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# FLOCCULATION OF FROTH FLOTATION TAILINGS FROM A WESTERN CANADIAN COAL WASHERY

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# FLOCCULATION OF FROTH FLOTATION TAILINGS FROM A COAL WASHERY

by

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ABSTRACT

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

The results show that, although different flocculants displayed 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 aids flocculant combinations it was concluded that use of flocculant aids can be economically justified only if 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 reduction of supernatant turbidity.

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# INTRODUCTION

This investigation is a contribution to a general CANMET study initiated in 1976 and directed towards improving coal cleaning processes especially for low-grade or fine coals and towards 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 report 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, (Figure 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. The sample (cyclone overflow) was collected in increments over a one-week period and later used as is throughout the entire investigation.

Future plans include retreating the centrate from the solid bowl centrifuge with another centrifuge inside which flocculants are to be added. The centrate of the second centrifuge and the overflow of the thickener could be combined and recycled to the washery after being diluted with make-up water. As an alternative the centrate of the second centrifuge could be sent to the thickener if its solids' content was too high for recycling as plant water.

Two flocculants are presently being used in the water treatment circuit: 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 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 was collected in increments at the washery over a period of one week in order to be representative of the plant situation. Sample characteristics shown in Tables 1, 2 and 3. Table 1 includes density, % ash and zeta potential of the solids and weight percent solids in 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). 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 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.

Determining the effluent characteristics, as outlined above, 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 tested in conjunction with several of the selected flocculants.

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 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 (Figures 2-6) where the rate of increase in settling velocity tapered off markedly upon 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 is based on a Cost Performance Index (CPI) as shown in Table 4, column 9, which is 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 settling rate of the interface.

The CPI at optimum dosage is quite sufficient for the purpose of this report 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 need to be developed in cases where for example, a new installation is being designed and where capital cost of the equipment should be taken into account. Ease of flocculant preparation, which will have a direct bearing on the size of the preparation equipment, as well as solids compaction and clarity of the supernatant liquid are other criteria which may be relevant to the CPI.

RESULTS AND DISCUSSION

Plots of flocculant dosage (lb/long ton) vs initial settling rates of the pulp interface (Figures 2-6), indicate that a range of dosage should be specified prior to selection of the most suitable flocculant. This is necessary because variation occurs in the relative performance of flocculants in different dosage ranges. Normally, economic limitations are the main factor which determines the highest dosages to be applied whereas the lowest dosage is determined by the minimum settling rate that can be tolerated for a thickener of given size.

The results 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, while at still higher dosages (0.31-0.57 lb/long ton), Percol 352 gives the best performance. Superfloc 127 gives best results at dosages higher than 0.57 lb/long ton.

The effect of price differences between individual flocculants can be seen in Figure 3 wherein ratings become 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 correlation 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.

The fact that flocculant performance varies with dosage range, imposes some difficulty on the universal application of CPI. However, knowledge of process conditions and limitations such as minimum settling rate requirement, maximum cost allowance etc., may facilitate the decision. For the purpose of this report no limitations have been imposed and the best flocculant was taken to be the one with minimum CPI value, which in this case is Separan MG 700.

The following combinations of reagents were tested to determine the effect of using a flocculant aid (Superfloc 330) in conjunction with a conventional flocculant. Two series of tests were carried out. In the first series, the pulp was conditioned with the optimum dosage of Superfloc 330 (0.49 lb/long ton). The flocculant, a polyacrylamide, was subsequently added in small imcrements to the preconditioned pulp and the settling rate determined after each increment. Addition to the polyacrylamide continued until it became apparent that the optimum dosage had been exceeded. In the second test series, the order of addition of the two reagents was reversed i.e., the optimum dosage of the polyacrylamide flocculant (as per Table 4) was 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 vs total dosage of the two reagents (lbs/long ton) is shown in Figure 4, while total reagent cost (cent/long ton) is shown in Figure 5. Comparison of Figures 4, 5 and Figures 2, 3 shows that preconditioning of the pulp with Superfloc 330 generally brought about varying degrees of improvement in optimum settling rates of the pulp. For instance, percent 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. In contrast to this, only one flocculant (Superfloc 127) showed a drop in performance when applied to a pulp preconditioned with Superfloc 330.

It is apparent from Figures 2, 3, 4 and 5, as well as from

Figures 6, 7, 8 and 9, that it would not be economically advantageous to use Superfloc 330 as a flocculant aid in conjunction with polyacrylamide flocculants when the latter are added below their optimum dosages. From Figure 6, a settling rate of 532 in./hr was produced at a cost of ~17¢/long ton when 1202 was used alone, while the same settling rate was obtained at a cost of ~36¢/long ton when the pulp was preconditioned with Superfloc 330. The difference was not as pronounced in the case of Percol 352.

Results of the second test series, where the pulp was first treated with optimum dosages of the polyacrylamide flocculant and then with incremental additions of Superfloc 330, are shown in Figures 6, 7, 8 and 9. Only two polyacrylamide flocculants were used for this series: Superfloc 1202 (an anionic liquid polyacrylamide) and Percol 352 (a cationic solid, polyacrylamide). It is apparent from the graphs that there was no advantage at all in this sequence of addition no matter what level of Superfloc 330 was used. Moreover in the case of Percol 352, the settling rate dropped below the level previously obtained by adding the optimum dosage of Percol 352 alone. The decrease may have been 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, is 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 will be the number of functional groups per molecule
3. the higher the number of functional groups per molecule, the higher will be 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 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; adsorption

of some of the flocculant functional groups on adsorption sites located at the surface of the particles and bridging of the remaining portion of the molecule to other particles or even to other segments of similarly adsorbed molecules. Thus, the final floc structure is a function of the available time for adsorption and the accessibility of other particles for bridging. Higher molecular weight flocculants have a better 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, when the low molecular weight polyamide flocculant aid is adsorbed first, smaller flocs are formed and when the high molecular weight polyacrylamide is added, adsorption sites may still be available on the surface of the particles forming these small flocs. The polyacrylamide then bridges between these small flocs forming larger ones.

## CONCLUSIONS

Based on the preceeding discussion, the following conclusions were drawn:

1. Process conditions have to be specified in order to select the best flocculant. However, Separan MG 700 was found to be the most economic on absolute terms.
2. The optimum dosage of Separan MG 700 was found to be approximately 0.11 lb/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 dosages of the flocculant are required, addition of Superfloc 330 becomes justified.
4. Using the low molecular weight polyamide (Superfloc 330) after addition of the polyacrylamide had no apparent advnatage.

## REFERENCES


1. Hamza, H.A. and Picard, J.L., "Index of Commercial Flocculants-1974"; CANMET, 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. AIMME; v.55, pp 356-384; 1916.

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 | Subsieve (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 | | |

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./hr) | (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 | .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 lbs; F.O.B. Edmonton otherwise the shipping charges are added.

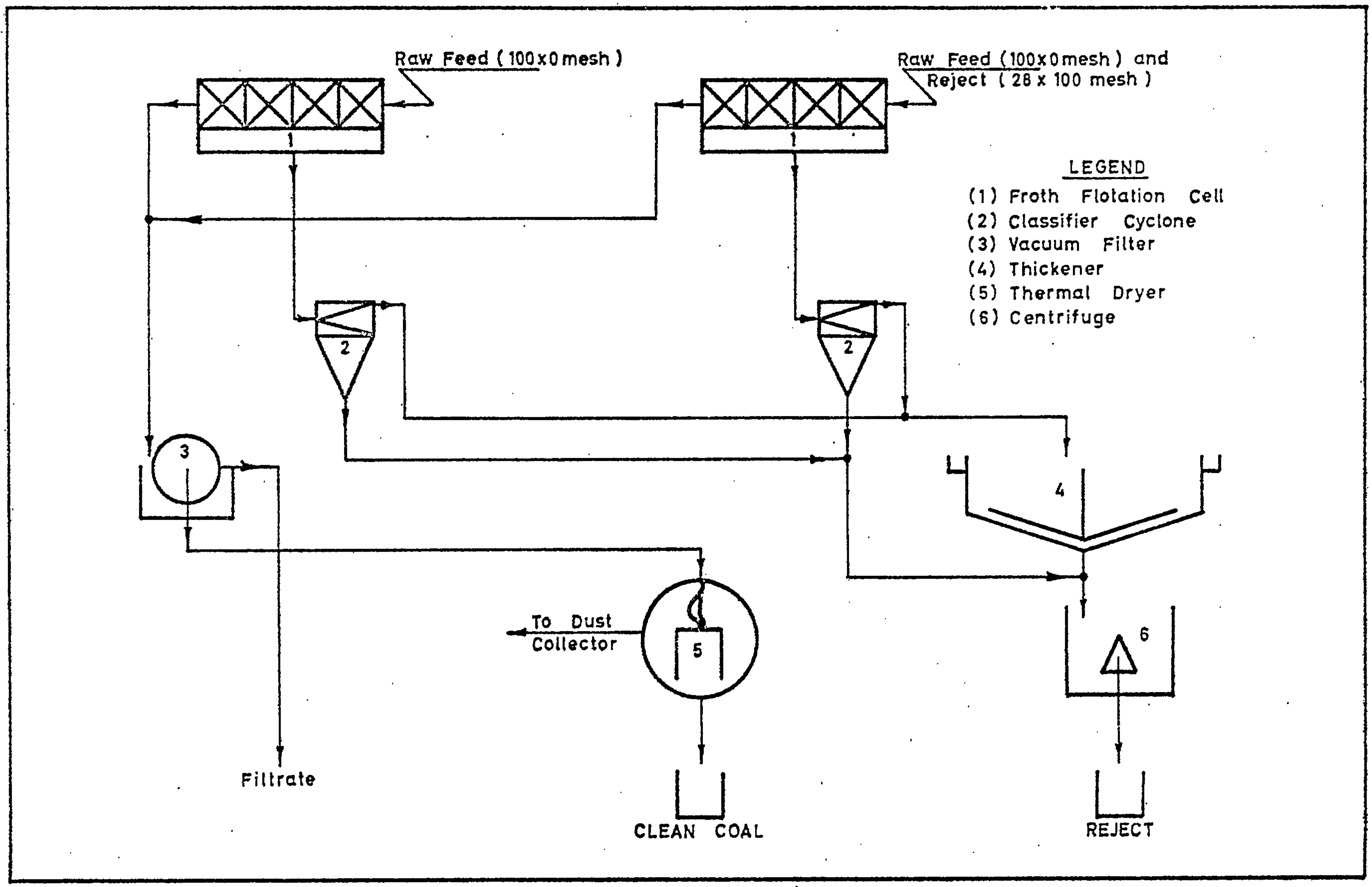


FIGURE 1: FLOWSHEET OF WATER TREATMENT CIRCUIT OF CARDINAL RIVER WASHERY

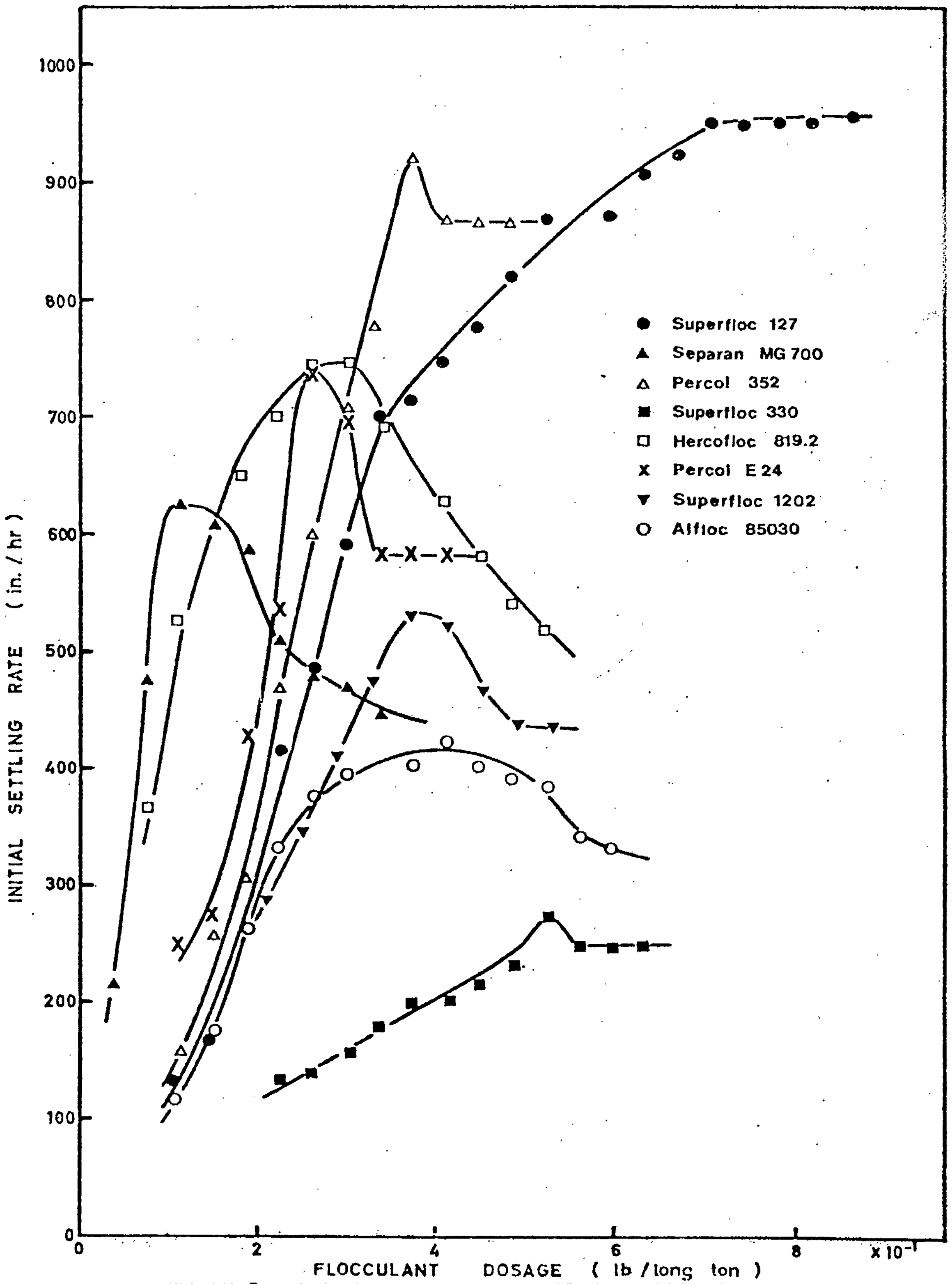


FIGURE 2: INITIAL SETTLING RATES VS FLOCCULANT DOSAGE FOR INDIVIDUAL FLOCCULANTS

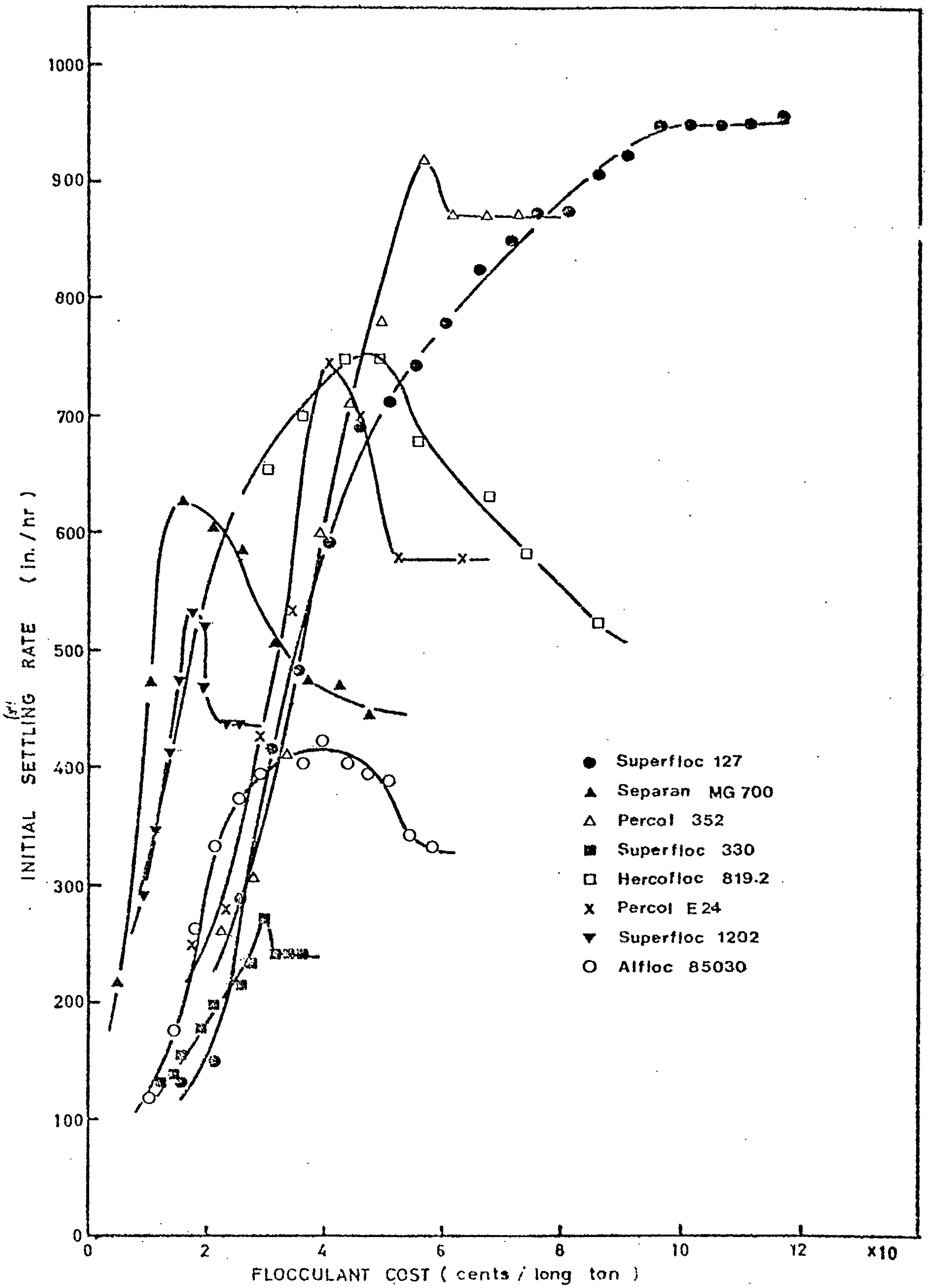


FIGURE 3: INITIAL SETTLING RATES VS FLOCCULANT COST FOR INDIVIDUAL FLOCCULANTS

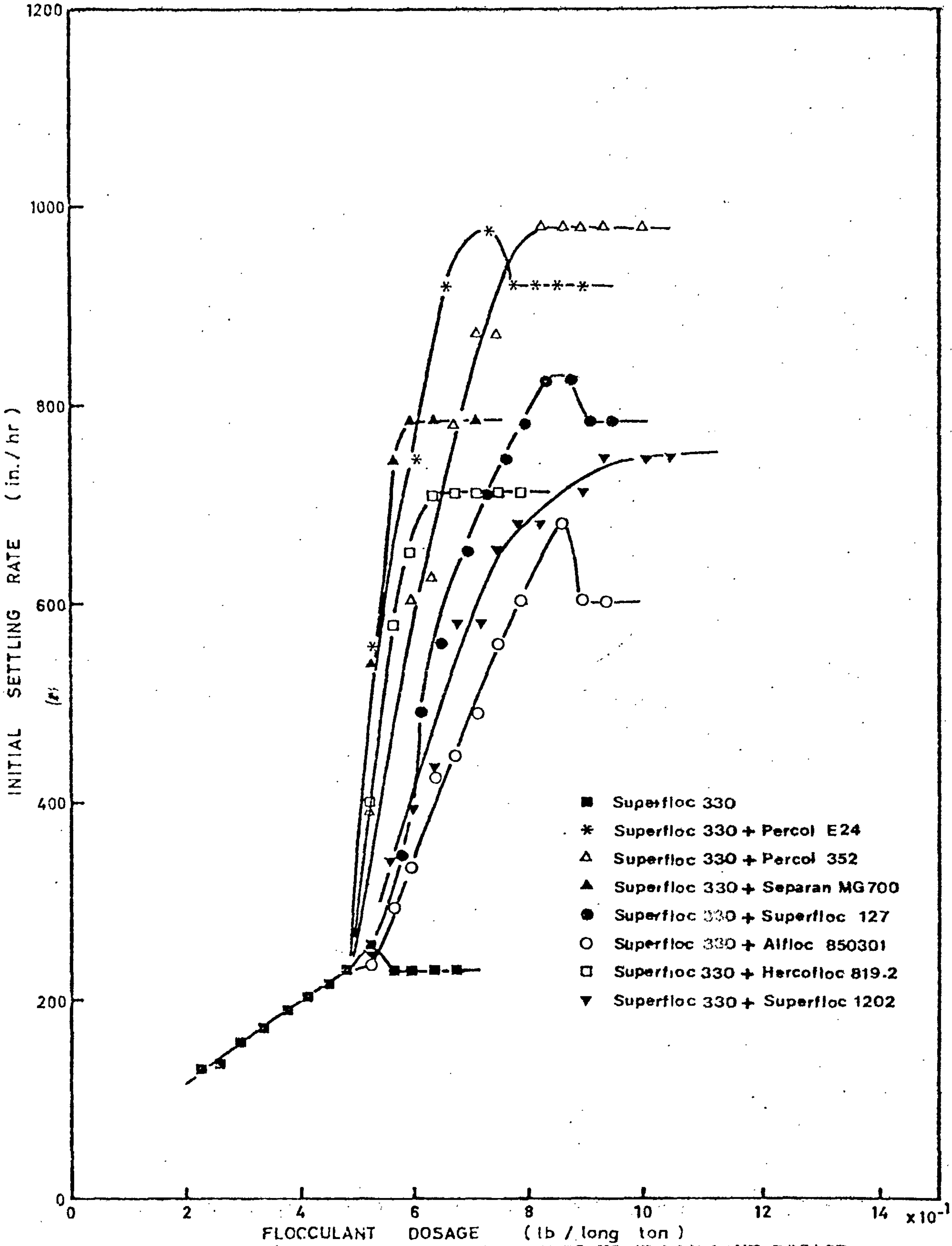


FIGURE 4: INITIAL SETTLING RATES VS FLOCCULANT DOSAGE FOR FLOCCULANT AID - FLOCCULANT COMBINATIONS

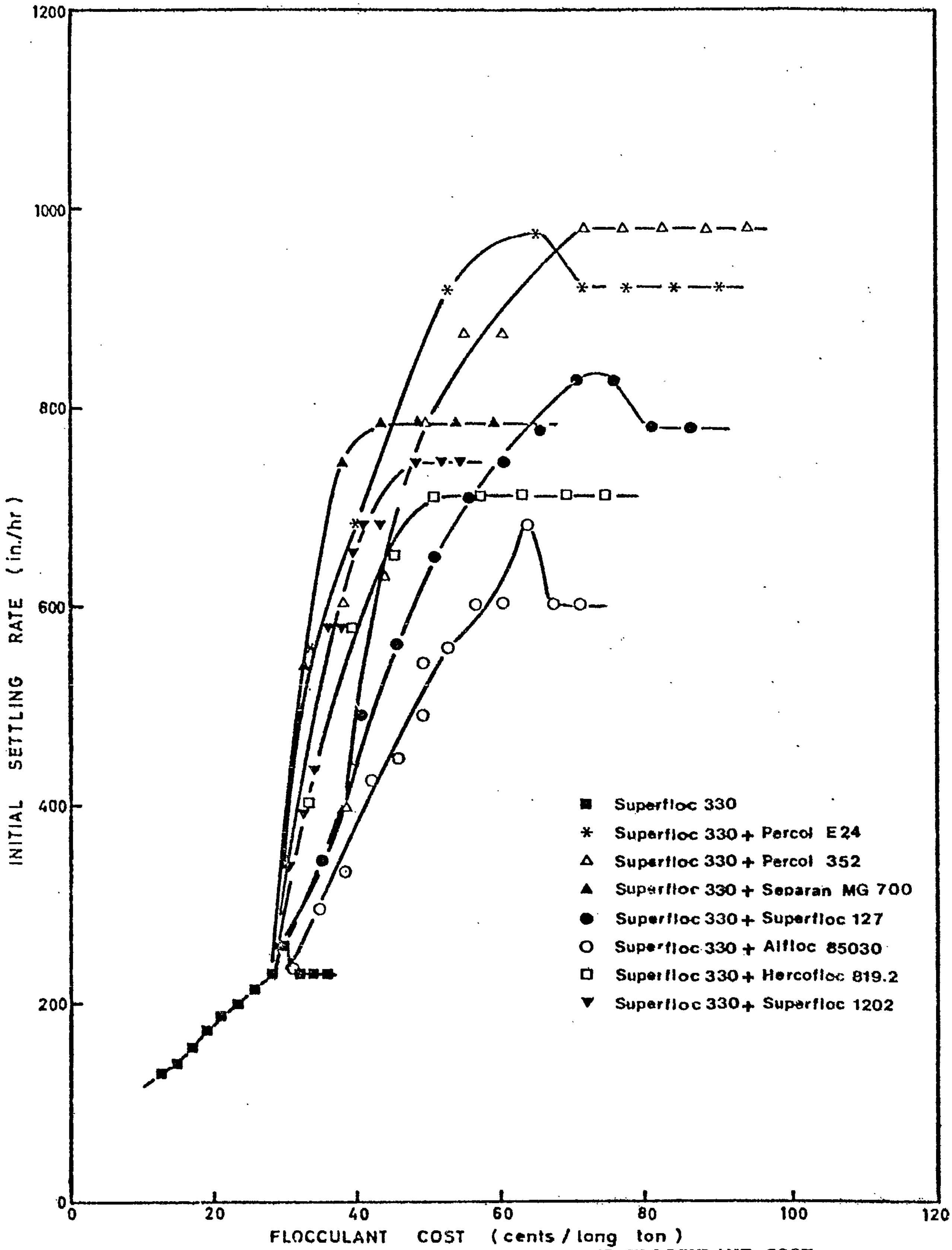


FIGURE 5: INITIAL SETTLING RATES VS FLOCCULANT COST

FOR FLOCCULANT AID - FLOCCULANT COMBINATIONS

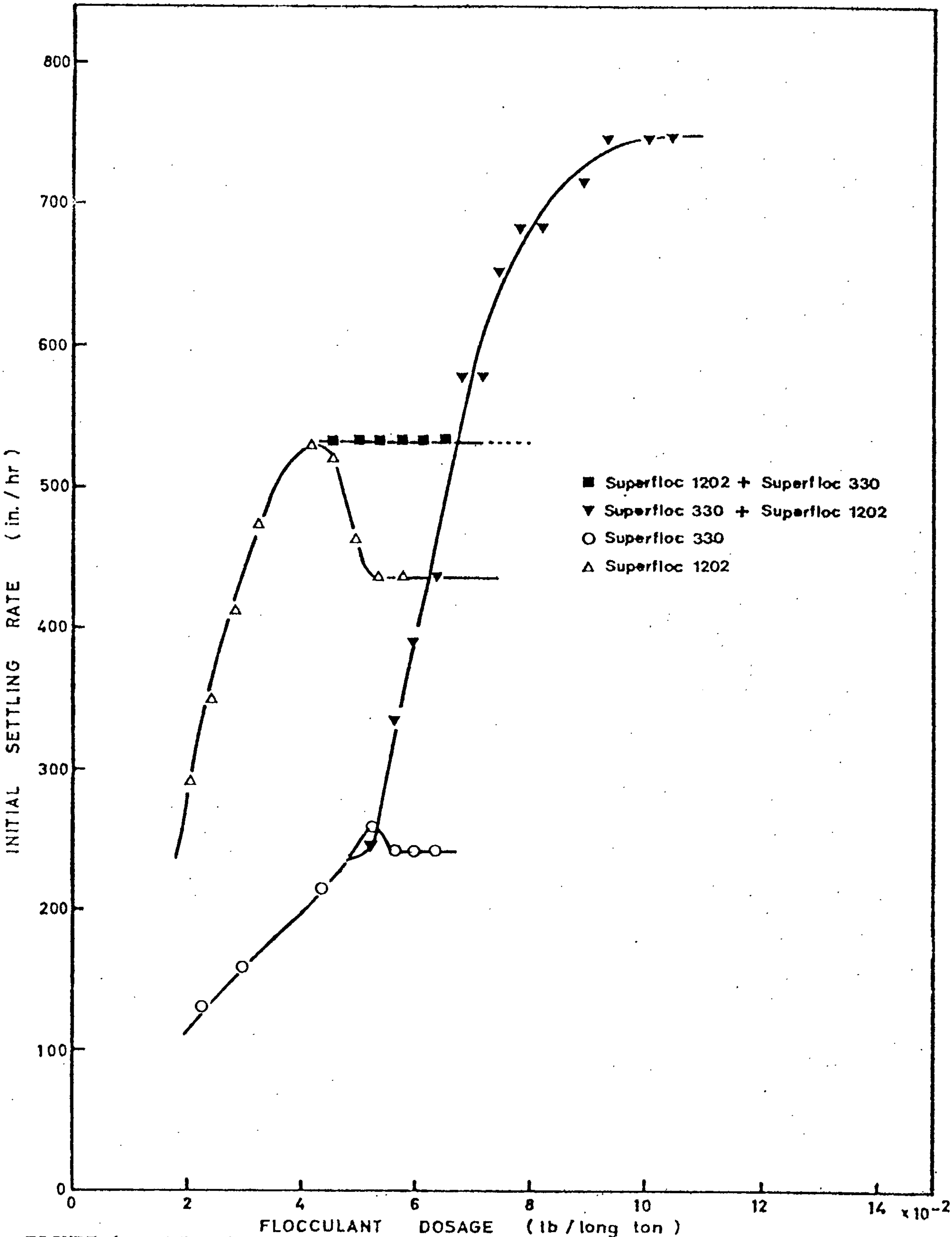


FIGURE 6: EFFECT OF SEQUENCE OF ADDITION OF SUPERFLOC 330 AND ALFLOC 1202
[INITIAL SETTLING RATE VS FLOCCULANT DOSAGE]

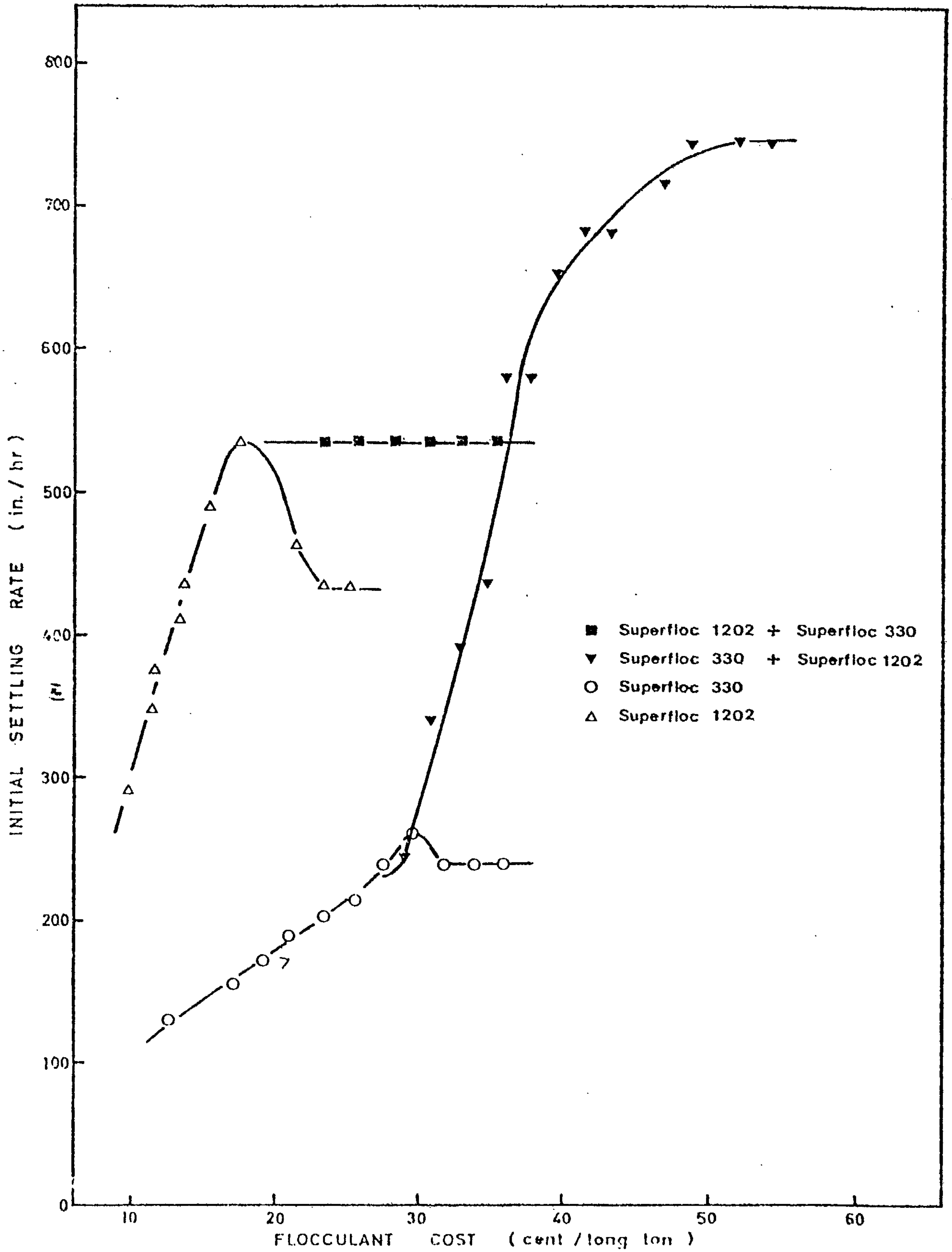


FIGURE 7: EFFECT OF SEQUENCE OF ADDITION OF SUPERFLOC 330 AND ALFLOC 1202
[INITIAL SETTLING RATE VS FLOCCULANT COST]

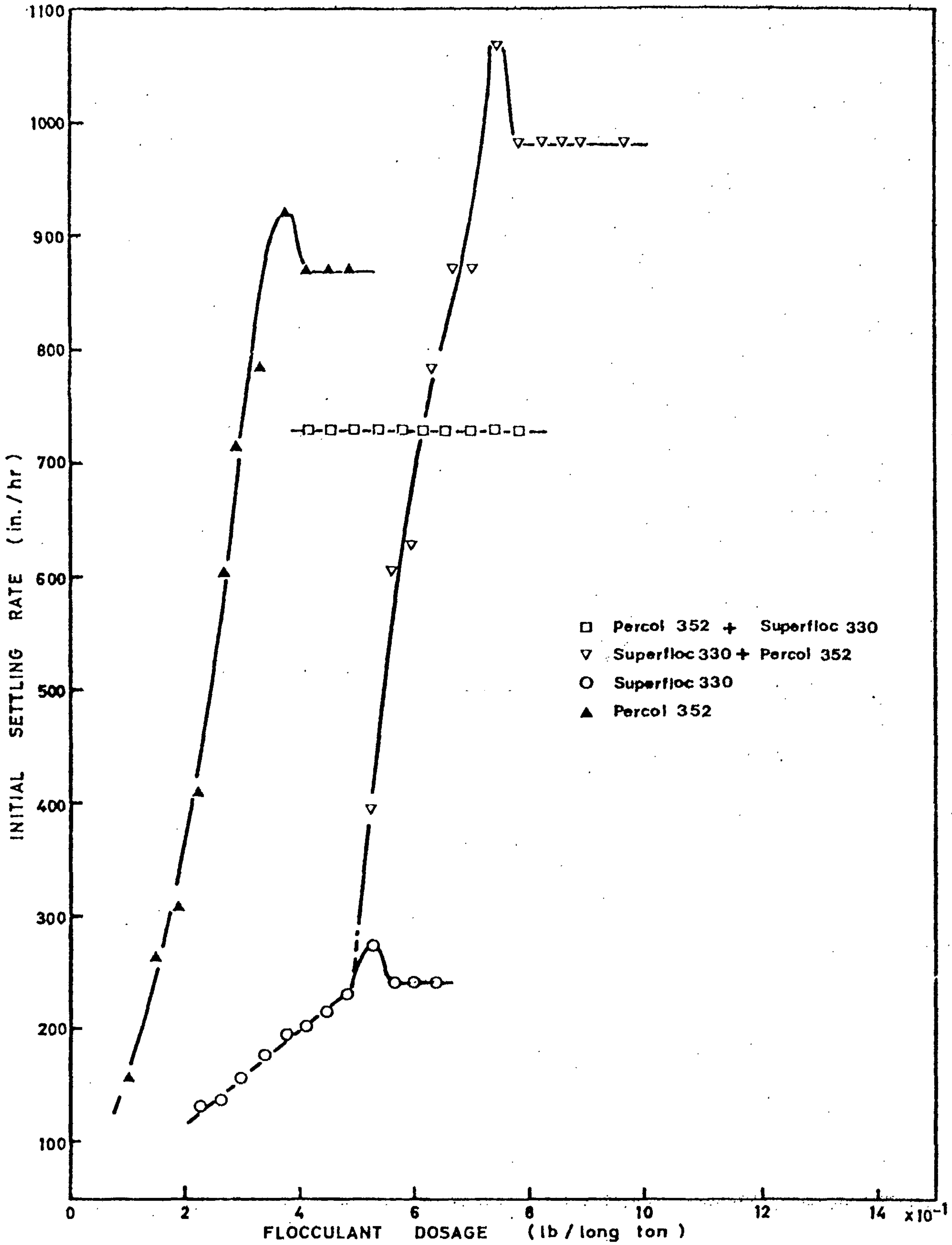


FIGURE 8: EFFECT OF SEQUENCE OF ADDITION OF SUPERFLOC 330 AND PERCOL 352
[INITIAL SETTLING RATE VS FLOCCULANT DOSAGE]

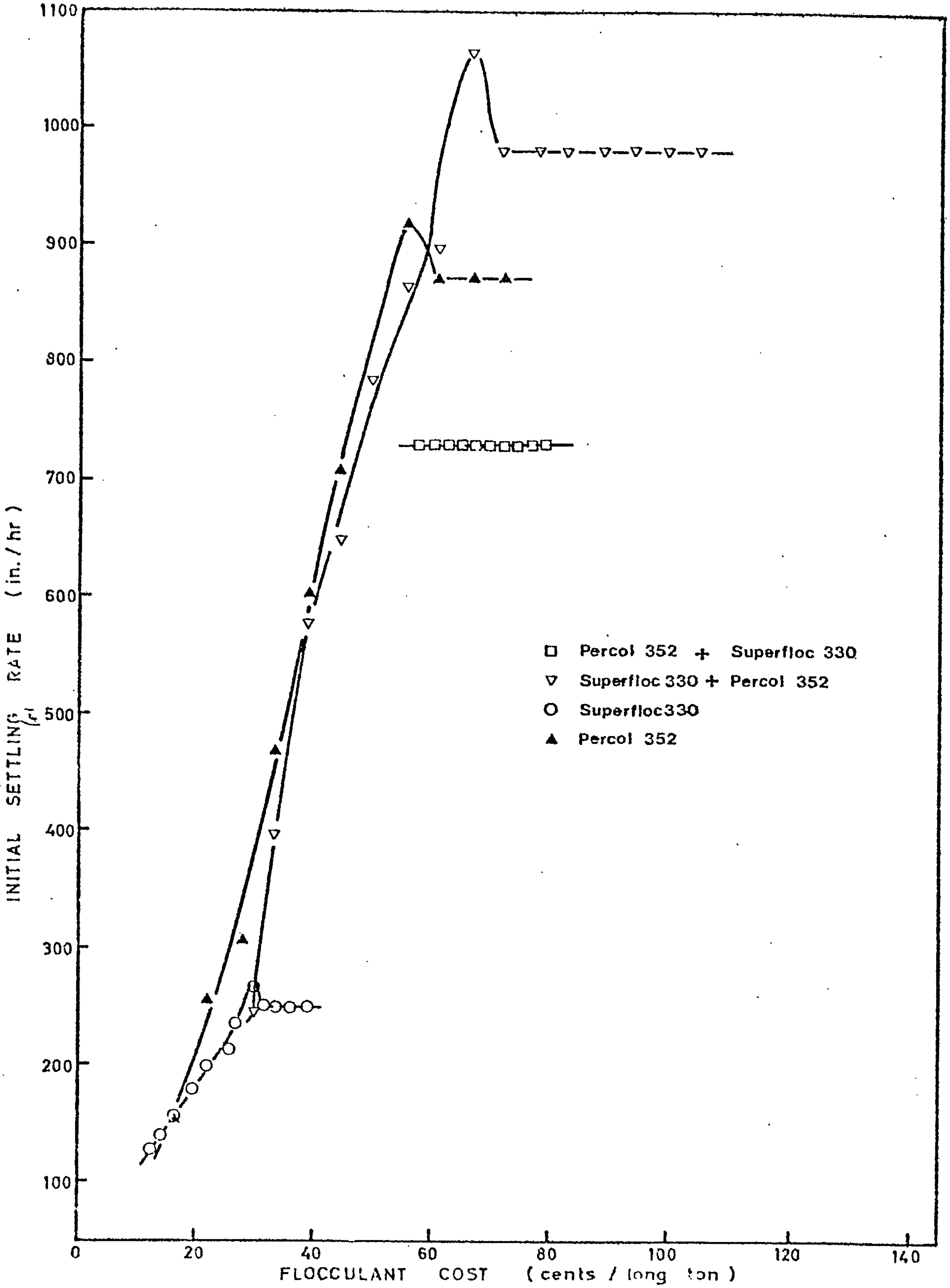


FIGURE 9: EFFECT OF SEQUENCE OF ADDITION OF SUPERFLOC 330 AND PERCOL 352 [INITIAL SETTLING RATE VS FLOCCULANT COST]