

**POLYMER-MODIFIED CLAY AS  
IMPERMEABLE BARRIERS FOR  
ACID MINING TAILINGS**

**MEND Report 6.2**

This report results from solicitation of proposals in 1992 by the New Ideas Task Force of the Mine Environment Neutral Drainage (MEND) Program.

The views and technical recommendations in this report are those of the author and do not necessarily reflect those of MEND or the Prevention and Control (P & C) Committee of MEND.

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**POLYMER-MODIFIED CLAY AS IMPERMEABLE  
BARRIERS FOR ACID MINING TAILINGS**

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## EXECUTIVE SUMMARY

Acidic drainage resulting from the oxidation of sulphide minerals is the single largest environmental problem facing the Canadian mining industry today. Sulphide oxidation, which generally occurs at shallow depths above the water table, can result in the production of highly acidic pore water containing elevated levels of many heavy metals and other deleterious constituents. It is generally agreed that the production of acid is controlled by the availability of the oxygen at the sulphide surface. In tailings the primary mode of oxygen transport is diffusion through porous spaces. An impermeable cover can eliminate or significantly alleviate the problems related to the acid mine wastes.

The Alberta Research Council (ARC) proposed to use its newly-developed super absorbent polymer (SAP) for the abatement of acid mine drainage. SAP is a patented product and is made of polyacrylamide-modified clay. When fully hydrated, one gram of SAP can adsorb more than 650 grams of fresh water and increases its volume significantly during the process. This very property of SAP could be very useful in the area of acid tailing abatement.

Preliminary tests with the SAP/sands mixture show a significant potential for SAP application in acid mine tailing abatement. Addition of 1 wt% of SAP into a medium sand can lower its hydraulic conductivity by four orders of magnitude. Moisture retention capability can also be increased significantly. The use of SAP in a bottom liner of a tailings pond is not a viable option because the poisoning effect of multi-valent cations on the SAP. However, a SAP-bearing cover should be an effective hydraulic barrier. Essentially, the cover would be an impermeable barrier and would retain its water saturation. If used in 0.2 wt% concentration, the cost of SAP will be about 1/20 of the total cost for the construction of the cover. The cost for this material may be offset by the savings on the transportation of another barrier material and construction of the cover.



## RÉSUMÉ

Les eaux de drainage acides résultant de l'oxydation des minéraux sulfurés est le plus grand problème environnemental de l'industrie minière canadienne aujourd'hui. L'oxydation par les sulfures, qui se produit en général à faible profondeur sous la nappe phréatique, peut entraîner la production d'eau interstitielle très acide à forte teneur en nombreux métaux lourds et autres constituants nuisibles. Il est généralement convenu que la production d'acide dépend de la disponibilité de l'oxygène à la surface des sulfures. Dans les résidus, le principal mode de transport de l'oxygène est la diffusion dans les espaces interstitiels. Une couverture imperméable peut éliminer ou atténuer grandement les problèmes relatifs aux déchets miniers acides.

L'Alberta Research Council (ARC) a proposé d'utiliser son nouveau polymère super-absorbant (PSA) pour lutter contre les effets des eaux de mine acides. Le PSA est un produit breveté constitué d'argile additionnée de polyacrylamide. À saturation, un gramme de PSA peut adsorber plus de 650 grammes d'eau douce et augmenter considérablement de volume entre-temps. Cette propriété du PSA pourrait être très utile dans le domaine de la lutte contre les résidus acides.

Les premiers essais sur un mélange de PSA et de sable indiquent que le PSA pourrait très bien être utilisé dans la lutte contre les résidus miniers acides. L'addition de 1 % en poids de PSA dans un sable à grain moyen peut en abaisser la conductivité hydraulique de quatre ordres de grandeur. La capacité de rétention peut aussi être accrue de beaucoup. La pose d'une membrane contenant du PSA au fond d'un étang à résidus n'est pas une bonne solution car les cations multivalents contamineraient le PSA. Toutefois, une couverture contenant du PSA pourrait constituer une barrière hydraulique efficace. La couverture agirait essentiellement comme une barrière imperméable et retiendrait l'eau jusqu'à saturation. Concentré à 0,2 % en poids, le PSA coûterait environ 1/20 du coût total de la construction de la couverture. Le coût d'un tel matériau serait compensé par les économies de transport d'un autre matériau et de construction de la couverture.



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## INTRODUCTION

Acidic drainage resulting from the oxidation of sulphide minerals is the single largest environmental problem facing the Canadian mining industry today. Sulphide oxidation, which generally occurs at shallow depths above the water table, can result in the production of highly acidic pore water containing elevated levels of many heavy metals and other deleterious constituents. It is generally agreed that the production of acid is controlled by the availability of the oxygen at the sulphide surface. In tailings the primary mode of oxygen transport is diffusion through porous spaces. The recognition of this process has led to the suggestion of a multi-layered barrier which can minimize the amount of air infiltration (Nicholson et al., 1989; Nicholson et al., 1991). Experimental studies based on this concept are being conducted at Noranda Technology Centre (Yanful, 1991; 1992; Yanful and St-Arnaud, 1991). In this concept, a layer of fine silt or clay material is underlain by a layer of coarse sands. The layers would be placed in such a way as to enhance drainage of the coarse layer, thereby lowering the effective hydraulic conductivity to near zero as it approaches residual saturation. At this state (residual saturation), the coarse layer can not transmit moisture downward from the upper layer. The upper fine layer therefore can maintain full saturation over a prolonged period of time.

Within the MEND New Ideas initiatives, the Alberta Research Council (ARC) proposed to use its newly-developed super absorbent polymer (SAP) for the abatement of acid mine drainage. The SAP is a patented product and is made of polyacrylamide-modified clay (Gao et al, 1993). When fully hydrated, one gram of SAP can adsorb more than 680 grams of fresh water and increases its volume significantly during the process. This very property of SAP could be very useful in the area of acid tailing abatement. First, if a layer of SAP-bearing composite material is placed on top of the acid tailings, the composite layer may constitute an impermeable barrier. This is because the high water-absorption capacity, strong moisture retention capability and large swelling pressure of SAP will virtually "seal off" the tailings. Secondly, if a layer of SAP-bearing composite material is placed at the bottom of a tailing pond as a liner, the composite material may prevent the seepage of the acid leachate into groundwater. The potentials of both options will be evaluated here.

The purpose of Phase I of the "Impermeable Modified Clay Barrier" project is to demonstrate the effect of SAP on the hydraulic conductivity and moisture retention characteristics of the cover material. In this report, we will 1) briefly introduce the properties of the SAP, 2) describe methods and results of hydraulic conductivity and moisture retention tests, 3) discuss the implication of the experimental results, and 4) present a preliminary economic analysis of the

SAP application. Based on all the information available, we believe that the use of SAP is technically advantageous and economically viable.

## **CHARACTERISTICS OF SUPER ABSORBENT POLYMER (SAP)**

The super absorbent polymer (SAP) used in this study is a polyacrylamide-montmorillonite composite and was originally developed at the Technical Physics Institute of the Heilongjiang Academy of Sciences (TPIHAS). Since 1991, the production technology and polymer properties have been improved through the cooperation between ARC and TPIHAS. SAP has wide applications in sanitary diaper, agriculture, forestry, oil field, etc.. The details of the SAP production and characteristics are discussed by Gao (1993). Only relevant properties are summarized here.

The commercial SAP is granular particles of about 0.5 mm in diameter and has a specific gravity of 1.62 g/cc. When they are placed in excessive amount of water, the SAP will experience a full hydration in less than 24 hours. In this process, its volume increases dramatically and the SAP becomes a gel-like material. The density of the gel is very close to that of water because of the large amount of water it adsorbs. The amount of water adsorbed by the SAP can be quantified by the water absorption capacity (WAC) which is defined as

$$WAC = (W - W_0)/W_0 \quad [1]$$

where  $W$  and  $W_0$  are the weights of swollen and dry samples respectively. It has been reported that the WAC of the SAP can be as high 1000 but our in-house bench tests indicate that the WAC is about 680 in fresh water. Note that WAC is not a percentage but represents net increase in its weight relative to the same material before hydration. To appreciate the magnitude of the WAC of SAP, the WAC of a pure Wyoming bentonite is only about 10. Therefore, the WAC of the SAP is 68 times greater than Wyoming bentonite.

Similar to swelling clays, the hydration and swelling of the SAP are affected by ionic strength and valence of the cations in the surrounding solution. The effect of ionic strength is commonly called "salt effect". Some models have been postulated in the literature on the salt effect (Gao, 1993) on the WAC, but these models are of little use in practice because they require a number of parameters which are not readily available. Our in-house bench tests indicate that the WAC will decrease 10 times as the NaCl concentration increases from 0 to 0.50 M (29,000 mg/l). The hydration of the SAP can be greatly reduced if a significant amount of divalent cations is present

in the solution. At an equal ionic strength, the WAC in  $\text{CaCl}_2$  solution is about 10 times less than that in NaCl solution.

The pH of the solution also has a pronounced effect on the hydration of the SAP. Figure 1 shows the WAC of the SAP as the function of the solution pH. It is obvious that the hydration of SAP is affected by both acidic and alkaline solutions and this detrimental effect is more pronounced in the acidic range than in the alkaline range. However, to keep things in perspective, it should be noted that in acidic solution with pH of 3.5, the WAC is still greater than 100 which is much greater than that of Wyoming bentonite. The acidic solution is equally detrimental to the hydration of clay minerals.

To appreciate the effect of hydration of the SAP on hydraulic conductivity of a cover material, let's consider an artificial case: suppose we have 1000 cc of porous media (sands) with 40% of porosity and particle density of 2.60 g/cc, the pore volume will be 400 ml and total weight of the solids will be about 600 cc X 2.6 g/cc = 1560 g. If one twentieth weight percent (0.05 wt%) of the solid is SAP, the SAP will weigh 1560 g X 0.05% = 0.78 g. Upon hydration in fresh water, the SAP will adsorb  $0.78 \text{ g} \times 680 \text{ g/g} = 530 \text{ g}$  of water and the volume of the gel will be about 530 ml. Therefore the SAP gel will be more than enough to fill out all the pore space in the porous media. In reality, the WAC of the SAP will be much less, depending on the ionic strength of the solution. Nevertheless, this calculation does illustrate the high potential for SAP to reduce the hydraulic conductivity of a porous media. Based on this analysis, we chose to add 1 wt% SAP to the sands and tailings in our experiments.

## **EXPERIMENTAL METHODS**

### **Materials**

The materials used in this study include silica sands, bentonite clays, the SAP, and acid tailings. The silica sands are commercial grade of 30-60 mesh size and were purchased from Sil Silica Inc. of Edmonton. The sands were used as received and no treatment was applied. The Wyoming bentonite was purchased from Ward's. The X-ray diffraction analysis indicates that the sample contain a significant amount quartz but no effort was made to purify the sample. The bentonite was used as received. The granular SAP particles were ground to pass 325 mesh size sieve before mixing with other material.

The tailings are from Waite Amulet mine and were supplied by Luc St-Arnaud of Noranda Technology Centre. For moisture retention and hydraulic conductivity measurements, the tailings as received were oven-dried at 103°C for overnight and aggregates of larger than 1 mm were removed. The grain (particle) density of the tailings was measured using the standard "Density Bottle Method" (Head, 1989) and is found to be 3.09 g/cc. The particle size distribution was determined by conventional sieving (for greater than 20  $\mu\text{m}$  particles) and gravitational sedimentation (for less than 20  $\mu\text{m}$  particles) methods. The tailings are composed of mainly silts and fine sands as shown in Figure 2.

Seven samples were used for hydraulic conductivity measurements and six samples were used for moisture retention. These samples are:

- A) Silica sands (35-60 mesh);
- B) 99 wt% silica sands plus 1 wt% SAP;
- C) 90 wt% sands plus 10 wt% Wyoming bentonite;
- D) Oven-dried acid tailings;
- E) 99 wt% tailings plus 1 wt% SAP;
- F) 90 wt% tailings plus 10 wt% Wyoming bentonite; and
- G) 89 wt% tailings plus 10 wt% silts and 1 wt% SAP.

One weight percent SAP was chosen for the reason stated in the last section. Ten percent of bentonite was used because a composite mixture containing 8% bentonite is being investigated by Noranda Technology Centre (St-Arnaud, personal communication). The bentonite sample used in this study contains some quartz. The bentonite concentration in our samples is thus comparable to that of used in Noranda Technology Centre.

### **Hydraulic Conductivity Measurement**

The apparatus used to determine the hydraulic conductivity of these samples consists of a tube containing the porous medium, a fluid delivery and collection system, and pressure monitoring devices to determine the head loss during flow (Figure 3). The porous medium was contained in a stainless steel tube 305 mm long by 22.1 mm I.D.. The tube had sintered stainless steel frits with a nominal 10 micron pore size to contain the particulates at both ends. Near each end of the tube, there is a set of pressure taps at the side of the tube, connected to two differential pressure (DP) transmitters which measure head loss during flow. The pressure taps were spaced 195 mm apart. The two sets of DP cells have working range of 20 kPa and 200 kPa

respectively. The head loss was used to calculate the permeability of the pack. Pressure transducers at the inlet and outlet end of the tube also measured the flow pressure up to 5 MPa. A bypass line with an isolation valve connected the inlet and outlet ends of the flow tube. This line was used only during the saturation stage of the experiments.

A back-pressure regulator at the outlet end of the tube maintained the static fluid pressure at approximately 1 MPa. A syringe pump was used to inject de-ionized water into the porous medium at a constant rate over the course of the experiment. In a stable thermal environment (constant temperature), the pump was capable of fluid delivery as low as 0.1 cc/hr at elevated pressures.

During packing, the flow tube was held in a vertical position in a vise and grounded to earth. Otherwise, a static charge will build up as a result of pouring the loose material into the tube. By grounding the tube, the static is discharged and this allows for a repeatable pack consistency. The porous medium was slowly poured into the tube through a funnel while tapping on the vise with a mallet. After the tube was filled to the top, tapping was continued and more material added until there was no further change in the level of material in the tube. The weight of the porous medium was determined by difference between the weights of the empty and filled tube. Porosity of the pack was determined from the weight and grain density of material in the tube and the volume of the tube.

After a sample was packed, the tube was mounted in the flow system. Air was displaced from the pack by flowing carbon dioxide through the tube. The tube was then evacuated to remove the carbon dioxide. In this way residual carbon dioxide that was not evacuated dissolved easily into the water as the core was saturated and was readily displaced as water flowed through the tube. The de-ionized water was then injected into both ends of the tube at a low rate to minimize the possibility of fines transport through the pack. The higher permeability sand and tailings packs saturated very quickly. For the samples containing clays and the SAP, the saturation of the pack took several hours or more. After saturation, the flow rate was fixed. The flow pressure fluctuated at the beginning and then stabilized. The flow rate and differential pressure data were used to calculate the hydraulic conductivity of the sample with Darcy's law. The procedures were repeated several times by changing the flow rate to ensure that the hydraulic conductivity calculated was independent of flow rate.

## Moisture Retention Curves

Moisture retention measurements were performed on six samples (A to F) using a standard "Pressure-Plate Extraction" method (Sheldrick, 1984). In this method, a sample is placed in a rubber ring which sits on a porous ceramic plate. The sample and the porous plate are then saturated from below. The plate is covered using a plastic sheet to prevent evaporation. After 24-hours or longer saturation, the plate is placed into a pressure pot. The pressure pot is sealed off and a gas pressure is applied to drive water out. When outflow has ceased, the sample is transferred to a tared drying can and weighed. Then the sample is oven-dried at 105°C and reweighed. The moisture retention is expressed as the equilibrium water content at a given pressure:

$$\text{Moisture retention} = [(\text{Weight}_{\text{wet}} - \text{Weight}_{\text{dry}})/\text{Weight}_{\text{dry}}] \times 100\% \quad [2]$$

Each sample was run in duplicates and at five different equilibrium pressures (0.10, 0.33, 1.00, 5.00, and 15.00 bars). In total, 30 tests were conducted in duplicates.

## EXPERIMENTAL RESULTS

### Hydraulic Conductivity

The results of the hydraulic conductivity tests are shown in Table 1. Samples A, B, and C are sand based and the pure sand sample (A) provides a baseline for this group of samples. When packed, the medium size sands had a porosity of 36.5%. The saturation of this sample was very fast (in minutes). At a fixed flow rate, the differential pressure was fairly stable. Small variations in permeability may be due to temperature fluctuation or other instrumental deviations (Figure 4). The permeability is calculated using Darcy's law:

$$\kappa = (Q/A)(\Delta l/\Delta p)\eta \quad [3]$$

where  $\kappa$  is the permeability,  $Q$  the flow rate,  $A$  the cross-section area of the tube,  $\Delta l$  the distance between the pressure transducers,  $\Delta p$  the differential pressure, and  $\eta$  the viscosity. The hydraulic conductivity ( $K$ ) is related to permeability by:

$$K = (\rho g/\eta)\kappa \quad [4]$$

where  $\rho$  is the density of the fluid and  $g$  the gravitational constant. For water at room temperature,  $\rho g/\eta$  is  $10^5$  s/cm. Therefore, if  $K$  is in cm/s and  $\kappa$  is in darcy (1 darcy (d) =  $9.87 \times 10^{-9}$  cm<sup>2</sup>),  $K$  (cm/s) =  $10^{-3}\kappa$  (d) or  $10^{-6}\kappa$  (md).

When the flow rate changed from 0.5 l/hr to 2.0 l/hr and then to 4.0 l/hr, the permeability stayed at 53 Darcy (or hydraulic conductivity at  $5.3 \times 10^{-2}$  cm/s) which is reasonable for this material.

When 1 wt% of SAP is mixed with the sands and packed (Sample B), the porosity changed very little but the saturation took much longer (a few hours). The permeability after the saturation was about 3 md (or hydraulic conductivity of  $3 \times 10^{-6}$  cm/s) but it slowly decreased to 1.9 md (or  $1.9 \times 10^{-6}$  cm/s) in 72 hours. This may indicate that the bulk of the SAP was hydrated in a few hours but a small fraction of the SAP was still hydrating and expanding in days. The hydraulic conductivity dropped four orders of magnitude from the pure sands. When the sample was removed from the tube after the hydraulic conductivity test, it showed some physical cohesiveness. When air-dried, the sample slowly became semi-consolidated. For Sample C, the addition of 10 wt% of Wyoming bentonite decreased the porosity to 33.1% but its hydraulic conductivity of was still twice as much as that of Sample B. The effect of SAP on hydraulic conductivity of the quartz sands is therefore at least 10 times greater than Wyoming bentonite.



**Table 1: Porosity and Hydraulic Conductivity of Test Samples**

| Sample ID | Composition wt% |          |      |     |        | Porosity % | Throughput pv | Permeability md | Hydraulic Conductivity cm/s |
|-----------|-----------------|----------|------|-----|--------|------------|---------------|-----------------|-----------------------------|
|           | Sand            | Tailings | Clay | SAP | Silica |            |               |                 |                             |
| A         | 100             | -        | -    | -   | -      | 36.5       | 92.3          | 53,000          | $5.3 \times 10^{-2}$        |
| B         | 99              | -        | -    | 1   | -      | 36.3       | 4.4           | 1.9             | $1.9 \times 10^{-6}$        |
| C         | 90              | -        | 10   | -   | -      | 33.1       | 17.7          | 3.9             | $3.9 \times 10^{-6}$        |
| D         | -               | 100      | -    | -   | -      | 44.0       | 56.8          | 130             | $1.3 \times 10^{-4}$        |
| E         | -               | 99       | -    | 1   | -      | 43.9       | 63.2          | 180             | $1.8 \times 10^{-4}$        |
| F         | -               | 90       | 10   | -   | -      | 44.8       | 21.0          | 28              | $2.8 \times 10^{-5}$        |
| G         | 89              | -        | -    | 1   | 10     | 30.1       | 2.4           | < 0.1           | $< 1.0 \times 10^{-7}$      |

When packed, the tailings-based samples (D, E, and F) had larger porosity values than the sand-based samples. This is consistent with the fact that the particle size of the tailings is smaller than that of the sands used in this study. The pure tailing sample (D) had a porosity of 40.0%. The tailings must contain a significant amount of soluble material because the effluent was brownish in colour and carried some fine particles. As a result, the permeability slowly increased over the course of the test. After 42.4 hours and 56.8 pore volume (pv) throughput, the test was terminated and the permeability at that point was 130 md (or hydraulic conductivity of  $1.3 \times 10^{-4}$  cm/s). When 1 wt% of SAP was mixed with the tailings, the porosity was virtually unchanged. The effluent was still brownish and the hydraulic conductivity also increased with time. After 69.42 hr and 63.2 pore volume, the test was terminated and the permeability at this point was 180 md (or hydraulic conductivity of  $1.8 \times 10^{-4}$  cm/s). This hydraulic conductivity value was even larger than that of the pure tailings but this increase was likely due to a greater amount of dissolution of the tailings during the much longer testing period and the larger throughput of fluids. In any case, it is fair to conclude that the effect of the SAP is very limited

when mixed with acid mine tailings. In contrast, when 10 wt% Wyoming bentonite was mixed into the tailings (Sample F), the hydraulic conductivity decreased about one order of magnitude. Nevertheless, this decrease is still small compared to that of the sand-based system where a four orders of magnitude decrease was achieved.

The last permeability test (Sample G) was performed to demonstrate that the performance of the SAP may be improved if a sand sample contains some silts. The sands used in Samples A, B, and C have a narrow size distribution (35 - 60 mesh). Natural sands have a wider size distribution. Thus, we added 10 wt% coarse silts (270 mesh) into Sample G, the amount of SAP was still 1 wt%. When packed, this sample had a quite low porosity at 30.1%. The saturation of this sample was very slow and the permeability was very low. At the very small flow rate (0.6 ml/hr), the accuracy of the syringe pump depends on a stable temperature over the course of the test. Because the temperature could not be controlled accurately during the test, only an upper limit of the permeability could be estimated at extremely low flow rates. Conservatively speaking, the hydraulic conductivity of this sample is less than  $1 \times 10^{-7}$  cm/s.

### **Moisture Retention**

The moisture retention results are shown in Table 2 and Figure 5. For pure sands (Sample A), its moisture retention capability is very small even at very low pressure (1.2% at 0.1 bar). When 1 wt% SAP was added (Sample B), the moisture retention can be improved significantly. At each of five equilibrium pressures, the water contents of Sample B (sand plus SAP) are 20 times greater than Sample A (sand only). Sample B and Sample C (sand plus bentonite) are comparable, indicating that the moisture retention capability of 1% SAP is equivalent of 10% Wyoming bentonite. It should be noted that the equilibrium pressures used here are high. At lower equilibrium pressures, the moisture retention of the SAP could be even better because the water adsorption capacity of the SAP at zero pressure is very large.

On the other hand, no significant improvement is shown when the SAP is used with acid mine tailings. The moisture retention capability of Sample E (tailings plus SAP) is similar to that of Sample D (tailings only), and both of which are a few percent less than Sample F (tailings plus bentonite).

**Table 2: Moisture Retention**

| Sample ID | Composition wt% |         |      |     |      | Equilibrium Pressure (Bars) |      |      |      |      |
|-----------|-----------------|---------|------|-----|------|-----------------------------|------|------|------|------|
|           | Sand            | Tailing | Clay | SAP | Silt | 0.1                         | 0.33 | 1.0  | 5.0  | 15   |
| A         | 100             | -       | -    | -   | -    | 1.2                         | 1.1  | 0.6  | 0.5  | 0.5  |
| B         | 99              | -       | -    | 1   | -    | 30.7                        | 26.8 | 25.0 | 10.6 | 9.2  |
| C         | 90              | -       | 10   | -   | -    | 32.8                        | 27.7 | 26.3 | 18.9 | 12.7 |
| D         | -               | 100     | -    | -   | -    | 32.5                        | 25.0 | 19.5 | 9.7  | 6.1  |
| E         | -               | 99      | -    | 1   | -    | 34.7                        | 32.1 | 17.5 | 9.0  | 6.2  |
| F         | -               | 90      | 10   | -   | -    | 38.4                        | 31.9 | 23.4 | 13.0 | 8.9  |

The moisture retention of Sample G was not measured but it would have the best moisture retention among all the samples tested here.

A comment should be made here about the moisture retention results for the tailings-based samples. Because the tailings contain a significant amount of soluble materials, and some of these soluble materials are the hydrated minerals (e.g. gypsum). During the oven-drying, these minerals will dehydrate. The weight loss from the mineral dehydration is included in the term  $(\text{Weight}_{\text{wet}} - \text{Weight}_{\text{dry}})$  of Equation 2. For instance, gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) will dehydrate to anhydride ( $\text{CaSO}_4$ ) at 60-70°C and this is accompanied by a 20% weight loss. The chemically bonded water lost during oven-drying would be recorded as physically adsorbed water in this conventional method for moisture retention measurement. Because of this, the reported moisture retention of the tailings-based samples could be significantly higher than actual values.

## **DISCUSSION AND CONCLUSIONS**

### **SAP Performance in the Sands**

Both the moisture retention and hydraulic conductivity data indicate that SAP would be a very effective hydraulic barrier when used with sands. The good performance in the sands is due to the full hydration/swelling of the SAP in the system. If the ionic strength of the solution is low, full SAP hydration/swelling can be realized. Based on the WAC - salt concentration relationship, we infer that SAP hydration/swelling would remain large even in moderate NaCl solution (< 0.1 M or 5800 mg/l). Moderate NaCl concentrations can also alleviate the poisoning effect of  $\text{Ca}^{2+}$  ions.

With the exception of Sample G, the sands used in the tests are fairly uniform and of medium size. The addition of 10 wt% silts into the sands reduced the hydraulic conductivity of the SAP/Sands mixture. When SAP is used with natural sands, its performance may be improved and the minimum concentration may be even lowered because natural sands always contain a variable amount of fine particles such as silts or clays.

### **SAP Performance in the Tailings**

The performance of the SAP is poor when used with acid mine tailings. This is most likely due to the poisoning of SAP by divalent cations leached out from the tailings. Divalent cations can cross link the polymer branches and make the polymer more "tight", therefore reducing the hydration of the polymer. In the oxidized tailings such as those used in our study, there is a large amount of gypsum (St-Arnaud, personal communication). Gypsum dissolves very fast in aqueous solution and will supply 15 mM  $\text{Ca}^{2+}$  (600 mg/l) to the solution at saturation. At this concentration, the hydration and the swelling of SAP will be greatly suppressed.

Even if the SAP is used with fresh mining tailings, its performance may be affected significantly. This is because that the fresh tailings pore water would be alkaline (pH 10) and would contain high calcium concentrations (St-Arnaud, personal communication). However, if the calcium concentration can be reduced, the performance of SAP in tailings can be improved. High pH is less detrimental than low pH.

## **Covers vs. Liners**

As mentioned in the INTRODUCTION, the SAP can be applied either as a cover or as a liner for acid mining tailings. The experimental results indicate that SAP is more suitable for the use in a cover. When a small amount of SAP (1 wt% or less) is mixed with a fine sands, the material will be an effective hydraulic barrier. Its moisture retention capability will increase dramatically. The SAP and sands mixtures are physically cohesive, indicating that the SAP has some "cementation" capability.

Because of the strong poisoning effect of divalent cations on SAP, a question may arise as how to prevent divalent cations from entering the cover. This will be especially relevant when the cover is underlain by a layer of oxidized tailings. In reality, this may not be a serious problem. First, in the event of precipitation, the flow will be downward and the only way the divalent cations can get into the cover is through diffusion. Cation diffusion in the porous media require a continuous aqueous phase in tailings which is seldom present. Second, after the SAP is hydrated, divalent cations have to work their way through the gel. This process would be much slower. Finally, if a multi-layer concept is used, the impermeable SAP-bearing layer would be underlain by a layer of coarse sands. This layer of coarse sands is at residual saturation which will eliminate the possibility of cation diffusion through it.

In summary, if a natural sand, silt, or till contains low to moderate dissolved components, the use of a small amount of SAP would make the natural material an effective hydraulic barrier. The performance of the SAP-bearing material would be improved if a layer of coarse sands is placed underneath.

When used in a bottom liner, the SAP will not function well because solution percolating through the acid mine tailings will poison the SAP performance. Without the swelling of the SAP, the liner won't be an effective hydraulic barrier.

## **Economics of SAP Application**

The economics of SAP application in acid mine abatement can not be fully evaluated until an optimum concentration is determined for a candidate cover material. It is certain however that only a small amount of SAP (one weight percent or less) is needed in the cover. The cost for the SAP production is estimated at \$1.17/kg (Wong, 1993). This cost estimate is based on

building a plant with an estimated 15 year life with the capacity to produce 20,000 dry metric tons of SAP annually. The manufacturing process involves blending the basic feed materials, Na-bentonite, acrylamide and caustic soda, while controlling the water content at 60%. The resulting slurry is drained into plastic bags, which are then transported by a conveyor belt to an electron beam accelerator for irradiation. After irradiation, the slurry turns into a gel. The gel is then cut into smaller pieces, and the moisture is removed in a dryer by hot air. After drying, the product is pulverized into a powder, to about 20 to 40 mesh (Figure 6).

In detail, this cost estimate is based on the current price for raw material (bentonite, acrylamide, caustic soda, etc.), capital investment (electron beam accelerator, mixing vessel, drying facility, etc.), and operating cost. If an existing facility can be found in the U.S., the manufacturing cost for the SAP would be cheaper. The major component of the cost is the purchase of the acrylamide at a cost of \$0.78 per kg of SAP produced, and is in part due to the absence of a Canadian producer.

In any case, the SAP would cost much more than Wyoming bentonite on a unit weight basis (compare \$1.17/kg to \$0.085/kg). However, for equal performance in moisture retention and as hydraulic barrier, the amount of SAP required in the cover is only one tenth of bentonite or even less. Savings on transportation can be substantial. In addition, mixing SAP with sands or silt will be very easy. Packing requirements may be not as strict since volume expansion of the SAP is so large that it will fill out all the pore space. All these savings may outweigh the high material cost. Ideally, the SAP can be directly mixed with a natural material such as the Heath Steele till or varved clay (Yanful, 1992). The amount of SAP required could be even much less (as low as 0.2 wt%) when used with these materials because these natural materials have a low hydraulic conductivity to start with.

MEND has estimated the costs of stabilizing existing and future acid mine waste sites will be \$200,000 to \$400,000 per hectare. For dry cover, \$200,000/hectare means \$20/m<sup>2</sup>. Assuming that the dry cover is 1.0 meter thick, of which 30 cm is SAP- or clay-modified impermeable layer, with 1.0 wt% SAP concentration and 1.5 tonne/m<sup>3</sup> bulk density, the amount of SAP required for a square meter of cover is  $(1.0 \text{ m}^2 \times 0.3 \text{ m}) \times 1,500 \text{ kg/m}^3 \times 0.01 = 4.50 \text{ kg}$ . The cost of the SAP will be  $4.50 \text{ kg} \times \$1.17/\text{kg} = \$5.26$ . If the SAP concentration can be lowered to 0.2 wt% as suggested in the last paragraph, the SAP cost will be \$1.05 per square meter of cover. This cost of SAP will be about 1/20 of the total cost for the construction of the cover. In addition there will be the cost of mixing the SAP into the cover material. However, we do not see any special requirement for the mixing. Any portable mixing tank such as a

cement mixing truck could be used. For the purpose of this calculation, it is considered that the additional cost due to mixing would be small and probably fall within the uncertainty of the estimated price of the SAP. From our perspective, the benefit of using SAP is that it may provide technical advantages over other natural materials. For example, if no natural material can achieve the required technical specifications, or if more than one type of natural material (e.g. sands plus clays) has to be mixed in order to achieve these technical specifications, the application of SAP may become an important alternative.

### **Conclusions**

Preliminary tests with the SAP/sands mixture show a significant potential for SAP application in acid mine tailing abatement. The use of SAP in bottom liner of a tailings pond is not a viable option because of the poisoning effect of multi-valent cations on the SAP. However, a SAP-bearing cover should be an effective hydraulic barrier. Essentially, the cover would be an impermeable barrier and would retain its water saturation. The cost for this material may be offset by the savings on the transportation of the barrier material and construction of the cover.

## **ACKNOWLEDGEMENTS**

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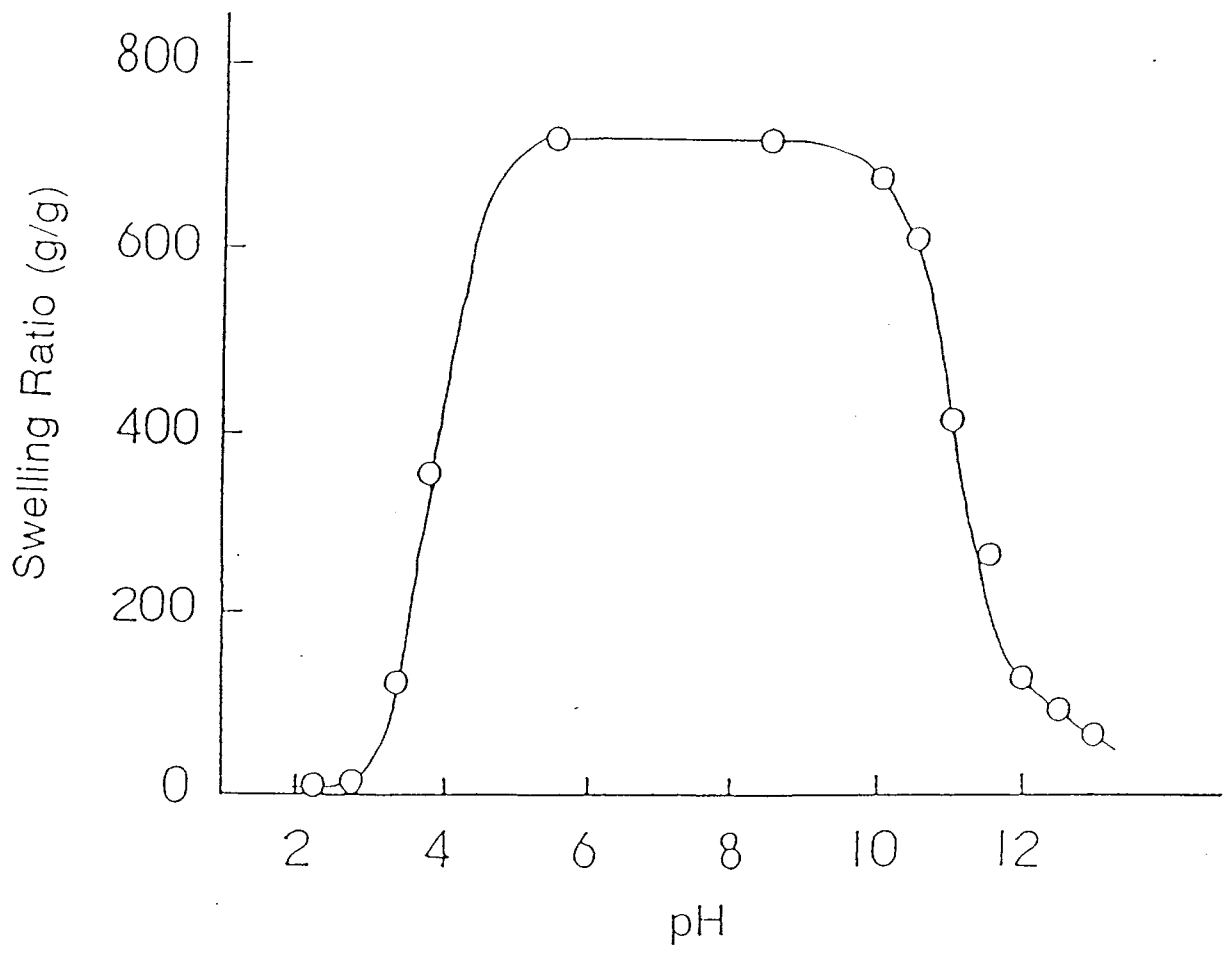


Figure 1. Effect of solution pH on the water adsorption capacity of the SAP.  
(From Gao, 1993)

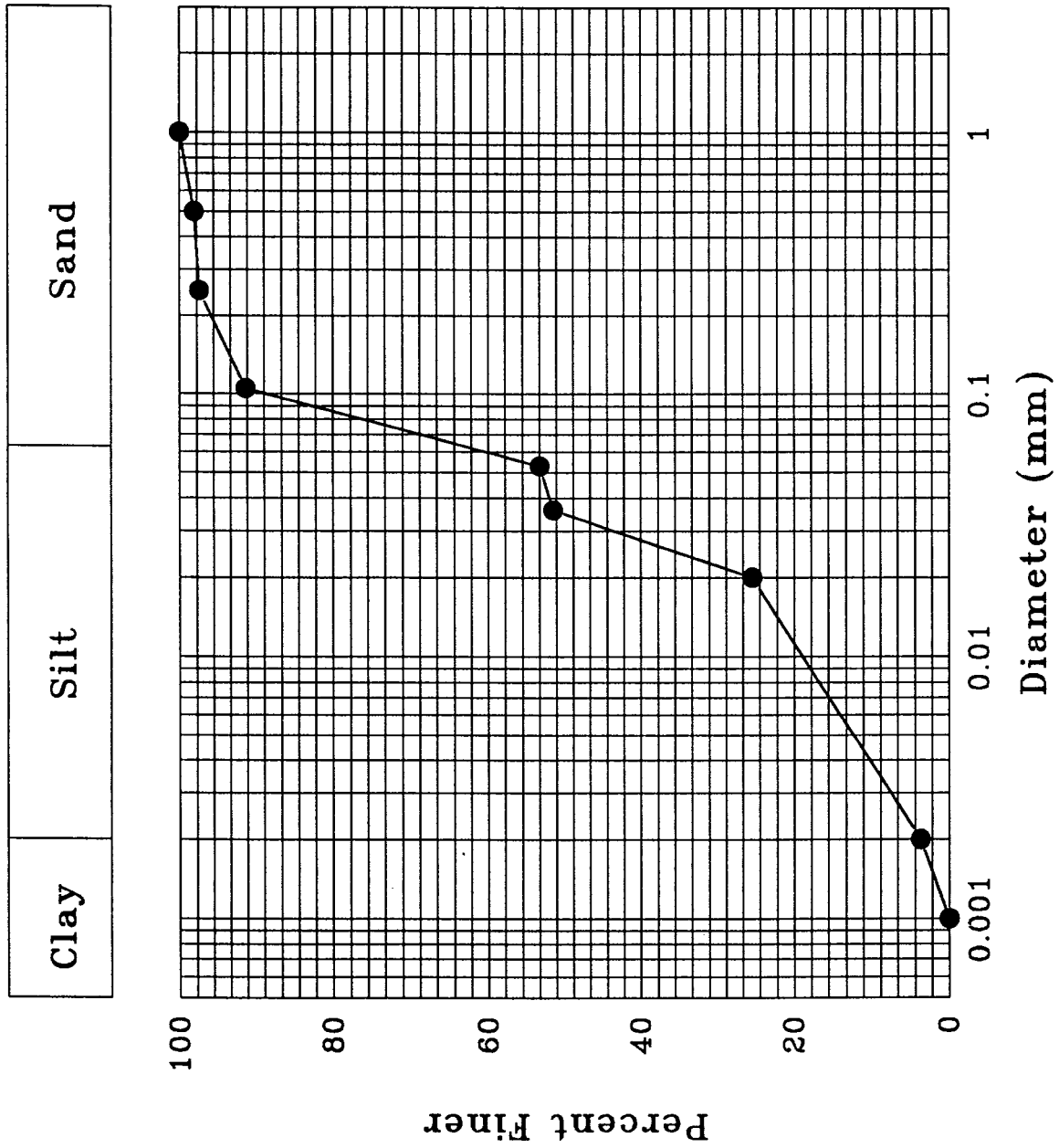


Figure 2. Particle size distribution of the tailings.

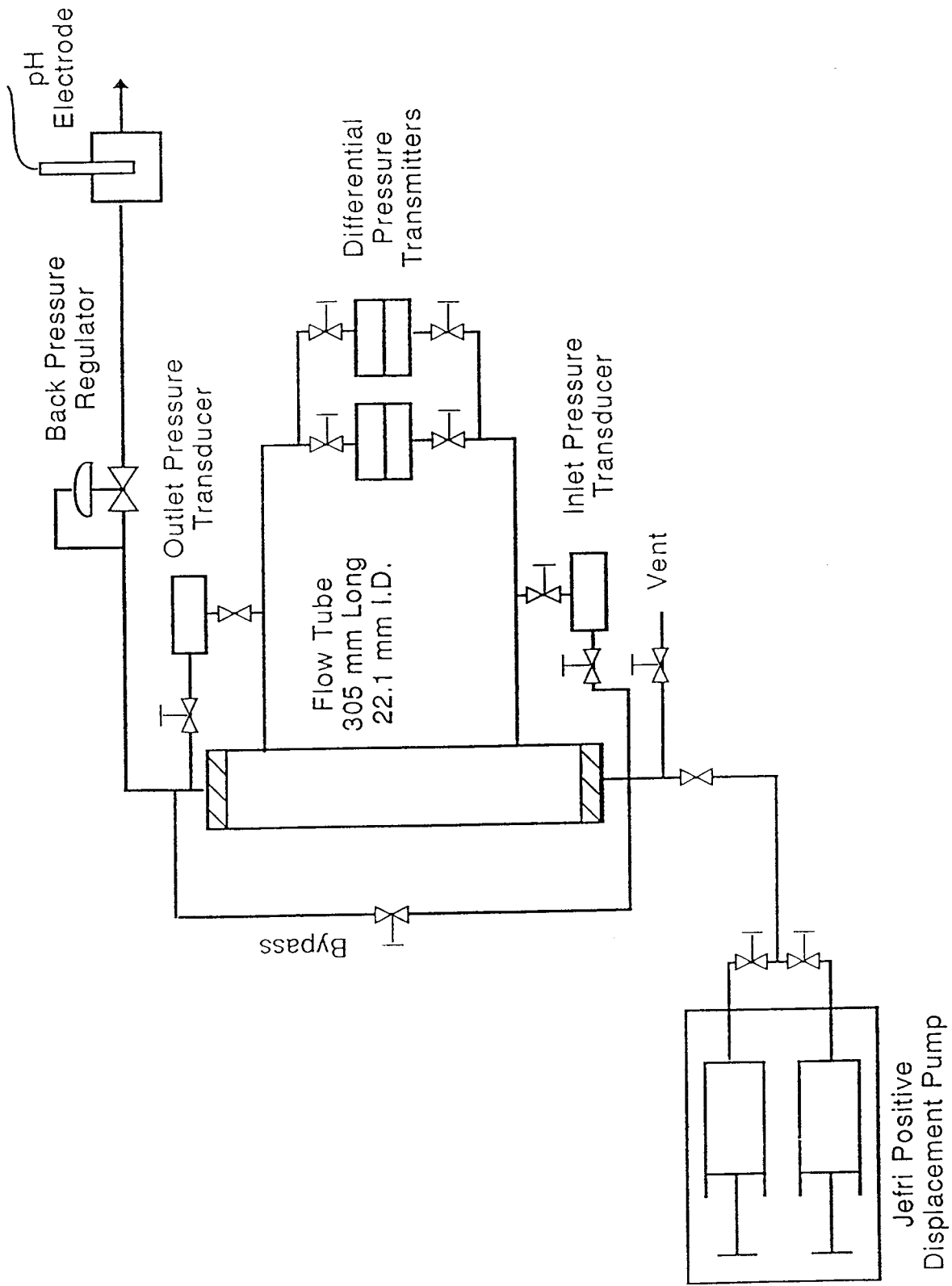


Figure 3. Experimental Apparatus for hydraulic conductivity measurements.

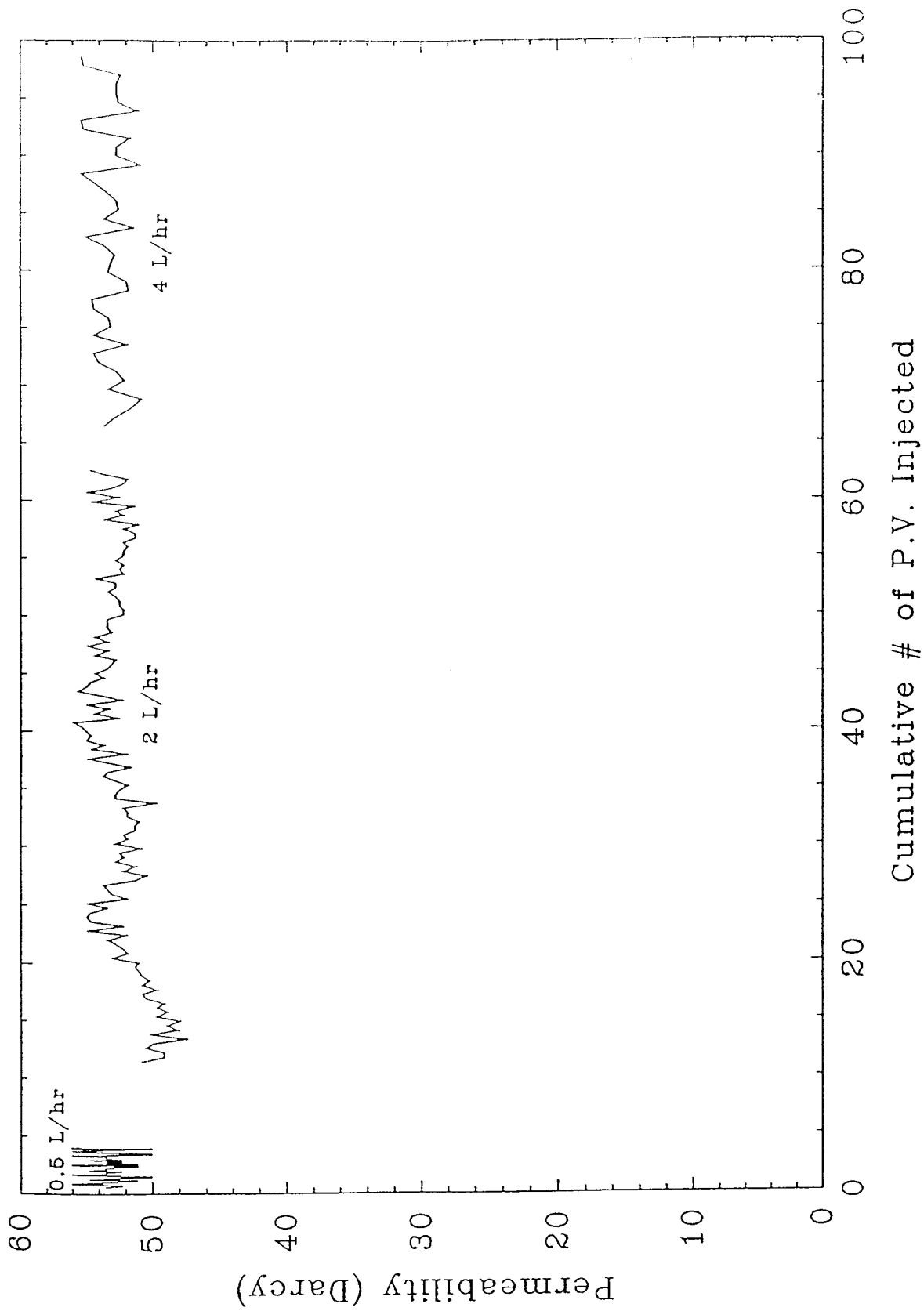


Figure 4. Permeability of Sample A (sands) to DIW at room temperature.

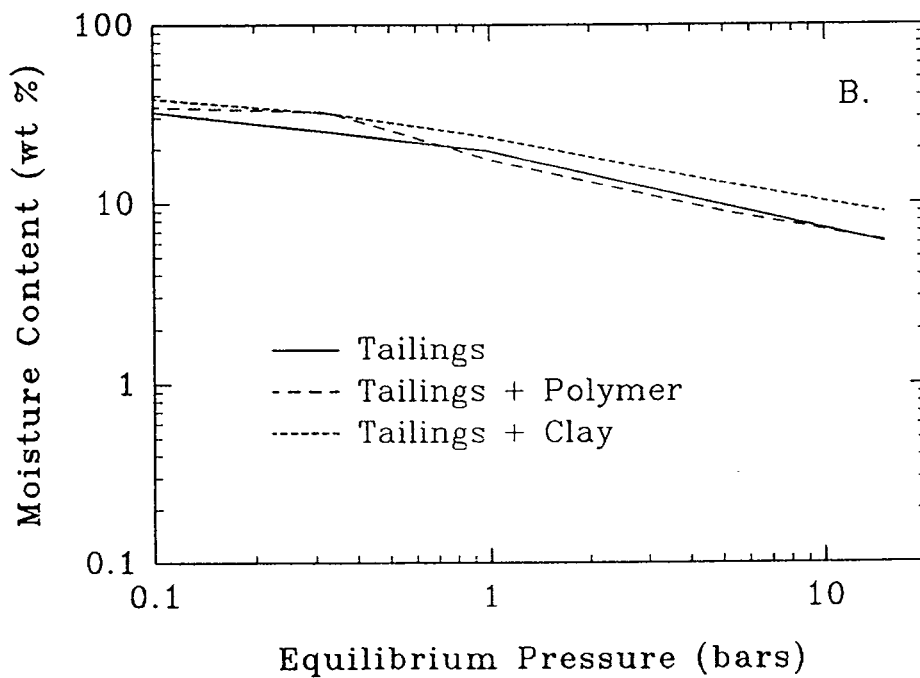
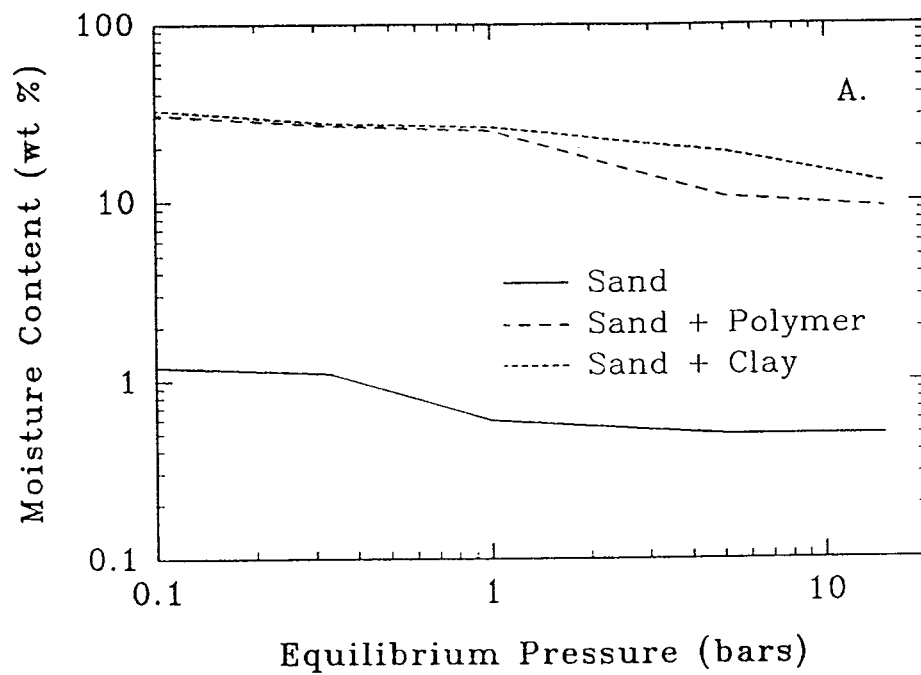


Figure 5. Moisture retention curves. A) Sands-based samples; B) Tailings-based samples.

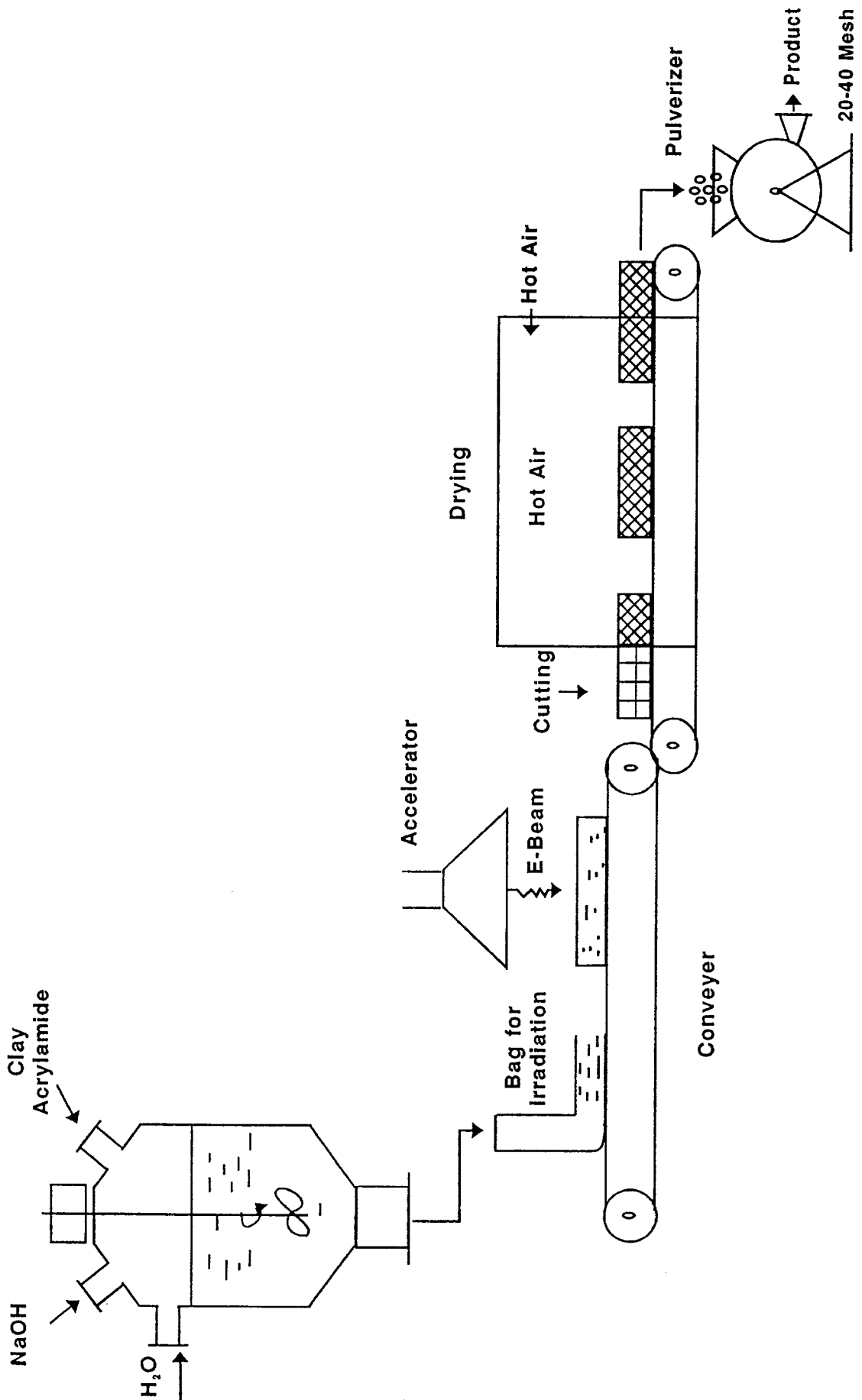


Figure 6. Preliminary flowchart for SAP manufacturing (From Wong, 1993).