The disposal of mine tailings: the real cost of excess water in residues

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SYNOPSIS

The paper examines the consequences of dam building with slime of high water content, and therefore low relative density, such as the tailings usually associated with the extraction of uranium. It shows how a low relative density reduces the practical maximum rate of rise, and hence the establishment cost, of slimes dams built by conventional means. Further hidden costs of such tailings dams are examined.

It is concluded that dewatering of tailings before their disposal is the most cost-effective means of increasing the rate at which a particular dam can be constructed, or of reducing operating or stability problems on existing dams. In the longer term, underground disposal seems to be a feasible alternative. However, it is pointed out that there are other factors that can compound the operating difficulties, and that these should be investigated before remedial steps are taken.

SAMEVATTING

Die referaat ondersoek die gevolge van die bou van damme met slyk met 'n hoë waterinhoud en gevolglik 'n lae relatiewe digtheid soos die uitskot wat gewoonlik met die ekstraksie van uraan geassosieer is. Dit toon hoe 'n lae relatiewe digtheid die praktiese maksimum stygtempo en gevolglik die vestigingskoste van slykdamme wat volgens die konvensionele metodes gebou word, verlaag. Verder word die verborge koste van sodanige uitskotdamme ondersoek.

Die gevolgtrekking word gemaak dat ontwatering van die uitskot voordat dit weggedoen word, die mees koste-effektiewe metode is om die tempo waarteen 'n bepaalde dam gebou kan word, te verhoog, of die bedryfs- of stabiliteitsprobleme by bestaande damme te verminder. Oor die langer termyn lyk ondergrondse wegdoening na 'n uitvoerbare alternatief. Daar word egter op gewys dat daar ander faktore is wat die bedryfsprobleme kan vererger en dat hierdie faktore ondersoek moet word voordat herstelmaatreëls getref, of nuwe damme gebou word.

Introduction

It is known, and generally accepted, that slime of low relative density or high water content creates difficulties in the building of dams and often leads to instability. However, the reason for these difficulties is not often understood.

This paper examines the consequences of dam building with the slime of high water content (low relative density) that is usually associated with the extraction of uranium, particularly where flotation plants are utilized to extract pyrite (and the occluded residual gold) from uranium tailings before their disposal.

Low Relative Density

Various processes for the extraction of uranium are in use in South Africa[1]. The fundamental difference between the processes lies in the solid–liquid separation and primary uranium-recovery circuits. The most common of these are illustrated in Fig. 1. The various solid–liquid separation methods produce different ratios between solids and water, and hence slime of different relative density.

The basic difference in quality between the water bled from the process after the uranium has been extracted from the filtrates that is relevant here can be found in the primary extraction process. The Bufflex process, incorporating resin columns (continuous ion exchange) and a small solvent-extraction plant, produces a large volume of solution (barren solution), which is free of entrained organic matter. The Purlex process, on the other hand, incorporates only a large solvent-extraction plant and produces a large volume of water (raffinate), which contains entrained organic material.

Where flotation plants are coupled to uranium plants so that the pyrite, and sometimes the occluded residual gold, can be extracted, entrained organic matter adversely affects the flotation performance. Raffinate (from Purlex) can therefore not be used as filter wash or in the repulping of feed to the plant. Barren solution, on the other hand, can be used for both. Therefore, whereas all the raffinate produced by the Purlex process must be discarded, as much as 60 per cent of the barren solution produced by the Bufflex process can be recycled.

In efficient plants, the raffinate, which is discarded with the flotation-plant tailings, reduces the relative density to a typical value of about 1,25. Plant inefficiency, spillage, and gland service water reduce the relative density further, and in some cases values as low as 1,15 are reached. Compared with relative density values of 1,4, which can be achieved from a Bufflex process or from conventional gold extraction, this difference is significant.

The total volume of slurry pumped to the tailings dam is significantly influenced by the relative density. For example, about 1 t of water goes to the dam for each ton of solids in a tailing with a relative density of 1,45, while about 3 t goes with each ton of solids in a tailing with a relative density of 1,18. Since the capital, maintenance, and running costs of pumps and piping are approximately proportional to the volume of slurry pumped, the cost of disposal per dry ton milled can be significantly greater for slime of low relative density.

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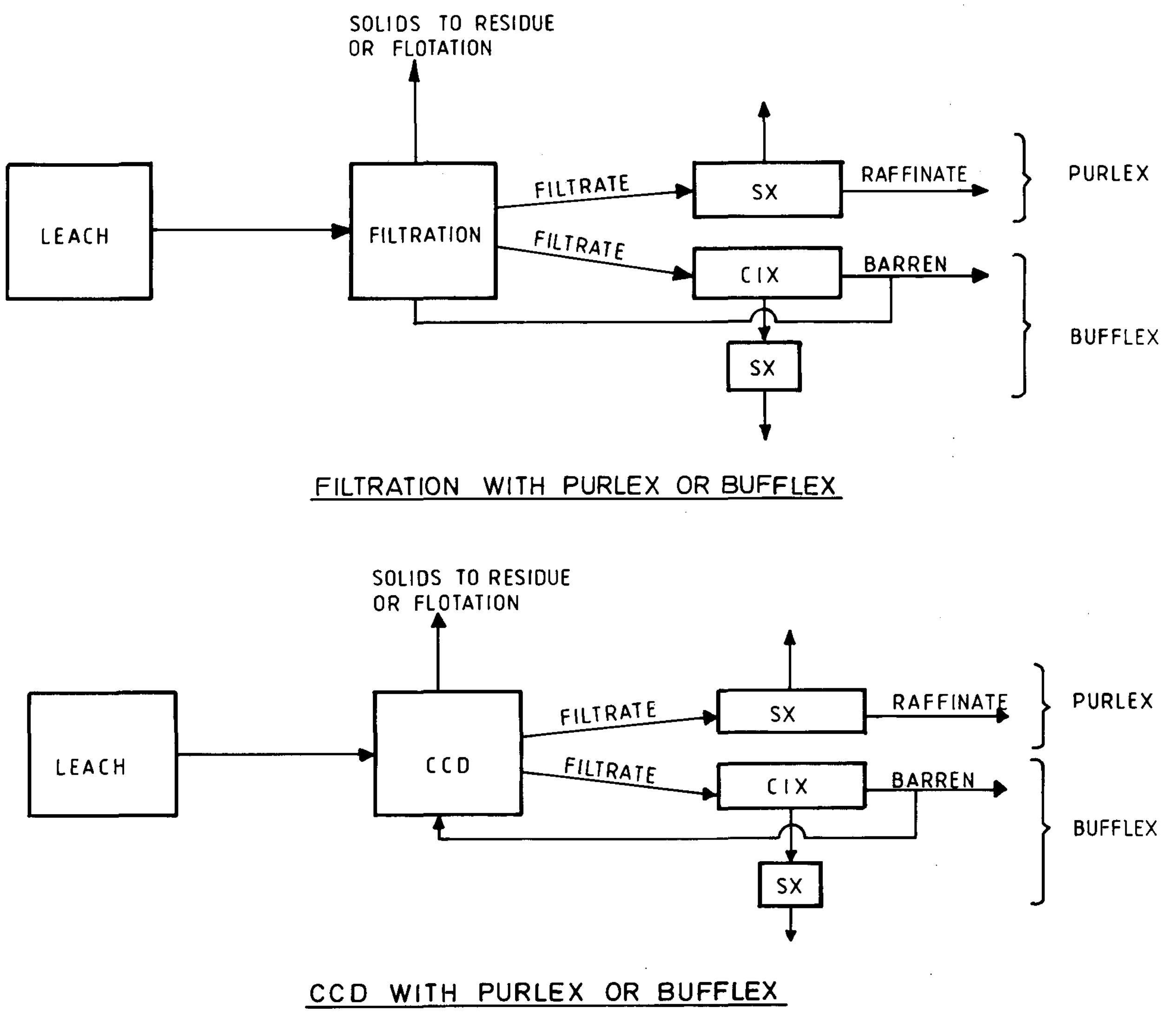

Fig. 1—Circuits for solid-liquid separation and primary recovery in a uranium plant
CCD = countercurrent decantation
CIX = Continuous ion exchange
SX = Solvent extraction

Further to the obvious influence that tailings density has on pumping costs, the effect on the establishment cost for the tailings dam can be significant. The section that follows illustrates how the relative density influences the maximum practical rate of rise, and hence the cost of dams.

Rate of Rise

In practical terms for gold and uranium tailings, the maximum rate of rise is the rate of deposition that allows a low enough cycle time on the dam's day paddocks to facilitate drying out (desiccation) of the tailings. Desiccation of the slime is essential in the first instance to bring about consolidation and the resulting strength gain and, in the second instance, to crack the slime and thereby reduce the ratio of horizontal to vertical permeability. From a practical point of view, slime must be relatively dry to allow access and to facilitate handpacking of a relatively impervious bund on the inner, and in particular on the outer, shoulders of the day paddock. In those cases where mechanical packers are employed, the surface of the paddock must be dry enough to provide a travelling surface for the tractors.

The cycle time should also be low enough to limit recharging of the phreatic surface (water table) within the slimes dam. Excessive recharging results in a rise in the phreatic surface, and may cause unstable conditions at the dam toe if the drainage capacity of the artificial blanket drains when present, and of the natural foundation materials, are exceeded.

The maximum practical rate of rise, and hence the minimum cycle time required for effective desiccation, stable phreatic surface conditions, and access requirements, is commonly thought to be a unique value for a given climatic region. For gold and uranium dams in the Transvaal and Orange Free State goldfields, a value of

2,5 m per year has been adopted as a maximum rate of rise[2,4]. The argument that follows is intended to illustrate that the maximum practical rate of rise is not unique, but that cycle time, which depends on the relative density of the tailings, should be limited.

Effect of Relative Density on Cycle Time

Conventional dam-building technique dictates the limiting volume of a day paddock. Fig. 2 shows a typical cross-section through a dam, and illustrates the width and depth of a day paddock. For a given depth and width, the length of paddock required to accommodate 8 daylight hours of slime increases as the total volume of slime increases. Simplified assumptions can be made to show that the cycle time therefore decreases as the volume of slime increases. Since the total volume can be increased by increasing water volume without a corresponding increase in dry tonnage, it follows that cycle time is a function of relative density.

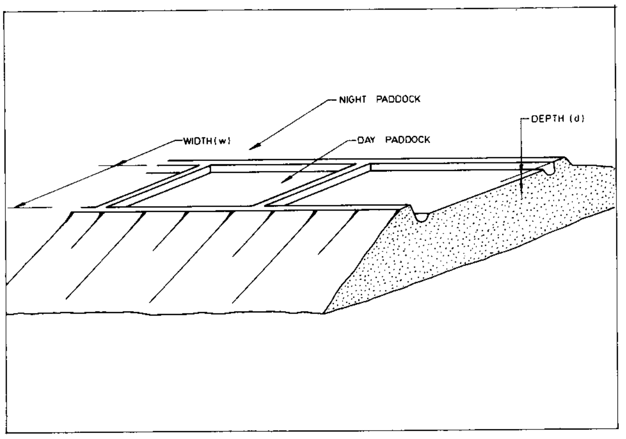

Fig. 2—Conventional method of slime deposition with paddocks

The relationship between water content (mass of water over mass of solids) and cycle time in Fig. 3 was derived theoretically from the assumption of a typical paddock depth of 200 mm and from the assumption that the individual day paddocks are filled in a discrete manner. For example, if the settled slime would occupy 20 per cent of the total volume of slurry, then after the supernatant water had been decanted, the paddock would have risen by 40 mm. For an annual rate of rise of 2,5 m, the paddock would have to be repacked and refilled about 62 times, or every 6 days. Similarly, if the settled slime occupied 40 per cent, the cycle time would be 12 days.

The problems associated with sliming at low relative density were further compounded recently as a result of a change in technique occasioned partially by labour costs and shortages. Previously, the slime was led to small paddocks formed by crosswalls at about 60 m centres via a furrow cut on the day wall. Crosswalls have now been abandoned on some dams, and the day wall is divided into longer units that are often more than 500 m long. During sliming, the entire surface of the large paddock is wet, and this is sustained for a longer period than for the smaller paddocks since the filling time is longer.

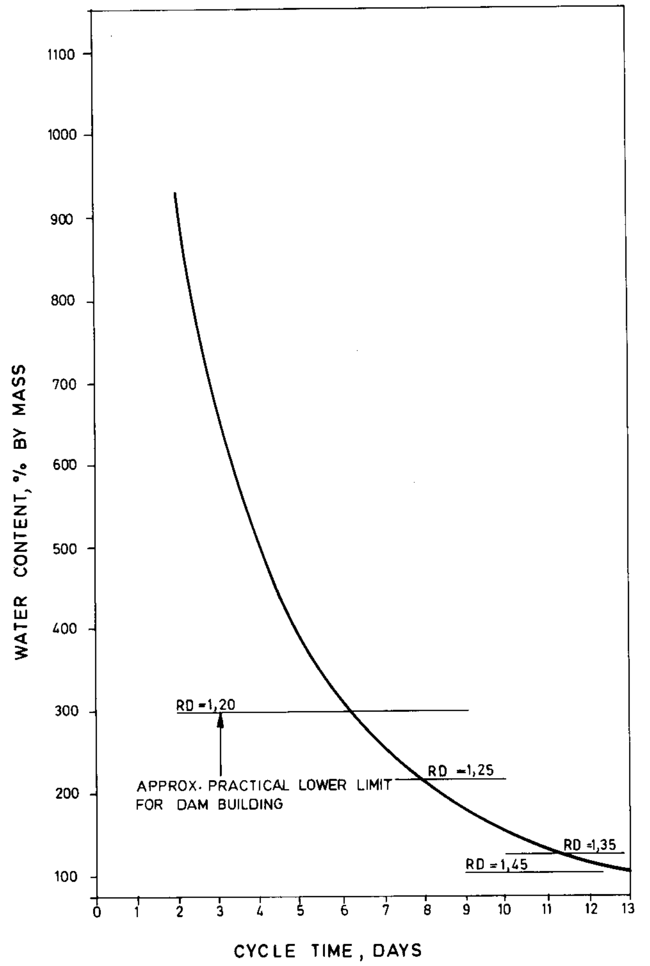

Fig. 3—Relationship between cycle time and water content

The consequence of this practice is illustrated in Figs. 4 and 5. Fig. 4 shows a dam with 14 paddocks, and Fig. 5 shows the same dam with only two paddocks. If one of the small paddocks takes a day to fill, then the cycle time would be 14 days, leaving 13 days for drying of the slime. The large paddocks would, for a dam of the same size, take 7 days each to fill, and the cycle time would be only 7 days, leaving the other 7 days for drying.

If it is accepted for the time being that cycle time, rather than rate of rise, is unique for given tailings and given climatic conditions, then the allowable rate of rise can be calculated as a function of water content or relative density. The relationship between allowable rate of rise and relative density, which is shown in Fig. 6, was derived on the assumption that the previously acceptable rate of 2,5 m per year was fixed from experience with gold tailings, i.e. for tailings with a relative density of 1,45. This, in effect, assumes that a cycle time of about 2 weeks is acceptable and should be maintained as a constant.

In practice, paddocks are not filled discretely but rather over a longer period, while supernatant water and some slime are decanted from the low side of the paddock. The argument presented above and the relationship derived in Fig. 2 are therefore not strictly correct for

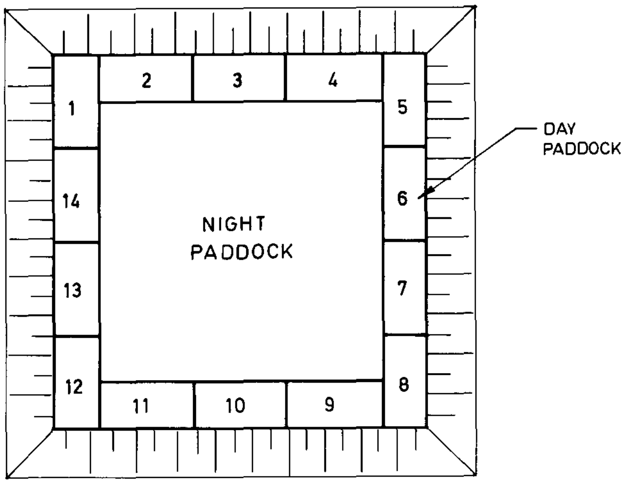

Fig. 4—Fourteen day paddocks

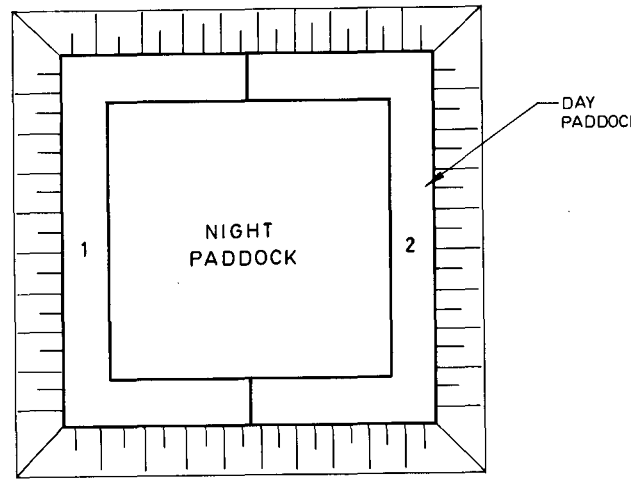

Fig. 5—Two day paddocks

actual practice. However, since the paddocks cannot be filled completely without loss of freeboard in the night area, the actual practice is a compromise between the two alternatives. Current practice combined with low relative density therefore leads to a combination of a decrease in cycle time and an increase in the period during which any particular paddock is exposed to wetting.

Recent experience of operational and stability problems on some dams has confirmed the hypothesis that cycle time, rather than rate of rise, should be considered to be the controlling variable. Failures and severe operating difficulties with uranium-tailings dams have occurred at rates of rise well below 2,5 m per year. These have been attributed to high water content, rather than to other factors commonly accepted. Failures of dams and operating difficulties are shown on Fig. 6 by a graph for the rate of rise at which the problems occurred against the relative density of the tailings for the dam in question. These cases can be seen to correlate relatively well with the calculated upper limit.

It is certain that skilful management of dam operation and timeous remedial measures could obviate some of the problems associated with sliming at low relative densities. However, it is never certain that a dam will be operated in the most skilful possible way throughout its life.

Mechanization is likely to become more popular owing to labour shortages and costs, and drier conditions will therefore be required.

If it is believed that skilful operation and management could increase the maximum practical rate of rise, then a modification such as the one shown for optimal dam-building procedure in Fig. 6 could be adopted.

Since the risk of foundation instability on dolomites is high, a reduced maximum allowable rate of rise has been proposed[3]. This maximum is also shown in Fig. 6.

If it is accepted that, in practice, low relative density leads to operating and stability problems, then it would be prudent to recognize these difficulties and to design new dams accordingly.

Costs

An example of the cost of the same dam, pumps, piping, and water-return system designed for an operation involving 250 000 dry tons per month at relative density values of 1,25 and 1,45 was prepared from Jan. 1983 rates for the construction and power. The dam was assumed to be located at the same elevation as the residue-disposal pachucas in the plant, and at a distance of 5 km from the plant. The velocity of flow in the pipeline was taken as 1,7 m/s, and the power consumption was based on operating experience. The life of the scheme was taken as 30 years, and the pumping and maintenance costs were first inflated at 12 per cent per annum and then discounted at 20 per cent to arrive at a present value of costs.

The tailings dam was assumed to be located on an even ground slope of 1:100, and the underdrainage provided by the natural soils underlying the dam was assumed to be poor. The dam was taken as rectangular with a length equal to twice the width, and was divided into two compartments. Provision was made for a lined return-water dam and an unlined storm-water dam. The capacity of the return-water dam was taken as four days of maximum average monthly return from the slimes dam. The storm-water dam was sized to retain the run-off from a storm with a recurrence interval of 1:100 years and of 24 hours duration on the slimes dam and immediate catchment.

Poor natural underdrainage was assumed to necessitate substantial artificial underdrainage. The dam foundation was taken to be relatively stable with no other geotechnical problems. No special features other than statutory requirements pertaining to pollution control were taken into account.

Fig. 7, which illustrates the relative costs of tailings dams of low relative density and of high relative density, shows that there can be a significant increase in the cost of capital expenditure and pumping as the relative density decreases. The increased cost is thought to be significant enough to warrant an examination of alternative approaches.

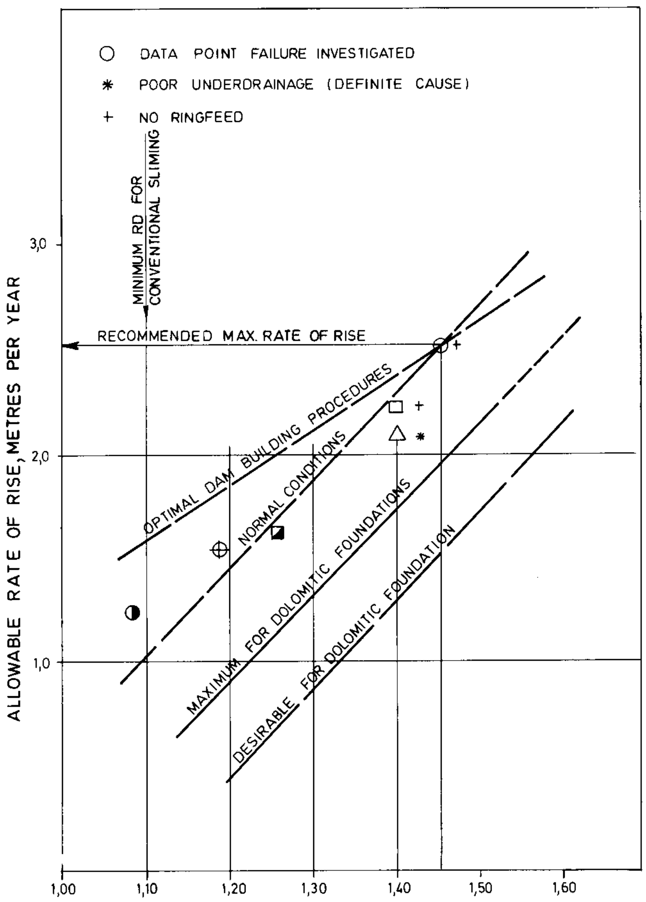

Fig. 6—Relationship between rate of rise and relative density of tailings

Alternative Solutions

The concept that the allowable rate of rise is related to the relative density of slime will naturally attract certain controversy since the conventional practice has been entrenched for so long. There are also a number of factors other than relative density that have an influence on whether problems will be experienced on a dam or not. The most important of these is perhaps the skill with which the dam is operated.

Skilful application of the rules can increase the practical maximum rate of rise on any dam. The following are examples of the options that can be exercised where the relative density is low:

(i) re-introduction of a 'paddocking' system, or

(ii) an increase in paddock depth by double packing.

Unfortunately, both these options require greater labour resources in most instances (the second could be achieved with special mechanical equipment). In view of the shortage and cost of labour of this nature, it is thought to be essential that other alternatives should be considered.

Some of these other alternatives are seen to be as follows:

(a) the adoption of techniques such as cycloning or spigoting,

(b) underground disposal of a portion of the slime (stope backfilling), and

(c) dewatering of the tailings at the plant or at the base of the slimes dam.

The particle-size distribution of gold and uranium tailings makes separation of the coarse and fine fractions difficult. Sufficient dewatering may, however, be achieved to facilitate centre-line construction with cyclones[4].

The problems at present associated with the disposal of tailings underground make this alternative difficult to apply[4]. However, future developments in this field may make the wide-scale use of this technique economically feasible[5]. In particular, where there are either space restrictions or pollution hazards, the technique may attract additional interest.

The most effective and simplest method is seen to be that of dewatering at the source, coupled with conventional sliming techniques. In some cases, this may merely involve an inexpensive rediversion of 'clean' water back into the process circuit. In general, however, the biggest decrease in water content could be achieved by neutralization of the raffinates in separate pachucas and transmission of the neutralized water and other excesses via a separate pipeline directly into the night compartment of the slimes dam. (This technique has been applied

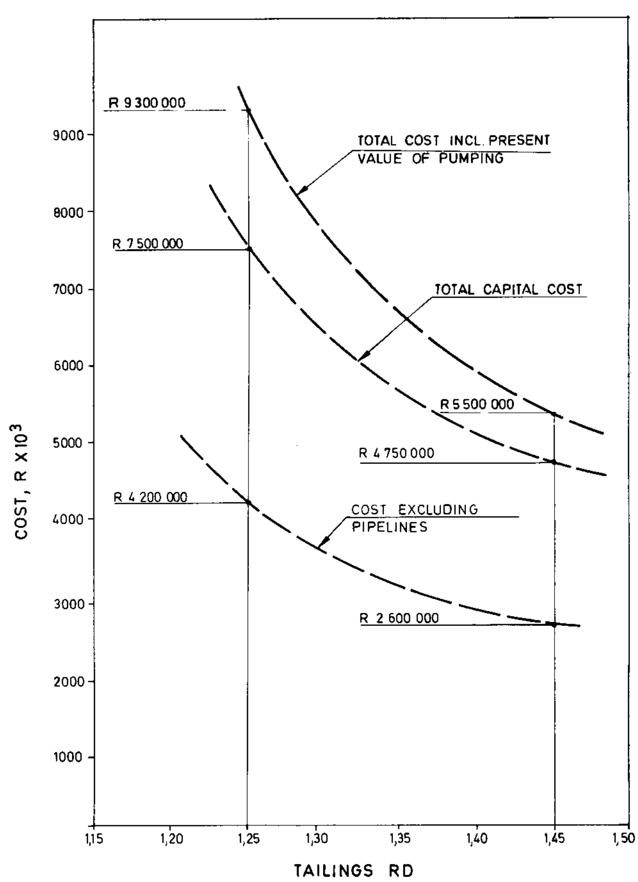

Fig. 7—Relationship between cost of dam building and relative density of tailings

successfully.) If necessary, dewatering thickeners could also be used to increase the relative density before the tailings are pumped to the dams. (Although the capital cost of thickeners is high, the operating costs are very low.)

Conclusions

(1) It has been shown that the maximum allowable rate of rise is controlled not only by the properties of the slime in gold- and uranium-tailings dams in a particular climatic region.

(2) The maximum allowable rate of rise is a function of the relative density or water content of the tailings, and is inversely proportional to the relative density. This conclusion has been confirmed where severe operating problems or instability have been experienced on dams with rates of rise of less than the 2,5 m per year, which is normally adopted as the upper safe limit.

(3) Apart from the cost implications of sliming at low relative density, the safety of the dam can be seriously impaired. Lower rates of rise must be adopted for tailings of low relative density, or alternative practices must be considered where possible.

(4) Dewatering of the tailings before disposal is thought to be the most cost-effective means of increasing the rate at which a particular dam can be constructed, or of reducing particular operating or stability problems on existing dams.

(5) In the longer term, underground disposal is seen to be a feasible alternative. At present, however, the unknowns associated with this method make it unattractive. It should also be borne in mind that it is not possible to dispose of the entire production by filling, since the density of the backfill would be only about 60 per cent of the density of the rock that has been removed.

(6) Increases in relative density can have a beneficial influence on the environment as a natural consequence. The availability of water at plants should prompt more efficient use of water, and primary treatment may render it suitable for introduction into the process circuit.

It must not be assumed that all the problems on gold- and uranium-slimes dams are associated with excess water or low relative density. There can be other factors that compound the operating difficulties. These should be adequately investigated before conclusions are drawn and remedial steps undertaken.

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Reagents in the minerals industry

The Institution of Mining and Metallurgy, in collaboration with the Instituto per il Trattamento dei Minerali, will hold an international conference in Rome from 18th to 22nd September, 1984. All the papers will be published in English, with French and Italian summaries. Full simultaneous translation facilities will operate at the Conference.

Papers will deal with the availability and requirements of reagents in relation to the treatment of

- Sulphide ores
- Oxide minerals
- Silicate minerals
- Fluorspar, barytes, etc.
- Phosphates and carbonates

The processes to be covered will include

- Comminution
- Flotation
- Liquid–solid separation
- Effluent treatment
- Leaching, precipitation, and extraction of metals from solution
- Materials handling and storage
- Electrowinning and electrorefining

An exhibition that will feature products relevant to the topic of the Conference is being planned, and technical tours to various operating plants in Italy are being arranged for the period 22nd to 26th September.

Enquiries about the Conference should be addressed to the Meetings Secretary, The Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England (telephone: 01-580 3802; telex: 261410 IMMG).

Fracture

The Sixth International Conference on Fracture is to be held in New Delhi from 4th to 10th December, 1984.

The main themes of the Conference are as follows: Fracture—Mechanics and Mechanisms; Fatigue—Mechanics and Mechanisms; Failure at High Temperatures—Mechanics and Mechanisms; Environmental Effects on Fracture; Dynamic Fracture; Fatigue and Fracture of Non-metallic Materials; Fatigue and Fracture of Composites; Engineering Applications of Fracture Mechanics; Test Techniques; and Failure Analysis.

Additional information is obtainable from Dr K. N. Raju, General Secretary, ICF 6, Deputy Director, National Aeronautical Laboratory, Bangalore 560017, India.