CIM

COAL PROCESSING

Flocculation of froth flotation tailings from a coal washery

H. A. HAMZA
Research Scientist, Western Research Laboratory
Energy Research Laboratories, CANMET
Department of Energy, Mines and Resources
Edmonton, Alberta

ABSTRACT

An experimental study of the settling characteristics of a washery effluent originating as tailings from a froth flotation circuit was undertaken by using a systematic approach to select the most appropriate flocculant(s) under predetermined conditions. Selection and evaluation procedures which greatly reduce the effort required to select flocculants are described.

The results show that, although different flocculants display superiority at different ranges of dosage, Separan MG 700 (Dow) is the most suitable on absolute economic grounds. Flocculant evaluation is based on a Cost Performance Index (CPI) which expresses the cost of flocculant (¢/ton) required to produce a unit settling rate (in./hr).

From experiments carried out with a number of flocculant aid and flocculant combinations, it was concluded that the use of flocculant aids can be economically justified only if the settling rates required are higher than those obtainable at the optimum flocculant dosage. Otherwise, the value of the flocculant aid appears to be limited largely to the reduction of supernatant turbidity.

Introduction

This investigation is a contribution to a general CANMET study initiated in 1976 and directed toward improving coal cleaning processes, especially for low-grade or fine coals, and alleviating environmental problems associated with the mining and processing industries.

Water conservation, reduction of land use for disposal and prevention of stream contamination by plant effluents are among the immediate benefits of such a study. Additional benefits stem from the availability of the results to industry on a scale and in a form immediately applicable to large-scale operations. The purpose of this paper is to outline a systematic method of selecting the most suitable flocculants, using this effluent as a field example.

The effluent used in the present investigation originated as a tailing from the flotation section of the Cardinal River Coals Ltd. washery at Luscar, Alberta (Fig. 1). The tailings from the flotation cells are fed to a number of classifier cyclones having a cutpoint of approximately 120 mesh (125 microns). Cyclone overflow constitutes the main portion of the feed to a 95-ft-diameter thickener. Cyclone underflow (plus 120 mesh) joins the thickener underflow to form the feed to a solid bowl centrifuge. The centrifuge solids are withdrawn as a final reject while the centrate is sent back to the thickener.

Alternative plans for the centrate from the solid bowl centrifuge might include retreating it in another centrifuge with provision for internal additional of flocculant, combining the centrate of this second centrifuge with the overflow of the thickener and recycling the stream to the washery after being diluted with make-up water. As another alternative, the centrate of the second centrifuge could be sent to the thickener if its solids content were too high to permit immediate recycling as plant water

At the time of the investigation, two flocculants were being used in the water treatment circuit of the plant: a cationic, added as far ahead of the thickener as possible; and an anionic, added at a point approximately 5 ft from the thickener inlet.

Test Procedure

The test procedure consisted of characterizing the tailing sample, prescreening for a number of suitable flocculants based on sample characteristics and, finally, rating of the prescreened flocculants on a cost-performance basis.

Effluent Characteristics

The effluent sample (cyclone overflow) was collected in increments at the washery over a period of one week in order to be as representative as possible of the plant situation. Sample characteristics are shown in Tables 1, 2 and 3. Table 1 includes density, % ash, zeta potential of the solids and weight per cent solids of the effluent. Water analysis is shown in Table 2 and size analysis of the solids in Table 3; standard sieves were used for sizes down to 325 mesh (44 microns). The subsieve distribution is the average of results obtained by three independent techniques: sedimentation on a balance-pan (Shimadzu Sedimentograph), X-ray scanning of settling particles (Micromeritics Sedigraph 5000) and the electronic sensing zone method (Coulter Counter TAII).

Prescreening of the Flocculants

Three hundred and ninety commercially available flocculants were prescreened by reference to an index of flocculants[1], wherein flocculant characteristics, prices and operating or process conditions and limitations are catalogued.

Knowledge of the effluent characteristics, as outlined above and given in the tables, permits rapid elimination of those flocculants which have little or no chance of performing well under existing effluent conditions.

Through the prescreening process, a number of suitable flocculants were selected. Characteristics of these flocculants are shown in Table 4, columns 2-5. Superfloc 330 (polyamide), used as a flocculant aid, was treated in conjunction with several of the selected flocculants.

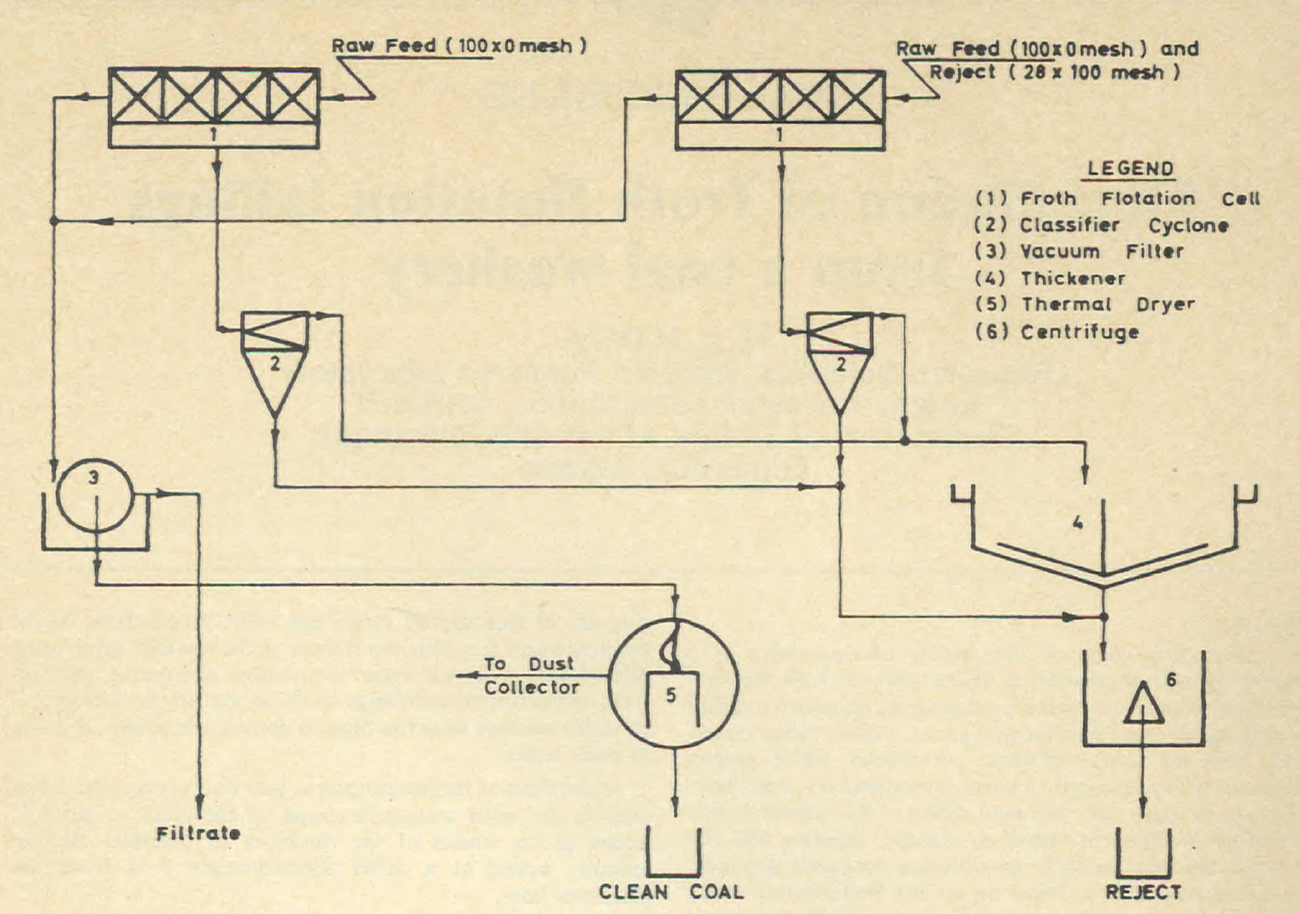

FIGURE 1. Flowsheet of water treatment circuit of Cardinal River washery.

TABLE 1. Effluent characteristics

Characteristic	Value
Solids Density (g/cc)*	2.09
Solids Content (%)	0.60
Ash Content (%)	45.60
Zeta Potential (mv)**	-18

*Determined by an air pycnometer.
**Determined by a zeta-meter.

TABLE 2. Water analysis

Ion	Content (ppm)
Ca	30.00*
Mg	9.30*
Fe	0.17*
Na	41.70**
pH	8.2

*Determined by atomic absorption.
**Determined by flame photometer.

TABLE 3. Size analysis of effluent solids

Size (mesh or microns)	Weight (%)	Cumulative Weight (% passing)	Notes
+ 100 mesh	1.3	100.0	Sieve (Mesh-Tyler)
-100 + 150	3.8	98.7	
-150 + 200	14.1	94.9	
-200 + 325	14.0	80.8	
-325 + 400	4.3	66.8	
-400 + 30 microns	2.9	62.5	Sub-sieve (Microns)
-30 + 25	3.6	59.6	
-25 + 20	3.8	56.0	
-20 + 15	5.4	52.2	
-15 + 10	7.3	46.8	
-10 + 5	13.0	39.5	
-5 + 1	19.1	26.5	
-1	7.4	7.4	
Total	100.00		

Rating of the Prescreened Flocculants

The flocculants listed in Table 4 were bench-tested on effluent samples having the characteristics shown in Tables 1, 2 and 3. Great care was exercised in splitting and preparing the effluent samples for the various tests and flocculant preparation and addition procedures were rigidly standardized to reduce errors arising from procedural inconsistency.

Settling rates were used to evaluate flocculant performance and were determined in stoppered 100-ml graduated cylinders, having a height of 7-3/16 inches between the zero and 100-ml marks. A standardized procedure of incremental flocculant addition and mixing by a number of end-to-end inversions of the cylinder was followed. Rate of descent of the interface between the pulp and the supernatant liquid was determined, starting from the 100-ml mark, and the results were plotted to obtain a profile of the settling rate after each reagent addition.

The settling rates shown in Table 4, column 8, are for essentially free-settling conditions and are frequently referred to as initial settling rates[2]. The settling rates shown were obtained at the optimum flocculant dosage, which was taken as the point on the settling rate - flocculant dosage curves (Figs. 2-6) where the rate of increase in settling velocity began to taper off markedly on further addition of the flocculant. For purposes of comparison between flocculants, "optimum dosage" as defined above was found to be a useful indicator. In practice, the economic optimum may be somewhat different.

Cost-Performance Evaluation

Evaluation of flocculants may be based on a Cost Performance Index (CPI), as shown in Table 4, column 9, which is

TABLE 4. Comparison criteria for flocculants tested

(1) Flocculant	(2) Source	(3) Type	(4) Ionic Charge	(5) Price* Per Pound ($)	(6) Optimum Dosage (lb/long ton)	(7) Optimum Dosage (¢/long ton)	(8) Settling Rate (in./hour)	(9) CPI x 10^-2	(10) Rating Order
None	-	-	-	-	-	-			
Superfloc 127	Cyanamid	PAM	Nonionic	1.36	0.707	96	950	10.11	7
Superfloc 330	Cyanamid	Polyamide	Cationic	0.57	0.523	30	274	10.95	8
Superfloc 1202	Cyanamid	PAM	Anionic	0.47	0.387	18	535	3.36	2
Percol E24	Allied Colloids	PAM	Anionic	1.53	0.260	40	738	5.42	3
Percol 352	Allied Colloids	PAM	Cationic	1.48	0.373	55	920	5.98	4
Hercolfloc 819.2	Hercules	PAM	Anionic	1.58	0.286	45	745	6.04	5
Separan MG 700	Dow	PAM	Anionic	1.42	0.113	16	625	2.56	1
Alfloc 85030	Alchem	PAM	Anionic	0.97	0.410	40	422	9.48	6

*Based on the lowest price, which usually corresponds to the largest amount ordered (e.g., truck loads or 30,000 lb; F.O.B. Edmonton, otherwise the shipping charges are added.

designed to serve as a measure of the suitability of the flocculants under the conditions of the experiment. In general, for a certain dosage, the CPI is a function of the flocculant cost and the settling rate produced. In its simplest form, the CPI is determined at the optimum flocculant dosage and is equal to the cost, in cents per long ton of the treated solids, divided by the initial ratio of subsidence (of the interface).

The CPI determined at optimum dosage is quite sufficient for purposes of this paper i.e., for selection of the most suitable flocculant for clarification and/or thickening in an existing clarifier or thickener. However, other forms of CPI would need to be developed where, for example, a new installation is being designed and where capital cost of the equipment should be taken into account. Other parameters, such as ease of flocculant dissolution, which will have a direct bearing on the size of the mixing and dilution equipment, the degree of solids compaction and clarity of the supernatant liquid, may also be relevant to the CPI.

Results and Discussion

Plots of initial settling rates of the pulp interface vs flocculant dosage (lb/long ton) (Figs. 2-6) indicate that a dosage range should be specified prior to deciding on the most suitable flocculant; this is important because, as seen from the plots, variation can occur in the relative performance of flocculants in different dosage ranges. Normally, the economic limit is the main factor which determines the highest dosage to be applied, whereas, the lowest dosage is determined by the minimum settling rate that can be tolerated for a thickener of fixed size.

The results plotted in Figure 2 show that, up to a dosage of 0.15 lb/long ton, Separan MG 700 is superior, between 0.15 and 0.31 lb/long ton, Hercofloc 819.2 is superior and at still higher dosages (0.31-0.57 lb/long ton), Percol 352 gives the best performance. Superfloc 127 is best at dosages higher than 0.57 lb/long ton.

The effect of price differences between individual flocculants can be seen in Figure 3, where ratings are shown to be only slightly modified when based on flocculant cost. This may be due to the prices of similar flocculants being very competitive as a result of an increasing market. The following was established: Separan MG 700, Hercofloc 819.2, Percol E24, Hercofloc 819.2, Percol 352 and Superfloc 127, were found to be superior in the cost ranges of ≤ 23, 23-36, 36-42, 42-47, 47-77 and 77-117 cents/long ton respectively.

Some difficulty with the universal application of CPI arises from the fact that flocculant performance varies with dosage range. However, knowledge of process conditions and limitations such as minimum settling rate requirement, maximum cost allowance, etc., may facilitate the decision. For the purposes of this paper, no such limitations were imposed and the best flocculant was taken to be the one with minimum CPI value, which, in this case, was Separan MG 700.

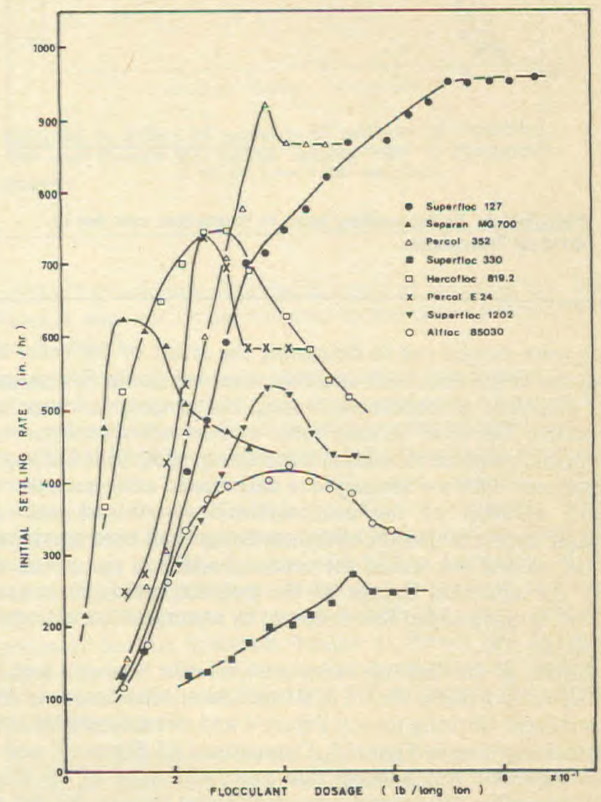

FIGURE 2. Initial settling rates vs flocculant dosage for individual flocculants.

Flocculant Aids

The following combinations of reagents were tested to determine the effect of using Superfloc 330 as a flocculant aid in combination with a polyacrylamide flocculant. Two series of

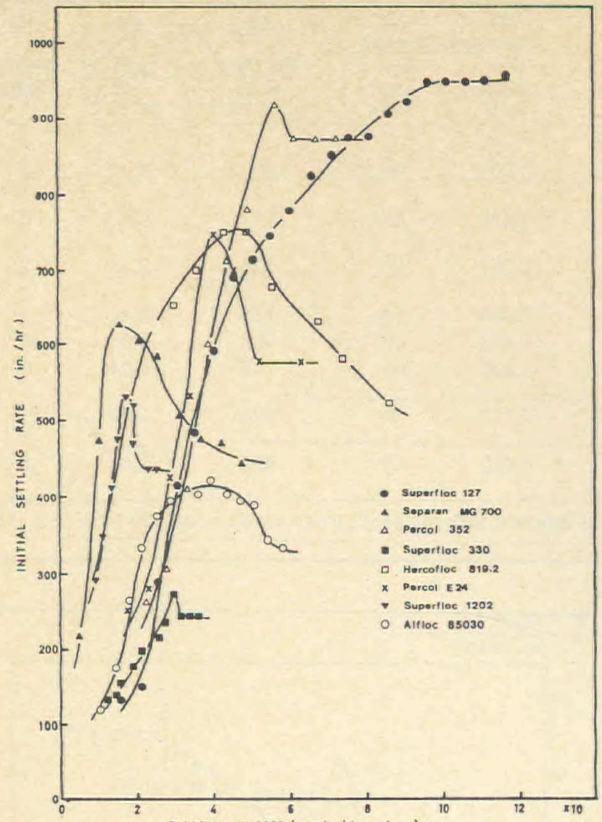

FIGURE 3. Initial settling rates vs flocculant cost for individual flocculants.

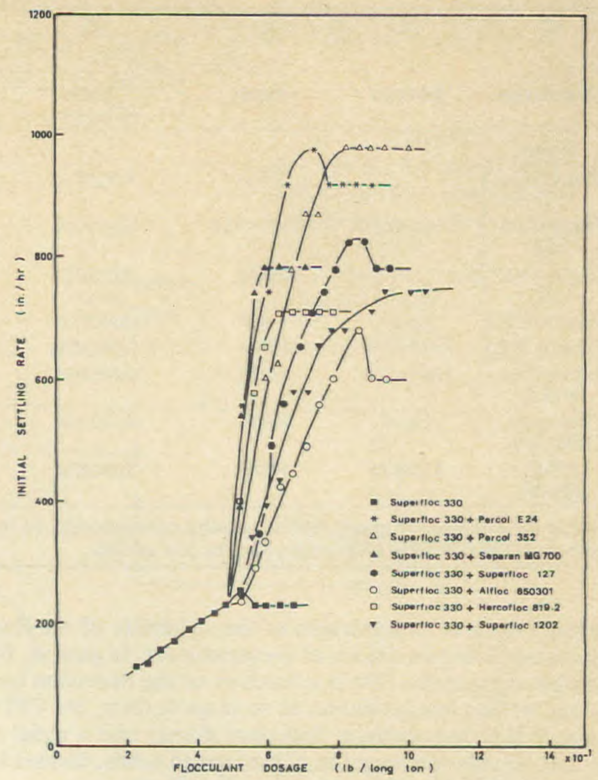

FIGURE 4. Initial settling rates vs flocculant dosage for flocculant aid - flocculant combinations.

tests were carried out to determine the effect of the order of addition of the flocculant and flocculant aid. In the first series, the pulp was preconditioned using the optimum dosage of Superfloc 330 (0.49 lb/long ton), as determined earlier, and the polyacrylamide flocculant was subsequently added in small increments with the settling rate determined after each increment; addition of the polyacrylamide continued until it became apparent that the optimum dosage had been exceeded. In the second test series, the order of addition was reversed, with the optimum dosage of the polyacrylamide flocculant (Table 4) being added first followed by incremental addition of Superfloc 330.

Results of the first test series are shown in Figures 4 and 5. Initial settling rate is shown as a function of total dosage of the two reagent (lb/long ton) in Figure 4 and of total reagent cost (cents/long ton) in Figure 5. Comparison of Figures 4 and 5 with Figures 2 and 3 shows that preconditioning of the pulp with Superfloc 330 generally brought about varying degrees of improvement in optimum settling rates of the pulp according to the flocculant used: per cent increases of 4.5, 5.4, 25.1, 31.4, 40.3 and 60.8 were observed for pulp samples treated with Hercofloc 819.2, Percol 352, Separan MG 700, Percol E24, Superfloc 1202 and Alfloc 85030 respectively. Only one flocculant (Superfloc 127) showed a drop in performance when used on the pulp preconditioned with Superfloc 330.

In contrast to the above, as is apparent from results for two reagent combinations shown in Figures 6, 7, 8 and 9, it would not be economically advantageous to use Superfloc 330 as a flocculant aid in conjunction with polyacrylamide flocculants if the latter were to be added at dosages below their optimum. As shown in Figure 7, a settling rate of 532 in./hr was produced at a cost of ~ 17¢/long ton when 1202 was used alone, whereas the same settling rate for the pulp preconditioned with

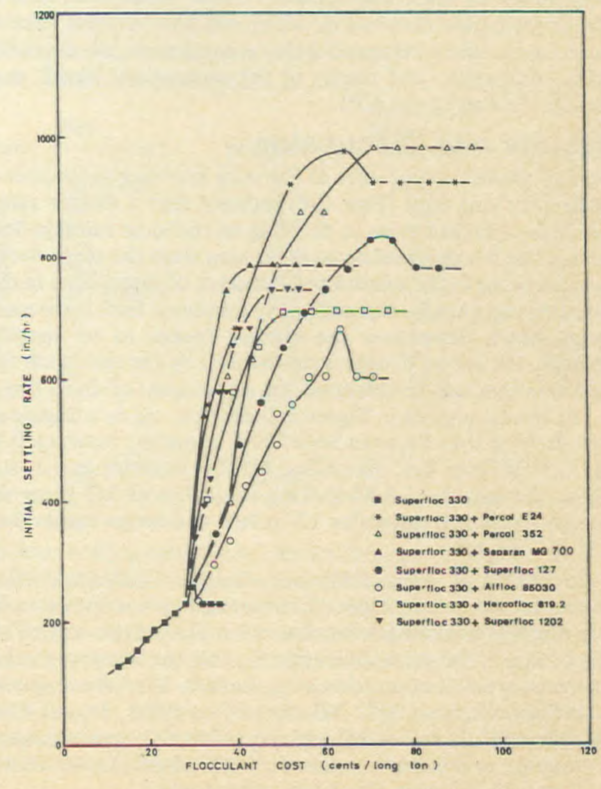

FIGURE 5. Initial settling rates vs flocculant cost for flocculant aid - flocculant combinations.

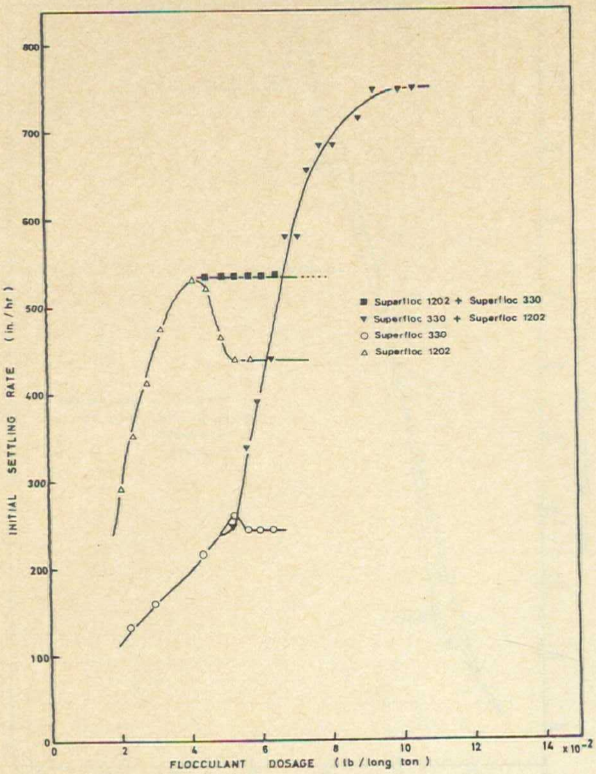

FIGURE 6. Effect of sequence of addition of Superfloc 330 and Alfloc 1202 (initial settling rate vs flocculant dosage).

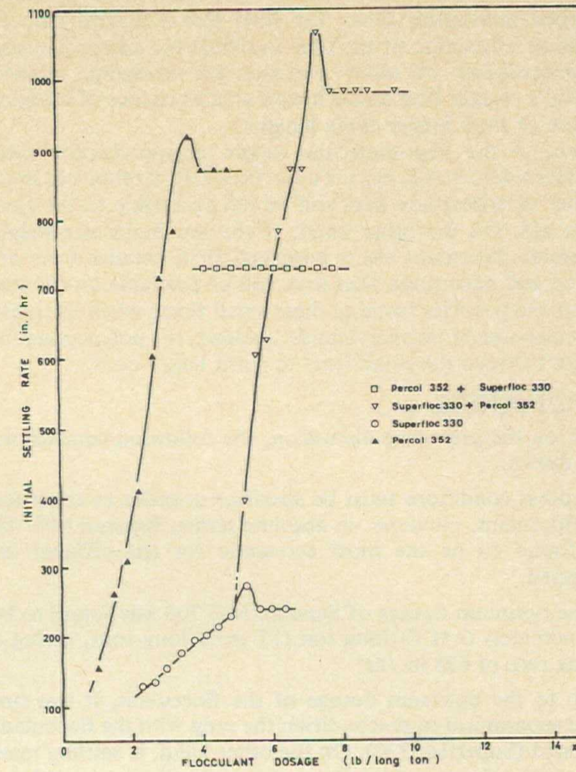

FIGURE 8. Effect of sequence of addition of Superfloc 330 and Percol 352 (initial settling rate vs flocculant dosage).

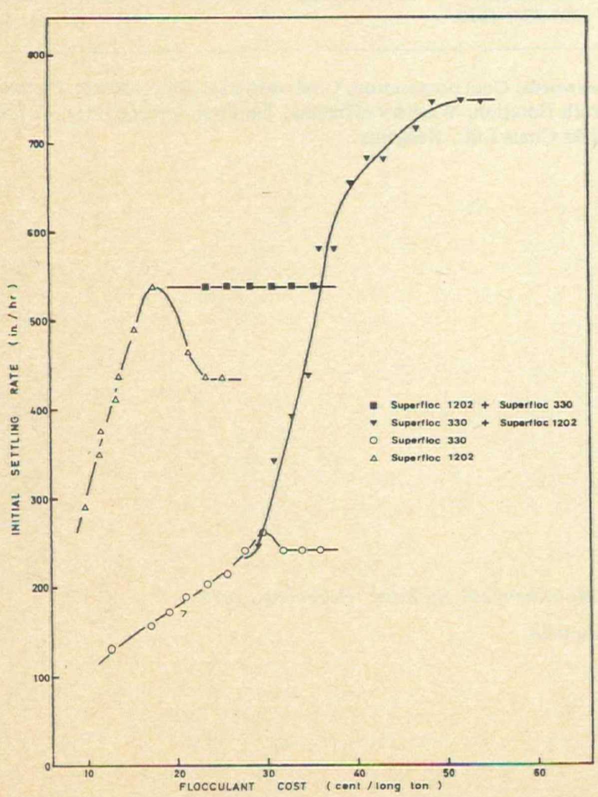

FIGURE 7. Effect of sequence of addition of Superfloc 330 and Alfloc 1202 (initial settling rate vs flocculant cost).

Superfloc 330 was only obtained at a cost of 36¢/long ton. The difference was not as pronounced in the case of Percol 352 (Figs. 8 and 9).

Results of the second test series are shown in Figures 6, 7, 8 and 9 for the pulp treated first at the optimum dosage of the polyacrylamide flocculant, then with incremental additions of Superfloc 330. Only two polyacrylamide flocculants were used in this series: Superfloc 1202, and anionic liquid polyacrylamide, and Percol 352, a cationic solid polyacrylamide. It is apparent from the graphs that there was no advantage to this sequence of addition regardless of the level of Superfloc 330 used. Moreover, in the case of Percol 352, the settling rate dropped below the level obtained previously for the optimum dosage of Percol 352 by itself. Such a decrease may be due to floc breakdown by agitation and the incapability of Superfloc 330 to restore the original state of flocculation.

The settling behaviour of the pulp when treated with a combination of flocculants can be explained by the following postulates.

1. A fixed number of adsorption sites occur on the surface of each solid particle.
2. In general, the higher the molecular weight of the flocculant, the longer the chain length and the larger the number of functional groups per molecule.
3. The higher the number of functional groups per molecule, the higher the probability of coverage of adsorption sites on the surface of each particle by the flocculant molecule. This is due to either direct adsorption of functional groups on the sites or to collapse of the molecule on the solid surface following initial adsorption of a number of functional groups.
4. Flocculation is a competition between two mechanisms: 1) adsorption of some of the flocculant functional groups on adsorption sites located at the surface of the particles and 2)

bridging of the remaining portion of the molecule to adsorption sites on other particles or to segments of other similarly adsorbed molecules. Thus, the final floc structure may be viewed as a function of the time available for adsorption and the accessibility of other particles for bridging. Higher-molecular-weight flocculants have a greater chance of bridging because of their longer chain lengths.

Thus, if the high-molecular-weight polyacrylamide (MG 700, Hercofloc 819.2, etc.) is adsorbed first, a relatively small number of adsorption sites will be left accessible to the flocculant aid. On the other hand, if the low-molecular-weight polyamide flocculant aid is adsorbed first, smaller flocs are formed and adsorption sites may still be available on the surface of the particles forming these small flocs; when the high-molecular-weight polyacrylamide is added, the polyacrylamide bridges between the small flocs to form larger ones.

Conclusions

Based on the preceding discussion, the following conclusions were drawn.

1. Process conditions must be specified in order to select the best flocculant. However, in absolute terms, Separan MG 700 was found to be the most economic for the effluent investigated.

2. The optimum dosage of Separan MG 700 was found to be approximately 0.11 lb/long ton (17 cents/long ton), giving a settling rate of 625 in./hr.

3. Up to the optimum dosage of the flocculant, it was not found economical to precondition the pulp with the flocculant aid tested (Superfloc 330). On the other hand, if settling rates higher than those produced by the optimum dosage of the flocculant are required, preconditioning with Superfloc 330 becomes justified.

4. Addition of the low-molecular-weight polyamide (Superfloc 330) subsequent to addition of the polyacrylamide was of no apparent advantage.

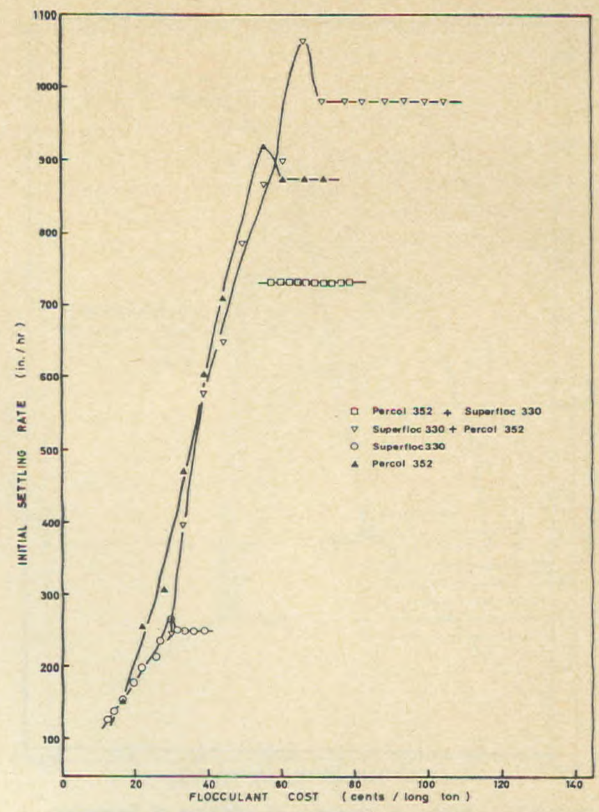

FIGURE 9. Effect of sequence of addition of Superfloc 330 and Percol 352 (initial settling rate vs flocculant cost).

REFERENCES

1. HAMZA, H. A., and PICARD, J. L., Index of Commercial Flocculants—1974; *CANMET Report ERP 77-8; 27 pp.; May 1977.*
2. COE, H. S., and CLEVENGER, G. H., Methods for determining the capacities of slime-settling tanks; *Trans. AIME; V. 55, pp. 356-384; 1916.*

Keywords: Coal preparation, Coal washeries, Flocculation, Flotation, Froth flotation, Washery effluents, Tailings, Settling rates, Cardinal River Coals Ltd., Reagents.

(Reprinted from The Canadian Mining and Metallurgical Bulletin, February, 1979)

Printed in Canada