. The need for this continuous bleed of air falls away if the approach pipe is properly sized.

The rate of flow of water down such over-sized pipes is determined almost entirely by the design of the inlet pipe and is hence not increased by having a larger pipe down the shaft. Thus, in situations where shortages of water occur, the mere provision of a larger pipe in the shaft will not markedly increase the water flow down the shaft.

When the approach pipe is correctly sized, the gauge pressure at the top of the vertical column will always be positive, so that no air can be drawn into the system and the flow down the vertical pipe will be at terminal velocity.

Pin-pointing Troubles

When difficulty is experienced with the water supply in mines, a few simple measurements with pressure

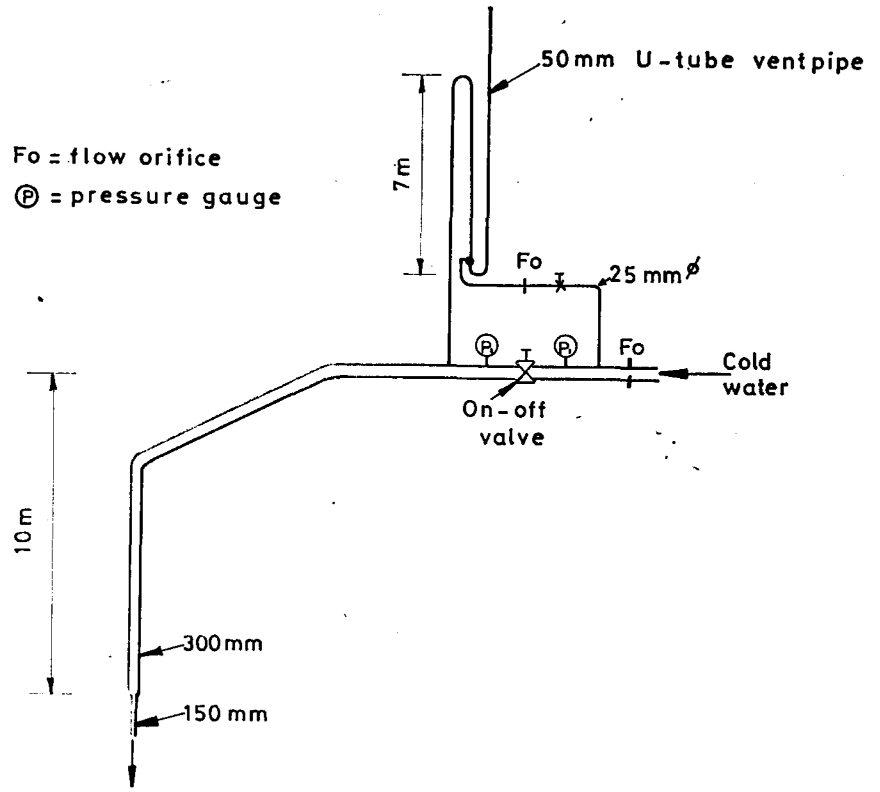
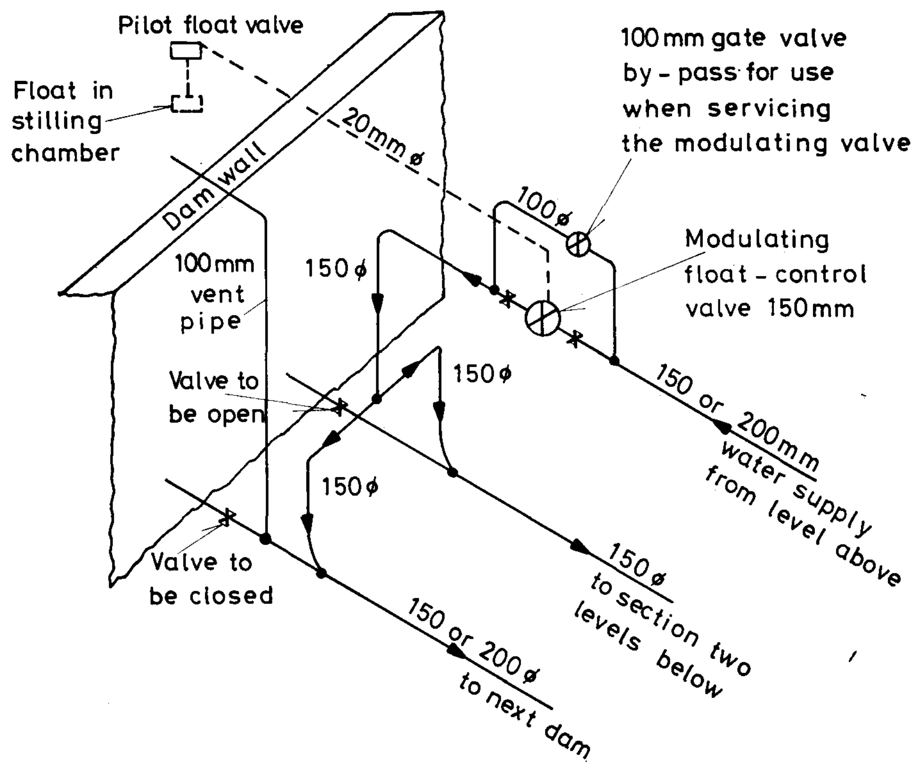


Fig. 5—Piping arrangement for feeding cold water down a shaft from surface



Valve size	Normal peak flow
100mm	50 to 60 l/s
150mm	120 to 130 l/s

For larger flows use two valves in parallel.

Do not oversize valves.

Fig. 6—Suggested piping arrangement at existing dams to ensure an adequate supply of water, and to prevent, at least partially, extensive production delays when water pipes are broken accidentally

gauges will often suffice to indicate the causes. For this it is imperative that suitable pressure tappings are provided on the pipes so that pressure gauges can be fitted quickly. Two important measuring points in the pipe leading to the shaft are indicated in Fig. 4. Another place is at the bottom of the pipeline in cases where flow regulation is provided at this position, or where the flow enters a pump or a heat exchanger such as a condenser. Measurements of these pressures, together with a knowledge of the relative altitudes of the measuring points from survey data, will usually indicate whether the difficulty is due to air entrainment, air accumulation resulting in pipelines running partially full, blockages, inadequate pipe diameters, poor inlet design, etc.

Intermittent Flow

When long pipelines carry cold water intermittently, or when the flow stops for considerable periods over weekends, the change in pipe temperature can give rise to difficulties as a result of thermal expansion. Thus, with a coefficient of thermal expansion of $10,7 \times 10^{-6}$ per °C, the change in length of a 1000 m long pipeline for a temperature change of 30 °C is 0,32 m. Provision must be incorporated in the support of the pipeline for this expansion and contraction.

One method for avoiding problems of expansion and contraction resulting from intermittent operation (particularly over weekends) is illustrated in Fig. 5, where a small continuous flow of water is provided down the pipe, the flow-rate being adjusted so as not to draw air down through the U-tube vent pipe. The height of the U-tube must be one to two metres less than the barometric head; typically it would be about 7 m, as illustrated. The U-tube has a second purpose in that it prevents the flow of air down the pipe during the off-periods, thus reducing internal corrosion.

Inadequate Piping Systems

Where water supply difficulties occur in existing installations, it will often be possible to remedy matters by laying a new, larger approach pipe, and by combining all the pipe connections that are already built through the dam wall to feed into a common header immediately outside the dam. Usually it will also be necessary to fit tapered goose-neck inlet sections to all the pipes that carry water out through the wall in order to prevent air being drawn into the pipes, and hence enabling the full volume of the dam to be utilized for surge capacity. In the method illustrated in Fig. 6, the peak water flow-rates can be handled without having to pass through the pipes in the dam wall, and delays in production arising from broken pipes can be reduced significantly.

It is important to note that, with the arrangement of piping and valves shown in Fig. 6, the dam would serve essentially as an open stand-pipe since the level of the water would vary by only a few centimetres each day. The volume storage capacity of the dam would be utilized only in the event of a broken pipe.

Conclusion

It is believed that adherence to the fundamental design principles outlined in this paper will ensure adequate water supplies in mines under all conditions.

Atlas Copco bursaries

With effect from 1977, two bursaries for study tours of Swedish mines will be awarded annually to young mining graduates. One bursary is open to engineers in any country who have at least three years' practical mining experience; the second bursary will be awarded to an engineer who is undertaking research at a British university and has a minimum of one year's practical mining experience.

The awards, which were established by the Atlas Copco organization in collaboration with the Swedish Mining Association, will comprise a three- to four-week tour of Swedish mining operations in September 1977. Travelling expenses from any country will be paid for the first bursar, and from London for the second; accommodation expenses will be met for both.

As in the past, the Council of the Institution of Mining and Metallurgy will assume responsibility for the selection of the bursars, who will be required to submit, before 1st December, 1977, a written report on any aspect of Swedish mining practice that they find of particular interest.

Application forms, which are available from the Secretary, Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England, should be returned before 1st May, 1977.

Hydrogen in metals

The second international congress on this subject is to be held in Paris from 6th to 10th June 1977. The congress is being organized by the I.S.M.C.M. (L'Institut Supérieur des Matériaux et de la Construction Mécanique). All correspondence concerning the congress should be addressed to the Secretariat General du 2 ème Congres, "L'Hydrogene dans les Metaux", I.S.M.C.M., 3 rue Fernand Hainaut, 93407 St Ouen Cedex, Paris.