rake action in the thickener also densified the sludge (Fig. 4).

The addition, during one test, of an anionic polyacrylamide as a flocculant for the clarification of the thickener overflow resulted in a loss of sludge density. The reduced density was probably caused by the long-chain polymer holding the iron hydroxide particles apart, with a subsequent higher amount of interstitial water and also preventing densification on sedimentation.

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DISCUSSION

R. T. RUDD*

I have the following comments on Mr Bosman's paper.

Before giving the company permission to discharge neutralized mine drainage containing 1800 mg/l of dissolved solids into a public stream, my Department had to consider the matter from both the legal and the practical viewpoint.

The legal position is that, as the acid water does not arise from the use of water in an industrial process, a permit for its discharge is not required. However, as it can still be considered to be polluting, the following practical considerations were taken into account.

(1) The quantity of water in the mine represents roughly 3 per cent of the capacity of Loskop Dam. If some natural catastrophe were to release all this water into the dam at its pH value of 2,7, the results would be disastrous.

(2) The use of calcium to neutralize the effluent would result in the formation of calcium sulphate, which in general would not be harmful to irrigated soil applied in the quantities in which it would reach (and leave) Loskop, and could under certain circumstances even be beneficial.

(3) The water from Loskop Dam is used almost exclusively for irrigation—in fact, the Olifants River from Loskop to Phalaborwa is at present used for little else.

(4) Previous methods of disposal, in which the acid water was left out of our streams by leading it to evaporation dams and evaporating it, posed the problem that we were merely transferring the water to another site where it could possibly cause trouble in future.

(5) The diluting effect of the dam and other waters reaching it from the catchment would be sufficient to reduce the calcium sulphate level to an insignificant figure.

It was therefore considered that the method described by Mr Bosman offered the best available solution to the problem.

It was pointed out that the dissolved solids in mine water, even fairly close to Kromdraai, varied by large amounts. The old T & D.B. Colliery, for instance, discharges a water containing some 4000 mg/l of dissolved solids, while figures for the old Douglas Collieries are somewhat lower.

Similarly, the pH of the waters varies from mine to mine, and figures between 1,9 and about 4 have been reported.

In view of this, the opening remarks made by the Chairman of this symposium, Mr Van Rensburg, that each mine would have its individual problem in this respect, were most apt.

However, with the mixture of ingenuity and scientific expertise shown by the Company's work on Kromdraai, it will no doubt be able to solve these problems satisfactorily in due course.

*Department of Water Affairs.

C. M. VAN STADEN*

Mr Bosman and his team are to be congratulated on the research work carried out by them on this high-density sludge (H.D.S.) process and in establishing the parameters ap-

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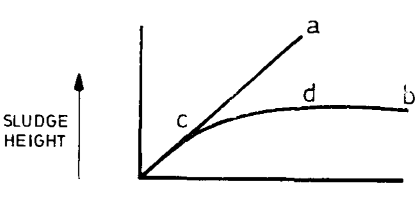
plicable to their specific conditions. In this same spirit, one cannot help but pay tribute to the original work done by Kostenbader and Haines of the Bethlehem Steel Company.

The recycling of sludge in a sewage plant to produce better oxidation and sludge settling is a well-known process. I have the utmost respect for the patience and perseverance of the first person who tried to make the H.D.S. process work on the iron hydroxide precipitated with lime from acidic mine drainage. In normal circumstances one would recycle sludge for 2 to 3 days, and, if nothing happened, not many of us would carry on. This is just where the catch is. One has to recycle for weeks before the desired high-density effect is achieved.

The following is a description of a comparatively rapid method of determining whether a water will respond to H.D.S. treatment. The test is conducted batchwise, but in effect simulates a continuous process.

A transparent tube, approximately 2 m long and 125 mm in diameter and sealed at the end, is used in the test. The sample of water (1 litre) is poured into the tube, milk of lime is added to increase the pH to approximately 7,0, and the mixture is stirred for a fixed period of 5 minutes. The solids in suspension are allowed to settle for a period of 45 minutes. The height of the sludge in the tube is then measured, after which the supernatant liquid is drawn off. Sufficient milk of lime is added to the contents of the tube to produce a final pH of 7,0 to 7,5.

An additional litre of water is added, and the mixture is oxidized and gently agitated by air. The process is then repeated. The number of cycles are plotted graphically against the sludge heights measured after settlement, and the following type of graph is obtained.



Theoretically if no H.D.S. is formed, a plot of the sludge heights and number of cycles should conform to graph a. However, if H.D.S. is formed, a curve similar to graph b should be obtained. Point c represents the point where H.D.S. begins to form. At point d, a sample of sludge could be drawn off and the solids in suspension determined.

This type of test indicates whether a water sample will respond to H.D.S. treatment and what sludge density can be expected.

Theie are three main processes for the neutralization of acidic underground water.

(1) The conventional process, in which hydrated lime powder or milk of lime made from unslaked lime in a slaker or lime slurry is used. With this method, we found an average sludge density of about 1 per cent, but on a few occasions, we got a density of 2 per cent.
(2) The calcium carbonate-lime process. Acidic underground water is treated with powdered limestone dust or limestone lumps in a trommel screen or a mill. The partially neutralized acidic water is aerated to drive off the carbon dioxide that forms and to oxidize the ferrous iron to ferric iron. Hydrated lime or milk of lime is then used to give the desired pH. The reaction time of the interaction between limestone dust and acidic underground water is about 20 minutes. Sludges of 10 to 15 per cent can be expected with this process.
(3) The H.D.S. process used at Kromdraai. Densities of 40 per cent can be obtained.

If higher sludge densities are required with methods (1) and (2), some mechanical means, for instance filters and centrifuges, must be applied. The latter will give a sludge density of about 30 per cent. This product has the consistency of a soft paste and cannot be handled by centrifugal pumps.

This H.D.S. process is an achievement and a blessing, especially when large volumes of acidic water have to be neutralized. Neutralization with lime is relatively easy, but sludges containing only 1 per cent solids can be so voluminous that sludge disposal can become an embarrassment. How and where does one dispose of this voluminous gelatinous mass? It cannot be used in the building of a disposal dam because it has no mechanical strength. The only place where it can be deposited is on a slimes dam, resulting in an increased hydraulic load to the reduction plant and building up to volumes that cannot be coped with.

This H.D.S. is at times disposed of by dumping it underground into worked-out areas. Although the authorities say that this method can be used, I am a little hesitant to recommend it, not knowing if the sludge will not redissolve and cause a build-up of recirculating iron in the underground water.

Mr Bosman presents an interesting theory concerning the iron compound formed during the H.D.S. process. With my present knowledge of the process, I support this theory of Fe-O-Fe linkages by chain structures. I should go even further and suggest that this structural build-up may extend three dimensionallyr

I should be grateful if the autho. would comment on the following questions.

(a) One disappointing result was reported in this paper; namely, the 60 mg/l of suspended solids in the overflow. At Kromdraai, the problem is to be overcome by the installation of holding dams with a retention time of about 25 days. What would the solution be when water is pumped at a rate of 40 000 m^3 per day?
(b) What sludge densities can be expected when the water becomes ferric rich instead of ferrous rich?
(c) What would the effect be if the total iron content of the water rises to levels that are ten times the concentration mentioned in the paper?
(d) In the gold mines, the underground water must be partially neutralized, say to pH 5,5, before being pumped to surface for the final treatment and settling. This is because the pumping of acidic underground water would cause excessive corrosion of the columns. At

this pH value of 5,5, some iron will precipitate out, but some—mostly ferrous iron—will remain in solution. What effect would this partial neutralization have on the final H.D.S. process?

(e) If sludge were recirculated by the injection of some return sludge into the column after the pumps, would it have any beneficial effect?

It is apparent that this H.D.S. process is of extreme importance to the mining industry and to industries where spent pickling liquors containing iron must be neutralized and the sludge disposed of or reused.

Further research and investigation on this process is strongly recommended. Is this not the type of research in which the Water Research Commission should actively participate?

Author's Reply

(a) The holding dams were not installed for the purpose of polishing the thickener effluent, but, since they are available, they are to be used for the removal of excessive amounts of suspended matter in the effluent. However, the full-scale plant, which will have a rising velocity of 0,4 m/h, should produce a clearer effluent than that from the pilot plant, where the rising velocity was 0,57 m/h. Furthermore, the full-scale plant at Bethlehem produced an effluent with less than 7 mg/l of iron at a rising velocity of 0,7 m/h, so that the effluent from the full-scale plant at Kromdraai should also be of the required clarity.

(b) Anglo American has not tested the sludge densities obtainable with water rich in ferric iron. The work done by Kostenbader and Haines appears to be the only source of information on this aspect. From their results, it appears that lower sludge densities will result from water with higher ratios of ferric to ferrous iron.

(c) Unfortunately, the author has no empirical information on the sludge densities obtainable from water of high iron content. Although they make no mention of the iron concentration, Kostenbader and Haines obtained a 45 per cent sludge with a synthetic steel-plant waste in which 95 per cent of the total iron content was in the form of ferrous iron.

(d) When acid mine drainage is partially neutralized to a pH value of 5,5, all the iron that has precipitated is in the same voluminous form as when it is precipitated by the conventional method. Furthermore, at a pH value of 5,5, the remaining ferrous iron will oxidize rapidly, losing the advantage of the high-density sludge obtained from water rich in ferrous iron.

(e) When recirculated sludge is introduced into the underground pump delivery column, sludge densification will occur only on the iron still in solution, the rest having formed a low-density sludge. Whatever benefits are obtainable from densification of a portion of the iron must be weighed against the cost of installing a return-sludge column from surface to the underground pump station.

G. TROLLOPE*

I should like to add my congratulations to the Author for his excellent and stimulating paper.

I have been associated with the Kromdraai problem on two occasions in the last three years. The first was a photo-interpretative search for potable underground water for farming purposes; the second involved proposing and organizing a successful Infrared False Colour Aerial Film survey of the area to locate areas where incipient seepages of acid mine water are adversely affecting the vegetation.

The Kromdraai area comprises the northern half of a dissected plateau, where the highest level of the water table cannot be far south of the national road from Pretoria to Witbank. Therefore, most, if not all, of the water influent to the old workings must be purely local rainfall. The overlying sand soils and the Ecca Shales and sandstones are now decalcified. It is unlikely that the solid rocks originally contained much calcium carbonate.

Does Mr Bosman think that intensive application of limestone, or any other source of calcium, to the overlying soils to ameliorate the soil conditions for agricultural purposes might also load the water influent to the mine workings with dissolved calcium carbonate, and result in *in situ* neutralization of the water and precipitation of solids within the workings, thus relieving the precipitation plant of a part of its load?

If so, might not a similar site be sought for a future experiment on the pre-treatment of influent water?

Author's Reply

If, before it enters a mine, water can be brought into contact with an alkali, it is highly likely that less acid will be formed, thus reducing the load on a neutralization plant.

Valuable information can be obtained from an experiment like that suggested by Mr Trollope. Although, it may be difficult to find a suitable test site, consideration should be given to the matter.

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