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by

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ABSTRACT

Deoiled tar sands tailings pond sludge was processed in a bench scale cross flow microfiltration apparatus to determine the permeation rate changes as water was removed. The mass transfer limitations of the process became evident, in particular when different operating pressures caused no change in the permeation rates. The thixotropic behaviour of the sludge resulted in its dewatering in the process beyond the point where it would flow when poured. The experimental results were used to prepare an order of magnitude cost survey.

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INTRODUCTION

Bitumen extraction from the Athabasca tar sands of Western Canada by the hot water process creates large tailings ponds. The sludge that settles in these ponds contains fine clay, bitumen and water. The bitumen is present as approximately 5% by weight, and as the tailings pond matures, the economic viability of its recovery increases. Methods that deoil the sludge require the addition of equivalent volumes of water to free the bitumen from the sludge. The recovery of this water and the dewatering of the deoiled sludge has the benefit of providing a solids free source of water and a dewatered sludge suitable for refilling the quarries from which the tar sands were mined. This work is a continuation of our investigation of the dewatering of deoiled sludge by the use of microfiltration (MF), a membrane separation process with pores in the range of 0.001 to 10 µm.

In a previous work with tar sands tailings sludge, water was removed from sludge by the use of both static and cross flow MF (1). In this work, a larger volume sample of deoiled tailings pond sludge was available for the evaluation of the performance of cross flow MF for the removal of water. Because of the larger volume of sample, the amount of water that could be recovered was not limited by the size of the testing equipment (1). As was shown in the previous work, the presence of bitumen interfered with the performance of the progressing cavity pump, and for this reason, deoiled sludge must be used in cross flow experiments. Since water is added as part of the flotation process to recover the bitumen, the deoiled sludge is more fluid than the raw sludge, and the recovery of the added water would be an advantage to the overall process.

The goal of this work was to determine the change of permeation rate with the amount of water removed from the deoiled sludge. This information was then used to make an order of magnitude cost survey of the use of microfiltration to recover water from deoiled sludge.

EXPERIMENTAL

The cross flow microfiltration apparatus used in this work is shown schematically in Fig. 1. Briefly, the system consisted of a progressing cavity pump, a temperature controller, an ultrafiltration membrane test cell, a back pressure controller, and a reservoir. The cross flow apparatus was operated in batch mode. A 0.1 μm nominal pore size Nylon 6,6 Ultipor (Pall) membrane of 62.2 cm^2 effective surface area was used. Operating conditions were: 20°C; pressures of nominally 50 and 100 kPa; and circulation rate 5 L/min.

As water was removed from the system as permeate, the level of recovery was determined as the percentage of water permeated compared to the original volume. The permeation rates were determined as follows. Deoiled sludge was dewatered in sequential steps, and the permeation rate was measured for each of these. Permeate was removed at 100 kPa until the desired volumetric recovery was achieved. The 100 kPa permeation rate was determined by collecting a sample of known volume during a measured period of time. The sample was then returned to the reservoir. The pressure was reduced to 50 kPa and the permeate was recycled for 10 minutes. Then the permeation rate at 50 kPa was determined in the same manner. The pressure was increased to 100 kPa and the permeate was removed until the next desired level of recovery was obtained.

The sample of deoiled sludge was supplied by the Alberta Research Council and was labelled "D7-24HR DECANT, 110 min deoil by aeration". It was reported to contain 40% raw sludge and 60% distilled water. The particle size was also reported to be less than 250 µm.

RESULTS AND DISCUSSION

MICROFILTRATION EXPERIMENTS

The permeation rates with the volume of permeate collected are shown in Fig. 2 and 3 for 50 and 100 kPa nominal operating pressure. There is not much difference between the permeation rates at 50 and 100 kPa, although based on either capillary flow (Hagen-Poiseuille equation) or filtration (Darcy equation), a doubling of permeation rate should occur from 50 to 100 kPa. The failure to obtain a significant permeation rate increase with a doubling of the operating pressure indicates that either severe membrane compaction is occurring or there are poor mass transfer conditions at the surface of the membrane resulting in "gel" formation. The low operating pressures used in these experiments precludes the membrane compaction effect. The high solids loading of the sludge suggests gel formation may be occurring though "bridging" may be a better description. This effect is caused by insufficient turbulence at the membrane surface to cause the removal of dewatered sludge from the membrane surface and its replacement with more watery bulk sludge. Thus, the membrane itself is in contact with sludge of a much higher solids content than would be measured in the retentate stream or in the reservoir.

The result of this effect is a loss of effective permeation rate, and a gross insensitivity to operating pressure as observed in the results of this experiment. These results suggest that a solids loading limitation effect may occur with sludges and slurries in MF. This can also be seen in both Fig. 2 and 3 where the permeation rate decreases as the volumetric recovery increases, which corresponds to an increase in the solids content of the sludge. It should be noted that in Fig. 2 and 3 at approximately 60% recovery there was an uncharacteristic increase in permeation rate. This coincides with the system being left for two days without operation, including stirring of the reservoir. It is considered that this is an artifact of that period.

At very high levels of recovery the amount of solids in the sludge caused the formation of a thixotropic slurry that was able to hold a peak in the reservoir but was fluid enough to flow readily when it was pumped. The experiment came to an end because of this effect, since the 80% reduced sludge was left in the system overnight without circulation. The absence of shear in the sludge caused the effective viscosity of the slurry to increase to the point where flow was hindered. Subsequent attempts to obtain the original circulation rate failed, with the corresponding large decrease in permeation. Larger recoveries and possibly higher permeation rates could have been obtained in this experimental apparatus if this effect had been avoided.

At the end of the experiment, the reservoir and any remaining sludge in the apparatus was collected and the volume determined. The retentate at 82.5% recovery was 335 mL of sludge, and the permeate collected to that point was 3.2 L with a loss of 7.1% compared to the original volume used for the experiment. The original sample contained 6.1 wt % solids and the retentate contained 37.5 wt % solids. The cell holder was disassembled and the membrane was found to be free from bitumen, although there was evidence that the flow was reduced by the presence of thixotropic sludge.

The presence of bitumen in the sludge was evident when the pump was disassembled for cleaning. The Viton rotor of the pump had accumulated bitumen as in our previous work with raw sludge (1), though there was a significantly smaller amount, and there was no evidence of this in the pump's performance. The fluid sludge in the reservoir did not contain any visible bitumen. It should be noted that the deoiled sludge as received was muddy brown and as fluid as water. The retentate in the reservoir was light gray with a pearly sheen and would not flow when poured unless severely shaken first. Bitumen slugs found in the pump were black and incorporated clay. The accumulated permeate was clear and solids-free, as observed in the earlier work.

PROCESS COSTING

Based on the above results, the cost of an MF dewatering process was determined for deoiled sludge. The types of membrane module configurations available for this service include plate and frame, small bore hollow fibre (1 mm ID), spiral wound, and tubular (12 mm ID). Because of the mass transfer limitations observed in the experimental part of this work, the tubular membranes should be used for this separation, since they offer the most effective mass transfer although they do not have the most efficient area distribution per module, and slightly higher operational expenses. However, the other configurations would be mass transfer limited for this case, and in the extreme case, they would be susceptible to blocking at the high recovery levels.

The design basis is for an MF unit capable of 80% dewatering of the deoiled sludge, with the thickened sludge product suitable for use as an engineering material for the recovery of the tar sands quarry and a clear water product suitable for reuse in the deoiling process as the dilution water. The flow to be treated was assumed to be 100 m^3/d of deoiled sludge, and at 80% recovery, 80 m^3 of permeate and 20 m^3 of retentate sludge would be produced as shown schematically in Fig. 4. It was assumed that operating conditions were 100 kPa, 20°C, and that the membrane performance was similar to that obtained in this work. Detergent cleaning of the membranes was to be used on a regular cycle of two weeks thus maintaining a usable membrane life of two years. The capital costs of the system were assumed to be amortized over 5 years at 11%, and the annual costs were determined as the mean annual expenses for the same 5 year period.

While batch operation has advantages for the exploitation of the greater permeation rates at the low recovery levels, the thixotropic nature of the high recovery sludge may preclude this operation. The alternative is operation in "feed and bleed" mode, with continuous operation of the membrane separation at the 80% recovery level. The permeation rate at 80% recovery is taken as 0.51 $m^3/m^2/d$, and to have 80 m^3/d of permeate, this requires a minimum of 157 m^2 of effective membrane surface area. In a similar study with ultrafiltration in a mass transfer limiting separation, a tubular module system of 161.6 m^2 surface area was used for the design (2). It is assumed that the cost of the MF version of this apparatus shall be the same.

For the feed and bleed case, the installed cost including service, design, instrumentation, pumps and contingencies is $521,000. As well, an estimate of the operating costs including electricity, labour, membrane cleaning and membrane replacement costs is $74,000 (2). The annual cost based upon the amortized capital costs is $215,000. This represents a cost of approximately $7.15/$m^3$ of deoiled sludge.

For operation in batch mode, assuming the difficulties of thixotropic flow are not severe, the average permeation rate between 0 and 80% recovery was used, 0.74 $m^3/m^2/d$.

With similar costing as those of the "feed and bleed" operation, the annual cost is estimated to be $147,000. This corresponds to a cost of $4.89/m^3 of deoiled sludge.

The ultimate products of this process are the bitumen that was removed in the deoiling, the permeated water, and the sludge concentrate. The recoverable bitumen content was determined to be 5 wt % of the raw sludge (1). For 100 m^3 of deoiled sludge, 40 m^3 of raw sludge of density 1.2 kg/m^3 was used with a bitumen recovery of 2.4 t/d. The value of this bitumen was assumed to be $100/t with an annual worth of $72,000. Assessment of the other products' values is difficult to determine, as well as the cost estimates for floating off the bitumen. Another economic advantage is the reduction of demand for tailings pond volume to further settle the deoiled sludge, which is also difficult to determine. The permeate water is also of value since it is solids-free and still has most of the caustic added in the original bitumen extraction process.

It is possible that membranes in a tubular configuration might cause an increase in the permeation rate because of the improved mass transfer characteristics, but this would require experimental investigation. The capacity assumed for the costing of the process is sufficiently large that there is very little improvement of cost with increase of capacity. The absence of process costing for the bitumen flotation system that would precede the membrane process prevents the assessment of the total sludge treatment process. The costing method used in this work is generally considered to be +50% and -30% of the actual costs.

CONCLUSIONS

Microfiltration can take advantage of the thixotropic behaviour of the sludge to produce a dewatered sludge with some engineering strength properties. The permeate water is solids-free and clear. The cost of removing the water by microfiltration was estimated with many assumptions. A mass transfer limitation on the performance of the process was observed, and there is some possibility that an alternative design based upon greater turbulence may give improved performance.

REFERENCES

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2. Zenon Environmental Inc., "Membrane processing of oilfield produced water for enhanced oil recovery (EOR) steam generation", Report prepared for Energy, Mines and Resources Canada, June, 1987.

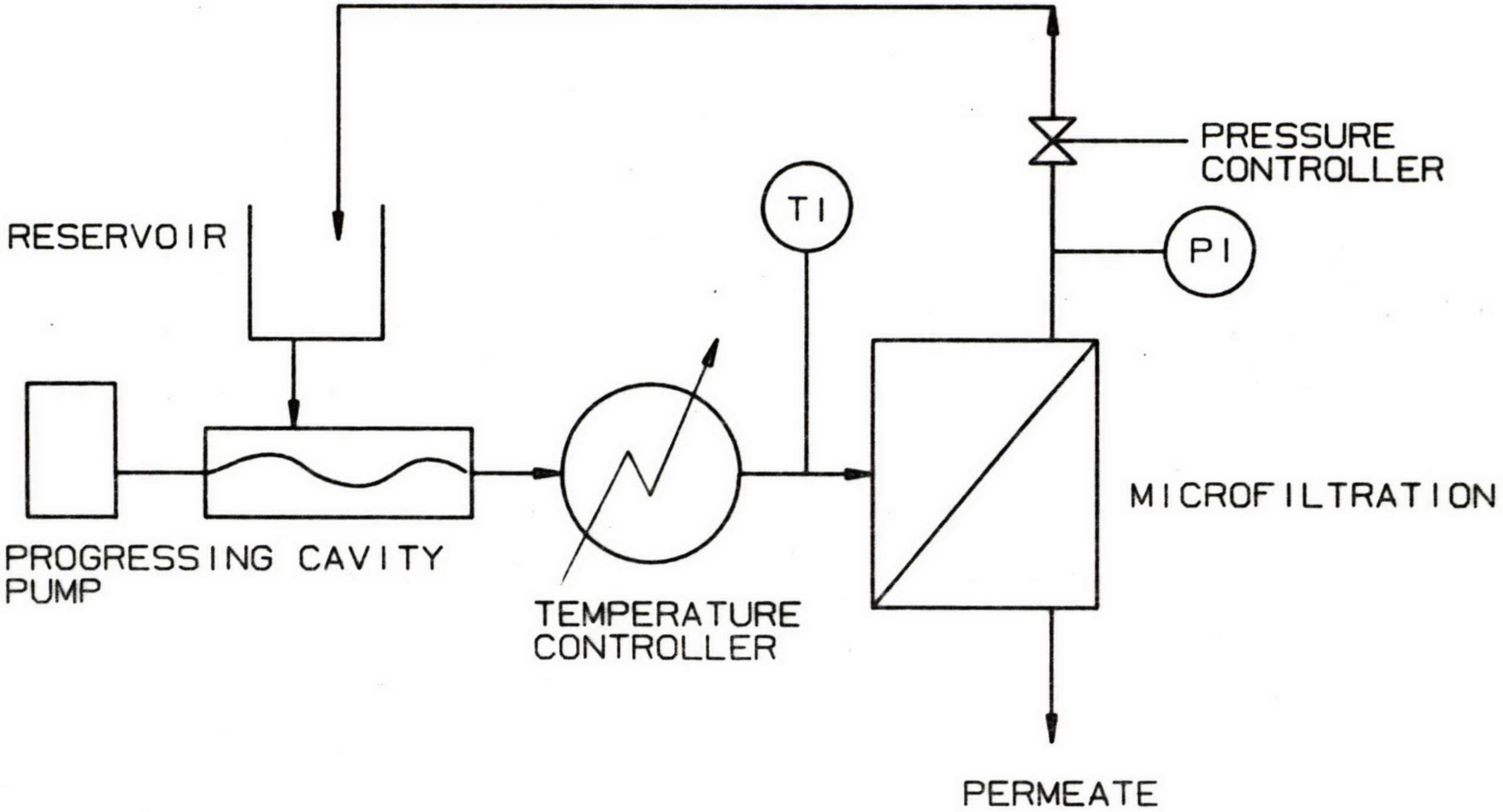
PRESSURE CONTROLLER
RESERVOIR
TI
PI
PROGRESSING CAVITY PUMP
MICROFILTRATION
TEMPERATURE CONTROLLER
PERMEATE

Fig. 1 – title

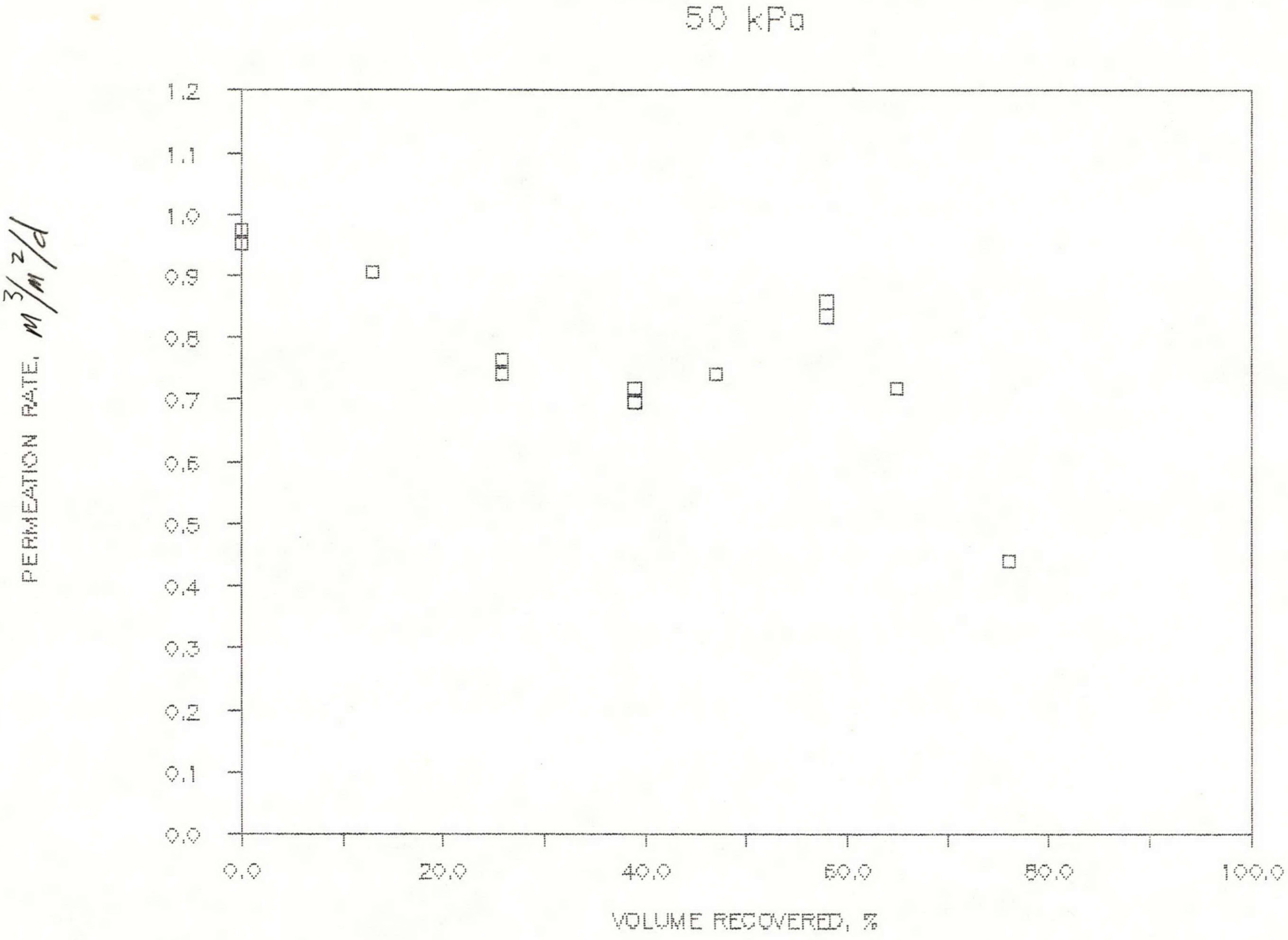
50 kPa
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PERMEATION RATE, $m^3/m^2/d$
0.0
20.0
40.0
60.0
80.0
100.0
VOLUME RECOVERED, %

Fig. 2 — —

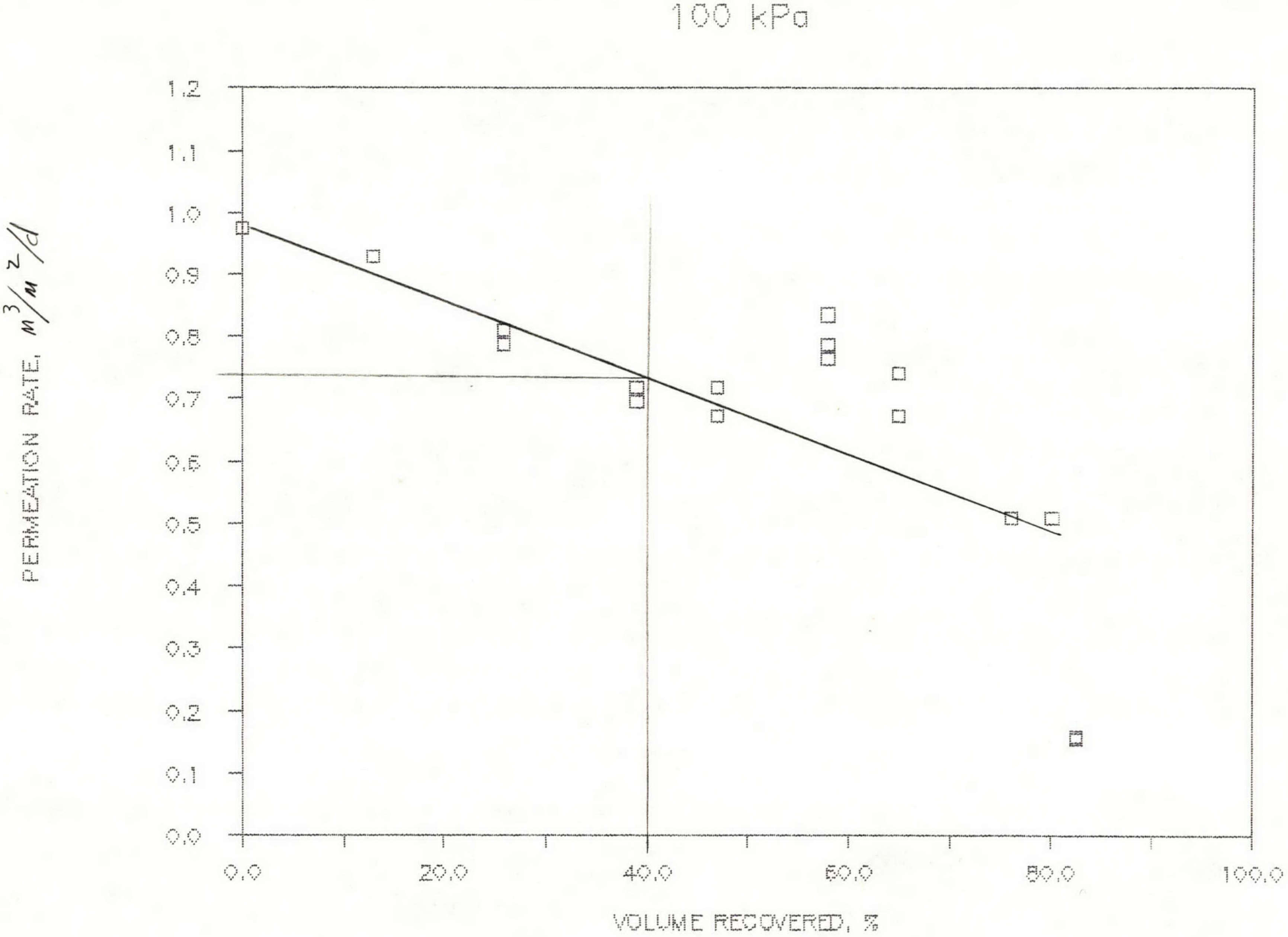
100 kPa
PERMEATION RATE, m³/m²/d
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
20.0
40.0
60.0
80.0
100.0
VOLUME RECOVERED, %

Fig. 3 —

Fig 4 Sludge deoiling with MF

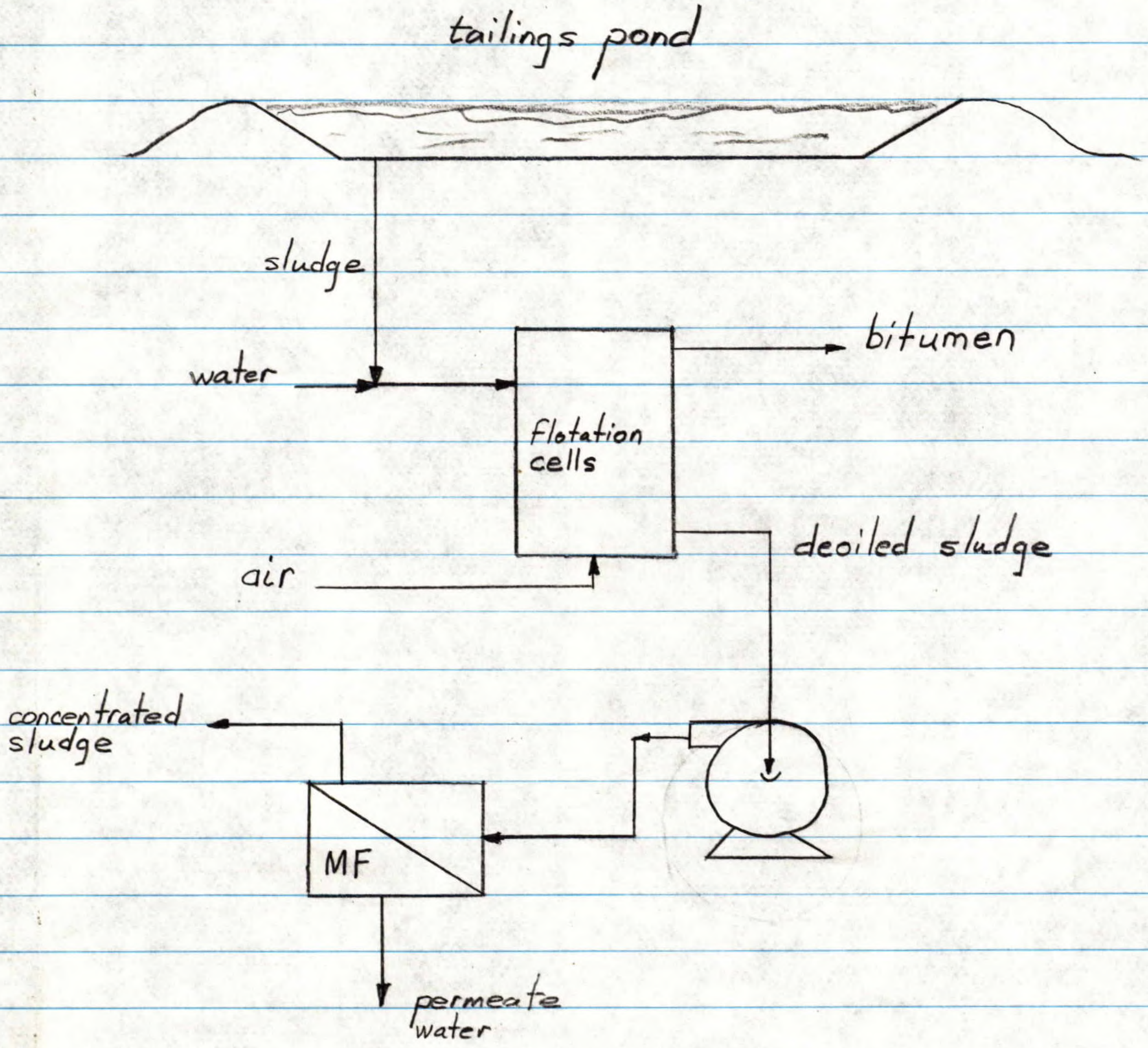

Fig. 4