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A SYSTEMATIC APPROACH FOR FLOCCULANT
SELECTION AND EVALUATION

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A SYSTEMATIC APPROACH FOR FLOCCULANT
SELECTION AND EVALUATION

by

H.A. Hamza*

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ABSTRACT

Various factors affecting flocculation are discussed and their significance in the process is indicated. A systematic procedure of flocculant selection for a given application is proposed which includes characterization of the solid-liquid system and prescreening of commercially-available flocculants on the basis of the system determined criteria. A method of economic evaluation based on performance parameters is introduced.

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INTRODUCTION

Since their introduction in the early 1950's, synthetic organic flocculants of high molecular weight have replaced lime, alum, ferric sulphate, glue and starch in many solid-liquid applications.

The first group of synthetic water soluble polymers were hydrolyzed polyacrylonitriles from Cyanamid; AEROFLOC 548 Reagent and AEROFLOC 522 Reagent, followed by a polyacrylamide marketed under the trade name AEROFLOC 3000 Reagent. Dow introduced the 10% hydrolyzed, slightly anionic polyacrylamide SEPARAN NP10 in 1954.

Because of the high expectations for these newly developed flocculants and since so few were being marketed in the 1950's the process of selecting proper flocculants caused few difficulties. The increasing number of flocculants that have become available since the early 1960's however, has created problems in selection that can best be described by the following quotations.

"The foremost problem in studying flocculation in the laboratory has been to establish reproducible methods of comparing and evaluating the effectiveness of various reagents...In order to compare the data obtained in these various types of test, the physical nature of the flocculated system must be examined in some detail." - Link and Booth, 1960 (1)

"Experience confirms that there is no universally applicable flocculant. Every requirement must be examined and a decision taken on the results of tests using a range of flocculants...it should be remembered that each application should be examined individually, using various types of flocculants and assessed solely on the results obtained, supported if possible by full scale process trials." - Thomas, 1966 (2)

"Although synthetic polymeric flocculants have been in use in the mineral processing industry for about 15 years, their potentialities are not yet fully exploited, mainly because the mode of action of these substances is inadequately understood. While there is no mystery about the general mechanism of flocculation by polymers, prediction of the appropriate type of flocculant to employ with a particular mineral "slime" is largely guesswork when the relevant surface chemistry has not been

sufficiently elucidated. Considerable basic research will be needed before the present hit-or-miss methods of selecting a flocculant from the numerous proprietary products now available can be dispensed with." - Slater et al, 1969 (3).

"The evaluation of polymers as an aid in flocculation and clarification has traditionally been a difficult and time-consuming procedure because there has not been a suitable methodology available. Usually a large number of commercially-available products are examined in a polymer use optimization program designed to solve the problem at hand. On occasion the most readily available polymer has been used." - Huck and Le Clair, 1974 (4).

"High molecular weight polymers, e.g., polyacrylamides and polyamines, have been known as excellent flocculants for several decades. Their wide scale application to waste treatment however, is a relatively recent phenomenon. To exploit the rising demand, many new commercial flocculants have been introduced in the market place. The user is thus confronted and bewildered by a host of brand names with very little technical backup as to the nature of the flocculant and the methodology for their evaluation." - Benedek & Hamielec, 1974 (5).

"It is important to point out that not all waters can be treated with equal success with the same polymer or the same dosage...Therefore, pilot studies including jar tests and familiarization with the nature of polymers and past experiences are quite important." - Kawamura, 1977 (6).

These are but a few of many comments on the situation facing flocculant users today. This paper is mainly concerned with introducing a procedure that will reduce the amount of painstaking work associated with the selection of a proper flocculant for a given system.

FLOCCULATION AND SYSTEM VARIABLES

Three main groups of factors should be considered when dealing with flocculation i.e. those factors associated with the process of flocculation, those related to the characteristics of the solid-liquid system

and those related to the properties of the flocculant itself.

Flocculation

Flocculation and/or coagulation may be employed to overcome the forces which cause dispersion of suspended solids. La Mer and co-workers have differentiated between "coagulation" and "flocculation" and restricted use of the former term to cases where colloidal particles coalesce because of reduction or neutralization of the repulsive forces between particles. Coagulation may be achieved by the addition of inorganic cations, for instance Al^{+3} , as in aluminum sulphate (alum) or Fe^{+3} , as in ferric sulphate.

Flocculation may simply be defined as the grouping of dispersed particles into relatively stable aggregates. For the purpose of this paper, the bridging theory according to La Mer and co-workers (7) will be adopted to explain the mechanism of formation of these aggregates. Briefly, this theory stipulates that adsorption of a fraction of the suspended solid. The segments of the polymer molecule which remain extended into the suspension can promote flocculation by two mechanisms: (1) the extended segments of the polymer molecule are adsorbed on one or more additional particles; and/or (2) the extended segments of the polymer molecule interact with the extended segments of other similarly adsorbed polymer molecules. The mechanism of flocculation by bridging is shown schematically in Figure 1.

It is still being debated as to whether adsorption of the flocculant's active segments on a particle surface occurs by hydrogen bonding, chemisorption, electrolytic attraction or a combination of all three.

Characteristics of the Solid-liquid System

The properties of a system which have a bearing on its response to flocculants are as follows:

1. Pulp: density (% solids), zeta potential, temperature.
2. Solids: surface area, size distribution, specific gravity.
3. Liquid: pH, dissolved salts.

1. Properties of the pulp

Properties related to the pulp, such as % solids, zeta potential and temperature have a substantial effect on the flocculation process.

Percentage solids

There is a marked effect of percentage solids on flocculation as will be explained by reference to Figures 2 and 3. Figure 2 shows the typical settling behaviour of a flocculated pulp. Region (W) may be termed the induction zone and represents the time required for flocs to grow and for eddy currents resulting from agitation to subside. A constant-rate period, sometimes termed initial settling rate period exists in region (X) and as flocs continue to approach one another, the settling solids enter a "transition" zone (Y) where hindered settling prevails. Later, compaction or compression occurs as represented by zone (Z).

Percentage solids greatly influences the initial settling behaviour of a pulp i.e. region (X) of Figure 2. In Figure 3, the initial settling rate is shown as a function of solids concentration. A very dilute pulp (region (A)) undergoes an extended induction period and displays a diffuse interface between flocs and supernatant. In this case agitation is essential to increase the probability of collision between particles; otherwise, the likelihood for the extended segments of the partially adsorbed flocculant molecule to wrap themselves around the particle(s) to which they remain attached becomes higher. This condition may actually promote dispersion instead of flocculation with the flocculant molecule then acting as a protective coating.

Settling rate and interface identification do not present any problems in region (B) where, with higher solids concentration, the probability of particle collision is greater, yet crowding is not sufficient to greatly hinder settling. In the region of yet higher concentrations (C), a severe decrease in the settling rate is brought about by small increases in percentage solids. This may be caused by the gradual formation of a flocculant-particle network, which tends to collapse at a much slower rate than would individual particles under hindered settling conditions. Further increases in percentage solids will cause the pulp to enter into compression settling from the very start. (region (D))

It should be noted that the relative widths and slopes of the different regions of the curve in Figure 3 depend on the properties of the solid particles, the characteristics of the flocculant and the process conditions.

Pulp density is also expected to affect to some extent the optimum flocculant dosage and at a given polymer dosage the stability of the flocs during agitation. The stability increases with increasing pulp density since if the flocs become torn apart, the probability of recombination of the fragments is enhanced by the increased solids content.

Zeta potential

A double layer, commonly known as the electrical double layer surrounds each colloid particle suspended in liquid. As has been described by Kruyt (8) the electrical double layer (shown schematically in Figure 4 consists of three parts, going from the solid to the liquid phase:

- (1) potential-determining ions which may be regarded as part of the solid lattice;
- (2) counter-ions which are held directly against the surface in a region called the Stern layer;
- (3) counter-ions which form an atmosphere called the Gouy or diffuse layer in which the ion population density decreases exponentially with distance from the particle surface.

As stated by Verwey and Overbeek (9), the double layer has its origin in the distribution of potential-determining ions in solution.

When the solid and liquid move relative to one another, the electrical potential at the plane of shear (Stern plane) is called the zeta potential. This potential is smaller in absolute value than the surface or total potential and is a function not only of the total potential, but also of the total electrolyte concentration of the liquid, as shown in Figure 5. Various methods of measuring the electrokinetic behaviour of particles are listed in Table 1.

Temperature

Settling rates increase with increasing temperature because of concurrent decrease in viscosity of the liquid. Moreover, as shown in Figure 6, increased temperature tends to cause uncoiling of the tight configuration of the flocculant molecule associated with poor solvents but the effect is less on the extended configuration which forms in good

solvents (10). Temperature also has an effect on dissolving glue, starch, etc.

There does not appear to be any significant effect on adsorption. For example, temperatures as high as 70°C contribute little to the adsorption of polyacrylamide on montmorillonite (11).

2. Properties of suspended solids

Surface area, nature of the surface, size distribution and density of solids are interrelated and sometimes have a complex effect on the process of flocculation.

Particle size distribution and surface area

Only sporadic mention has been made of these factors in the literature as they affect flocculation. This was pointed out by Iler (12) in an article on the relationship of particle size of colloidal silica to the amount of polymer required for flocculation. He also found that for silica particles smaller than 40nm, the amount of quaternary ammonium-substituted methacrylate polymer required for sedimentation of unit weights varied inversely with the particle diameter, whereas for silica particles larger than this, the amount of flocculant varied inversely with the square of the diameter.

Specific gravity

Particles of high specific gravity would normally be expected to form flocs with a high settling rate. However, some materials, e.g. montmorillonite, because of their swelling nature will have a much reduced effective density in water. The settling rate is often determined by the nature of the floc porosity, etc., rather than the specific gravity of the individual particles forming the floc.

3. Properties of the liquid

Liquid properties such as pH, ionic strength and presence of electrolytes are complex in their effects since they produce simultaneous changes in the nature of the polymer as well as in the solid surface.

pH of the system

The pH of the system may affect flocculation in two ways. Firstly,

it may affect the stability of the suspension by creating an environment for reduction of the repulsive forces between particles hence allowing van der Waals forces of attraction to draw particles together. This is especially true where the particle charge may have its origin in the ionization of functional groups on the surface of the particles or in some cases, in the preferential adsorption of certain potential-determining ions from solution- (13).

Secondly, the pH of the suspension will have an effect on the flocculant molecule in solution, especially when the same water is used for dissolving the flocculant or diluting the flocculant solution. The degree of dissociation of the functional groups on the flocculant molecule and the chain configuration in solution are mainly affected. For instance the flocculating power of a partially hydrolyzed (anionic) polyacrylamide will be impaired in acidic media presumably because of the inhibiting effect that hydrogen ion has on the ionization of COOH groups (14). This in turn will tend to reduce the extension of the flocculant molecule (15). The more complete the hydrolysis of the polyacrylamide the more the molecules will coil-up in acid medium.

Anionic flocculants are not recommended for applications where pH is lower than 6.5 unless a high concentration of cations such as Ca^{+2} , Fe^{+3} , Al^{+3} etc. is present, in which case these flocculants could be effective down to pH 4.3 (16).

In neutral or alkaline media, hydrolyzed anionic polyacrylamide becomes stretched out and its flocculating properties are improved; e.g. Separan AP273 was found effective for application in an alkaline leach solution of pH 9.7 (17).

On the other hand the polyacrylamide polymer which is non-ionic (or slightly cationic in acidic media) is effective over a wide pH range and is found to be a powerful flocculant in acidic media e.g. Superfloc 16 was effective in treating an acid leach pulp of pH 2.35 (18). Cationic polyacrylamide-based flocculants are generally most effective at low pH conditions.

Dissolved salts

Dissolved salts influence the flocculation process in several

ways. They affect both the solid particle and the flocculant molecule and may have a separate effect on the flocculation process itself.

For example, in a suspension containing negatively charged particles it may be stated that:

- (i) increasing the ionic strength brings about a decrease in zeta potential;
- (ii) at equivalent concentrations, salts having higher valency cations reduce the zeta potential to the greatest extent;
- (iii) the effect of anions is relatively less important.

The effect of ions which are common to the crystal lattice and to the solution (e.g. H^+ and OH^- for clays) termed potential-determining ions, is much greater than that of all other ions (indifferent ions).

Apart from altering the particle surface or zeta potential, inorganic electrolytes reduce the effective surface area of the solids by coagulating them so that consumption (i.e. optimum dosage of polymer subsequently added) may often be reduced. The conjoint use of inorganic salts such as lime, calcium chloride and aluminum sulphate with water-soluble polymers has resulted in improvements in settling rate and clarity and savings on the quantity of flocculant required, especially in suspensions of low solids content.

The presence of ions in the bulk of the solution is also considered to be one of the factors affecting the configuration of the flocculant molecule in solution. Polyelectrolytes become extended as a result of mutual repulsion of co-ions along the chain of the molecule. This mutual repulsion is reduced when the co-ions are shielded by the presence of oppositely-charged ions around them and consequently extension of the polymer chain will be impaired. This effect is shown schematically in Figure 7. Net charge of the polymer will be affected by ionic valences in accordance with the Schulze-Hardy rule.

It has been reported (19) that in the presence of calcium or magnesium ions, polyacrylates such as B.T.I. A-130 tend to form insoluble salts whereas the salts of partially anionic polyacrylamides were found to

be soluble. Magnesium sulphate ($MgSO_4$) was reported to improve flocculation by reducing repulsive forces but detrimental effects observed for excess $MgSO_4$ were attributed to the adverse influence of this salt on the polymer chains in solution. A few ppm of Mg^{+2} in solution have been said to greatly hinder the effectiveness of polyacrylates (16).

It has also been claimed that di- or tri-ions of opposite charge to the surface may function as "activators" to promote the attachment of polymeric ions of like charge to the surface, analogous to flotation (20).

Flocculants and Coagulants

Structure and performance

Inorganic substances such as lime, alum, ferric sulphate, etc., have long been known as coagulating agents and function by reducing the negative zeta potential of the particles. Excessive addition of these reagents could result in redispersion.

Natural polymers such as starch and its derivatives were considered a major breakthrough when first introduced as flocculants but they were later superseded by the synthetic organic polymers.

Polyacrylamides and their hydrolysis or copolymerization products are the most widely used synthetic organic flocculants. They function in the manner described previously i.e., by adsorption on active sites of the surface of the solid particle followed by bridging between individual particles. These and the other synthetic organic compounds may be broadly classified according to their charge: anionic, nonionic or cationic. As seen from Figures (8a) and (8b), the nature of the charge is dependent upon the functional group(s) associated with the polymer chain.

Cationics are frequently based on polyvinyl pyridine or polyethyleneimine compounds although some cationic derivatives of polyacrylamide are available. Polyacrylamide itself is nonionic (slightly cationic in acidic media). Adsorption of these polymer molecules on the surface of solid particles may involve several types of bonding, according to the nature of the surface and the functional groups of the polymer.

Efficiency of a linear polymer as a flocculant will be increased by increasing the molecular weight since a longer chain will be able to

bridge more particles. The efficiency will also be influenced by the configuration assumed by the polymer chains in solution which, as described previously, is affected by pH and the concentration of ions in the solution.

The sign and proportion of ionic functional groups on the polymer molecule determine its activity as a flocculant. For instance, a high proportion of anionic groups will inhibit adsorption of the polymer in a suspension composed largely of negatively charged particles. The same is true when cationic flocculants are added to suspensions containing positively charged particles.

Solubility

Molecules of solid polymers are held together by van der Waals forces and in some cases by hydrogen bonding or interaction of polar groups. Forces between molecules increase with molecular size and in the case of linear molecules, with their length.

In a given solvent at a particular temperature, the solubility of a polymer will decrease with increasing molecular weight (chain length in linear molecules). Cross-linking and crystallinity will greatly hinder or eliminate solubility.

The random coil model which assumes a highly kinked and twisted chain is adopted here for the configuration of the polymer molecule in solution. In a good solvent, the secondary forces between polymer segments and solvent molecules are strong and the polymer molecules assume a spread-out configuration in solution (Figure 6). In a poor solvent, attractive forces between segments are dominant and the chain will ball-up tightly.

In dissolving solid polymers, it is essential to wet and disperse individual particles very quickly. Otherwise, "fisheyes", which are partly dissolved aggregates of flocculant molecules and which serve no useful purpose in flocculation will occur.

The hygroscopic nature of many of the solid flocculants necessitates precautions in handling and storage; many have a limited shelf life even when properly stored. The useful life of flocculants in solution, which decreases with lower concentration, is generally limited to a few days and in the case of some cationics to a few hours.

FLOCCULANT EVALUATION

Prescreening (Preselecting)

Having determined the characteristics of the suspension to be flocculated, the next step of a proposed selection procedure is to choose a limited number of likely flocculants out of the broad range of commercially-available products. The process of prescreening may be carried out by reference to the Index of Commercial Flocculants (21) wherein flocculant characteristics, prices, operating and process conditions have been compiled.

The information contained in the Index has been gathered from four major sources: a) published and unpublished information from flocculant manufacturers, b) laboratory characterization of flocculants, c) experience gained from applying flocculants to a variety of industrial problems and d) experience of other investigators and the technical literature.

Many gaps exist in the present edition of the above Index, but these gaps will be gradually filled as new data become available for future editions. It is anticipated that information will ultimately be stored in a national computerized data system which will enable operators to obtain a list of suitable flocculants, based on their effluent characteristics. Tied in with computerized on-line plant control to detect major variations in effluent streams, this data system will be useful as a means of finding suitable reagents.

For a given effluent for which flocculation is sought, the Index of Commercial Flocculants permits rapid elimination of those flocculants which are unlikely to perform well and thus minimizes the number of flocculants to be evaluated more thoroughly.

Bench testing of the prescreened flocculants

Those flocculants found to be promising in the previous step require further screening by bench testing to determine their relative effectiveness for the effluent in question.

The parameter(s) chosen as the basis for the bench tests will depend on the unit operation which will follow flocculation. Settling rate is the parameter most commonly chosen, as this will yield information for either clarifying or thickening operations if combined with clarity of the supernatant or compaction of the sediment. For filtration applications, the sedimented or total flocculated suspension has to be tested for permeability and/or filtration rate.

Evaluation of test results

Results obtained from bench tests are tabulated in the form illustrated in Table 2: Columns 1-6 contain descriptive information on the flocculant; columns 7-13 are used for data obtained from bench tests. The cost-performance index in column 14 is designed as a measure of comparative performance of the possible flocculants selected for this application. In general, the cost-performance index is a function of the variables shown in Table 2. A number of these are discussed below.

Optimum flocculant dosage

With increasing polymer dosage, a suspension passes from a dispersed state to progressively increased states of aggregation, with concurrent increase in settling rate. As flocculant continues to be added to the system, an increasing number of adsorption sites on the particles are occupied and vacant sites for bridging become so sparse that the suspension may eventually revert to a dispersed state. Typical settling rate-dosage curves are shown in Figure 9; curve 2 indicates partial reversion to a dispersed state.

The optimum flocculant dosage (point X, Figure 9) may be defined as the dosage at which additional increments of flocculant yield smaller increases or decreases in the settling rate. Both the optimum dosage and degree of flocculation are functions of many variables, notably the specific surface area of the solids, the molecular weight of the flocculant and the configuration of the flocculant molecule in solution.

Solubility of the flocculant

Because of the cost of preparation, the ease with which the flocculant goes into solution is one of the factors which should be considered

in flocculant selection.

An arbitrary scale such as shown in Table 3 is useful to rate flocculant solubility; from easily dissolved flocculants, including liquid flocculants (requiring less than 1/2 hour of preparation) to the most difficult flocculants (requiring 4 hours or more). Very long dissolution time may prohibit the use of certain flocculants.

Handling ability - liquid vs solid flocculants

From a handling point of view, liquid flocculants have the following advantages over solid flocculants: they require less manual labour, they dissolve more quickly and they present no dust problems.

Solid flocculants have the following advantages: they are more stable. For example, assuming suitable storage conditions, solid polymers can be stored for one year or more with no detrimental effect whereas liquid polymers generally have a shelf life of a few months and may freeze during shipping and storage. Solid flocculants are also more effective per unit weight.

Cost-performance index (CPI)

For industrial purposes, the rating of flocculants should be based on economic as well as technical factors. In order to properly evaluate the relative performance of flocculants, values and weights must be assigned to the variables shown in Table 2. Other relevant factors such as floc shear resistance, permeability, filtration rate etc., may also have to be taken into account.

Ideally a flocculant should:

- a) promote rapid settling
- b) produce clarified supernatant
- c) give good thickening properties
- d) create flocs of high shear resistance
- e) enhance filtration rate
- f) dissolve easily
- g) thoroughly and readily disperse into suspension
- h) be convenient to store and handle
- i) be inexpensive
- j) be non-toxic

No commercially-available flocculant possesses all these properties and in any case many applications would not require all. However, each property may be essential for efficient operation of a particular process.

Generally the cost-performance index is a relationship of the following form:

$$\text{CPI} = f(R, S, C \dots)$$

where R, S, C, etc. are the weighted relevant factors.

Size of existing facilities, profit margin, pollution standards, etc. are other factors which may further limit flocculant selection.

PRACTICAL CONSIDERATIONS

Sample preparation

"Live" effluent samples i.e., fresh representative samples from the plant should be used for bench tests. Care should be taken in splitting these samples to obtain proper aliquots. Standardized procedures in the preparation and addition of the flocculant as well as in handling of the effluent after flocculation are essential.

It has been consistently found that results are influenced by the time elapsed between obtaining samples from an operation and running of bench tests. Samples should be tested as soon as possible after collection.

Flocculant preparation and addition

The higher the molecular weight of the polymer, the more difficult it is to obtain solutions of appreciable concentration. Therefore, in comparing flocculants, the relative concentration and ease of preparation should be considered.

One can usually obtain higher concentrations when dissolving low molecular weight polymers, but this advantage would be offset by the higher dosages required for flocculation.

It is good practice to add flocculant as a dilute solution to the effluent; if the solution is too concentrated, the flocculant will be

rapidly adsorbed on only a portion of the solids before uniform mixing can be achieved. As flocculation is essentially an irreversible process, the flocculant added will not be utilized efficiently. In practice it is found that up to a certain dosage most of the flocculant is adsorbed onto the solid particles. As more flocculant is added, unadsorbed or residual flocculant builds up in solution. The distribution of flocculant between solid and solution is shown in Figure 10. Environmental as well as economic considerations, make it essential to operate at minimum flocculant dosage requirements.

Efficient utilization is best achieved under ideal mixing conditions, whereby uniform distribution of the flocculant over the solid particles is achieved almost instantaneously. Floccs should be removed from the mixing zone as soon as possible after their formation to prevent breakage. Any mixing method must be a compromise between thoroughness and shortness of mixing time.

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TABLE 1

Methods of Measuring
Electrokinetic Effects

State of Solid Surface Potential	Stationary (e.g., a wall or apparatus surface)	Moving (e.g. a colloidal particle)
Applied	Electroosmosis	Electrophoresis
Induced	Streaming Potential	Sedimentation Potential

TABLE 2
 Cost-performance Evaluation of Various Flocculants

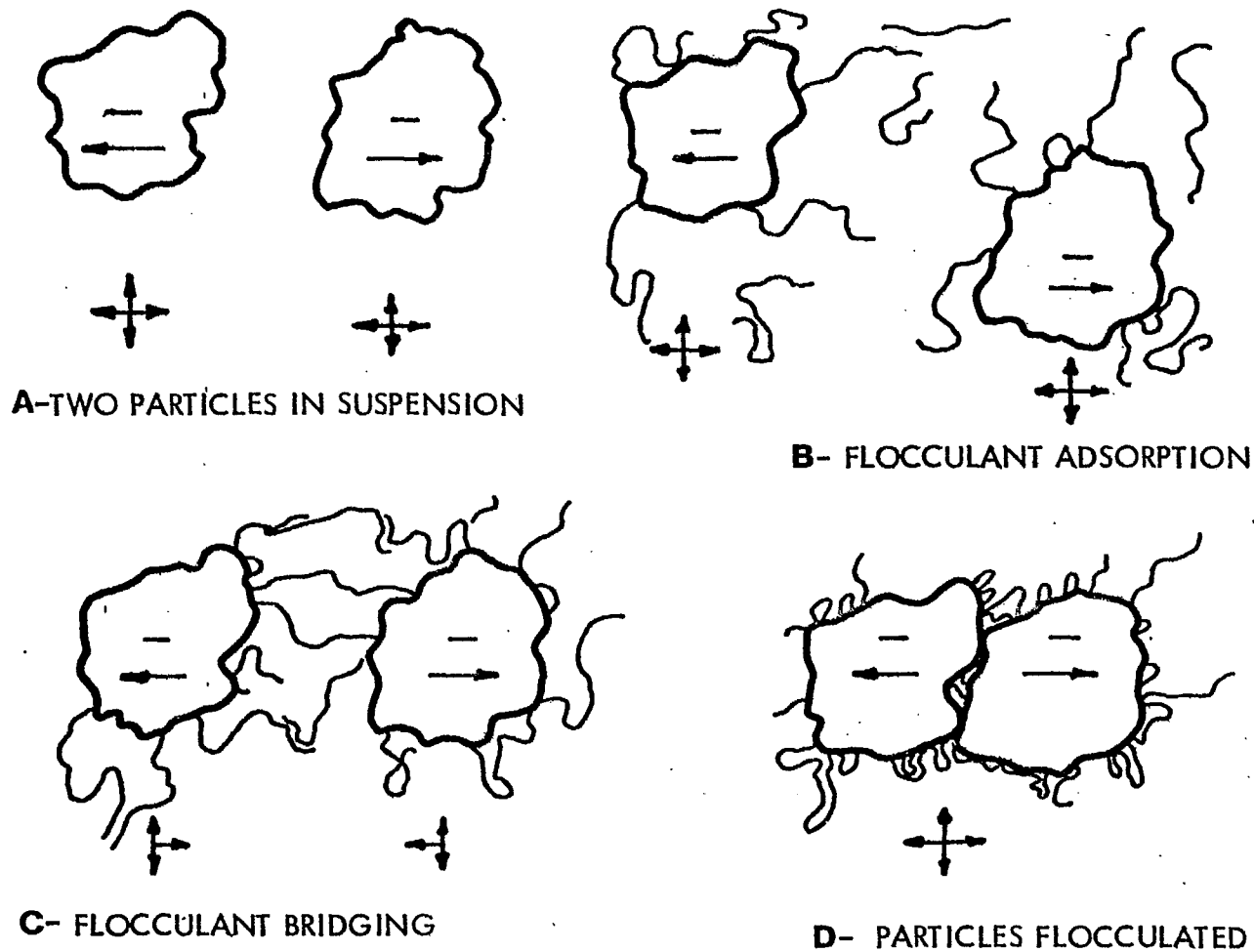
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
FLOCCULANT TRADE NAME	SOURCE	PHYSICAL NATURE	IONIC CHARGE	COMPOSITION	PRICE PER POUND OF FLOCCULANT (\$)	OPTIMUM DOSAGE IN LBS. PER TON OR PER 1,000 GALLONS	FLOCCULANT COST PER TON SOLIDS OR 1,000 GALLONS OF EFFLUENT TREATED	SOLUBILITY*	SHIPPING & STORAGE SHELF LIFE FEEDING & METERING ABILITY **	HANDLING FEEDING & METERING ABILITY **	INITIAL SETTLING RATE *** IN in./hr	CLARITY	COMPACTION RATIO	COST PERFORMANCE INDEX (CPI)
WEIGHTING FACTORS ****														
X	X.Co.	Solid	Nonionic	PAM	.80-1.40	0.20	.22				80			
Y	Y.Co.	Solid	Anionic	PAM	1.00-1.60	0.12	.16				120			
Z	Z.Co.	Liquid	Cationic	PAM	.50-.80	0.30	.20				20			

* Arbitrary scale as suggested as shown in Table 3

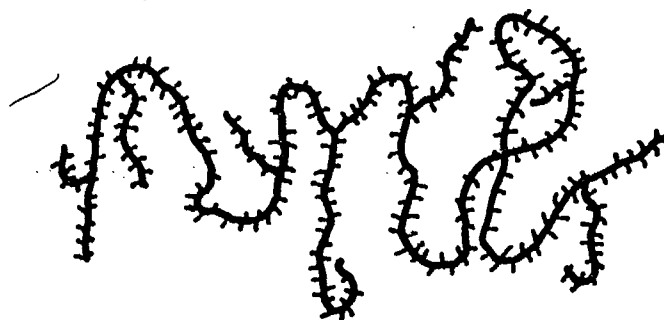
** Arbitrary scale

*** See Figure 2, region X

**** Weightings could be determined according to the relative importance of each factor.



MECHANISM OF FLOCCULATION BY BRIDGING



SCHMATIC OF A FLOCCULANT MOLECULE

Figure 1 - Bridging Model (Top) and Schematic of Flocculant Molecule (Bottom)

TABLE 3

Flocculant Solubility Factor
(Arbitrary Scale)

	Time For Complete Dissolution (Hrs)	Weight Factor
Very High (VH)	1/2	1
High (H)	1/2 - 1	2
Medium (M)	1 - 2	3
Low (L)	2 - 3	4
Very Low (VL)	> 3	5

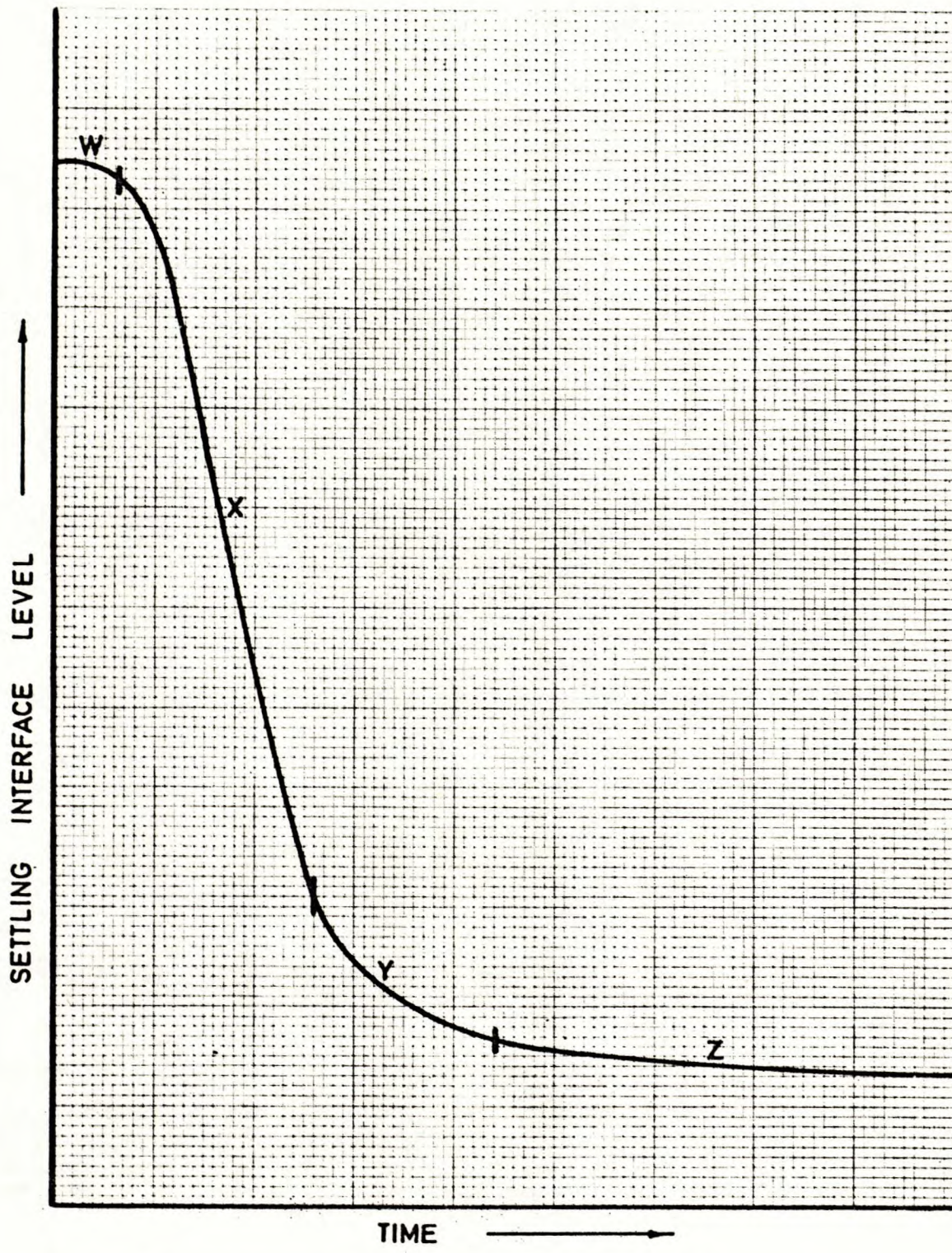


Figure 2 - A Typical Settling Curve for a Suspension Interface Level vs Time

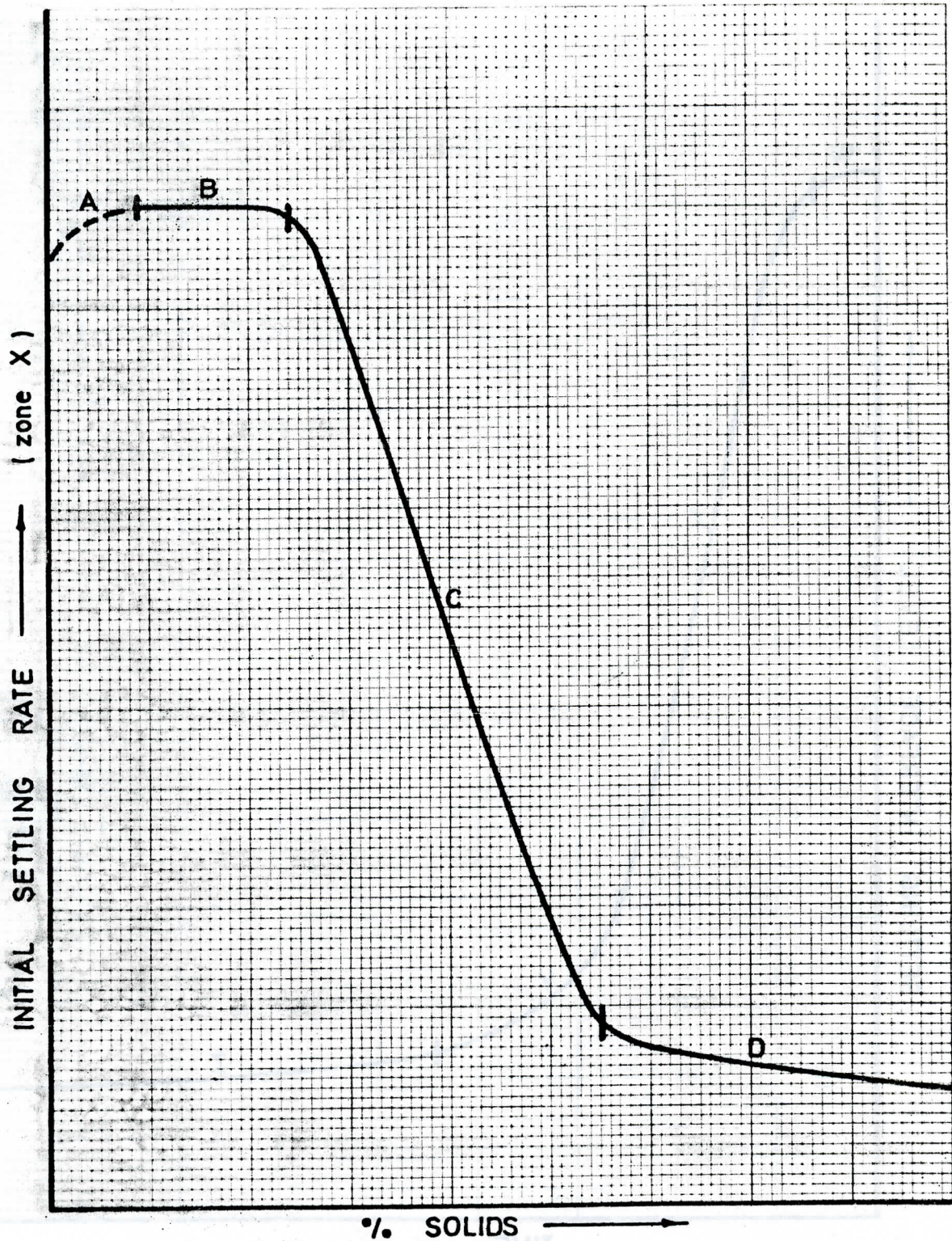
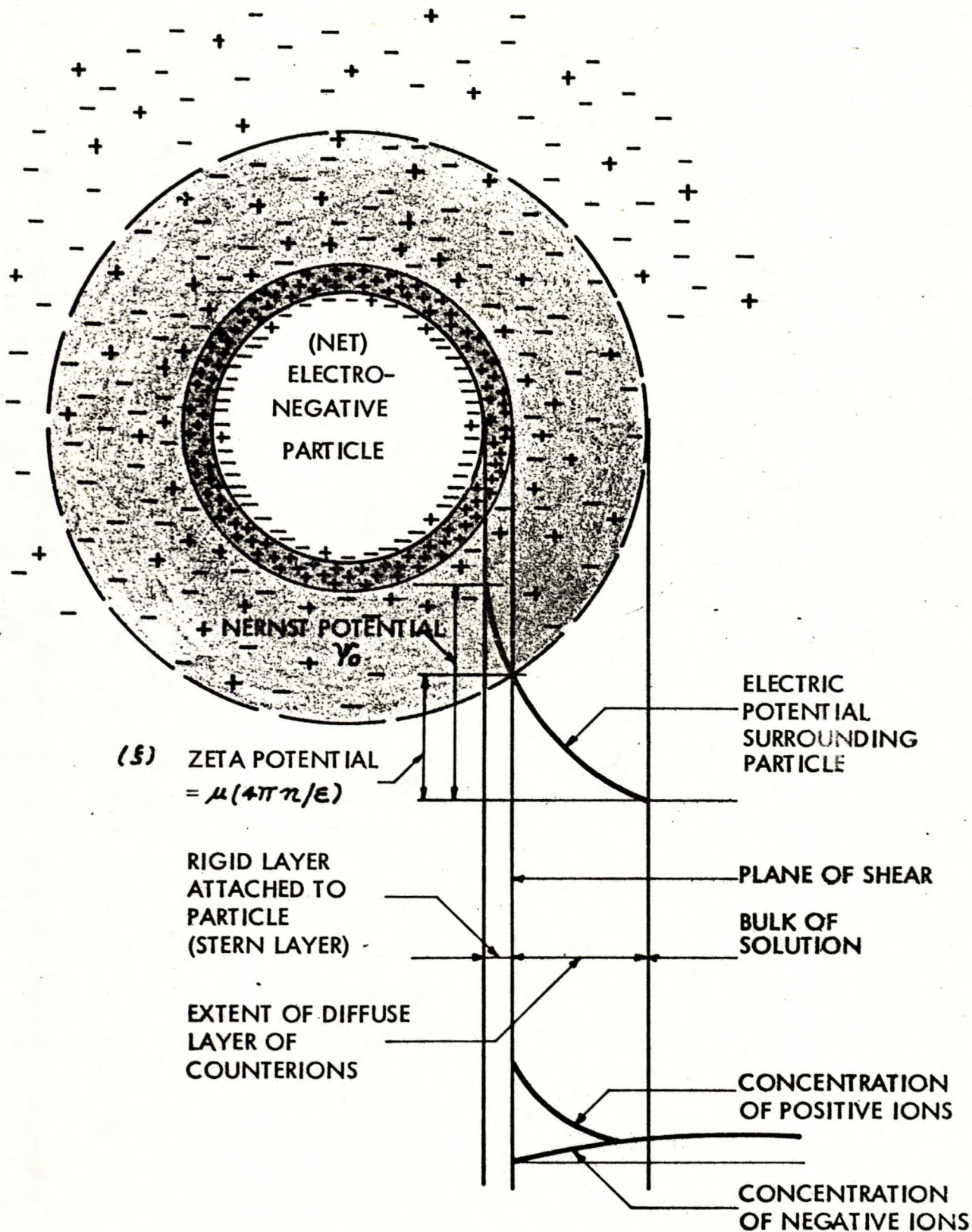


Figure 3 - Effect of Percent Solids in the Pulp on Initial Settling Rate



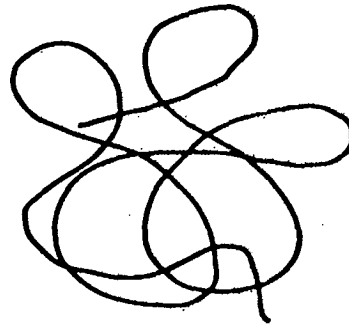
CONCEPT OF THE ZETA POTENTIAL

Figure 4 - The Electrical Double Layer Surrounding a Particle Suspended in Liquid

FLOCCULANT MOLECULE
IN SOLUTION



POOR
SOLVENT



GOOD
SOLVENT

→
TEMP. EFFECT

Figure 5 - Effect of Solvent and Temperature
on Configuration of Flocculant Molecule in Solution

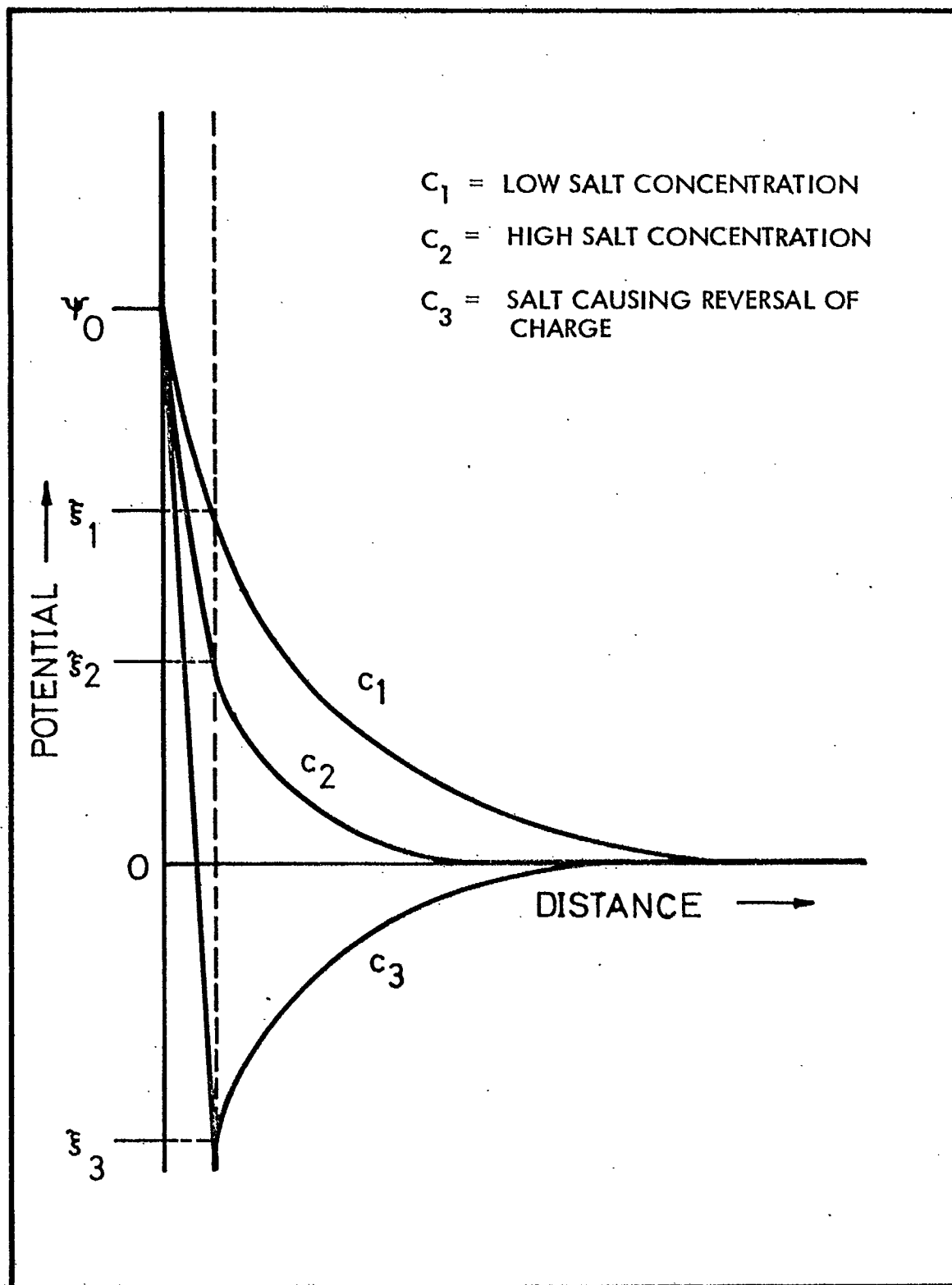


Figure 6 - Effect of Salt Concentration on Zeta Potential

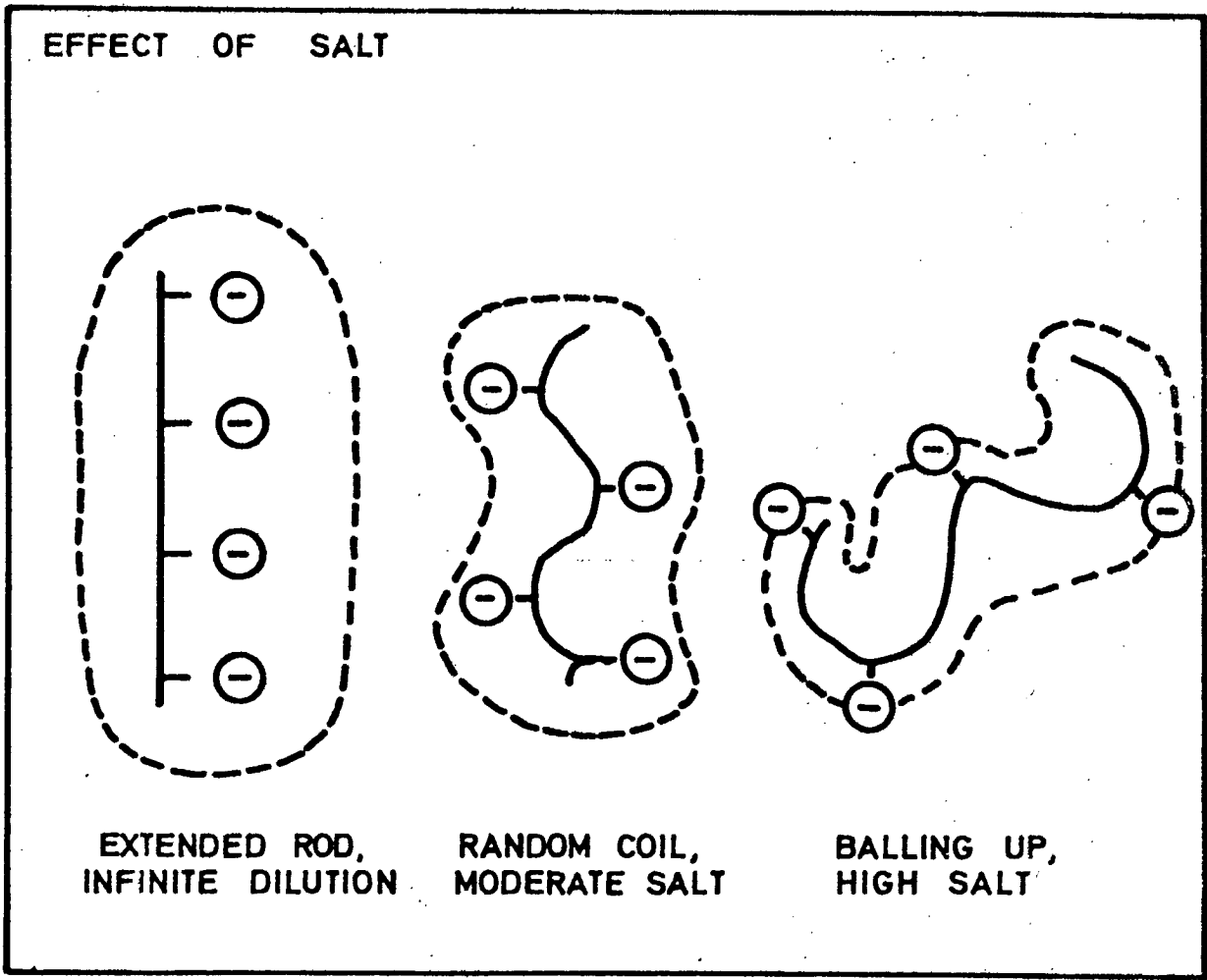
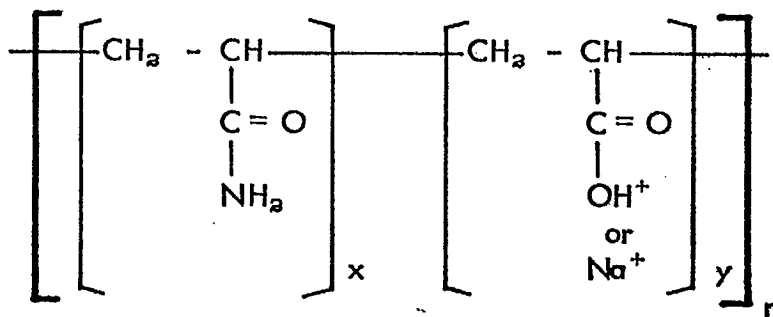


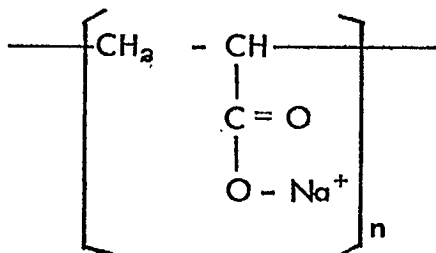
Figure 7 - Effect of Salt Concentration on Configuration of Flocculant Molecule - From Priesing, C.P. (22)

POLYACRYLAMIDE
PARTIALLY HYDROLYZED
OR
POLYACRYLATES



e.g., SEPARAN NP10 $y = 10\%$
SEPARAN NP20 $y = 20\%$
SEPARAN NP30 $y = 30\%$

POLYACRYLATES



POLYMETHACRYLATES

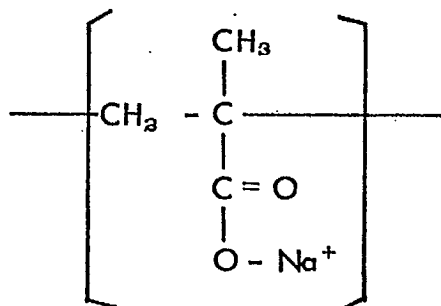
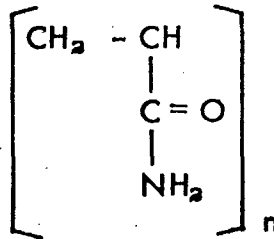
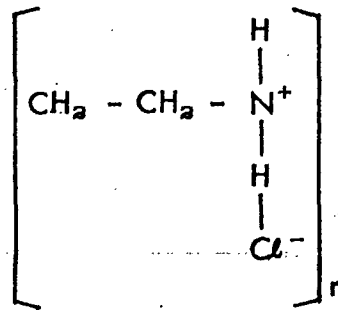


Figure 8(a): Structure of Synthetic Organic Flocculants
Typical Anionics

NONIONIC
POLYACRYLAMIDE



CATIONIC
POLYETHYLENEIMINE



CATIONIC
POLYACRYLAMIDE

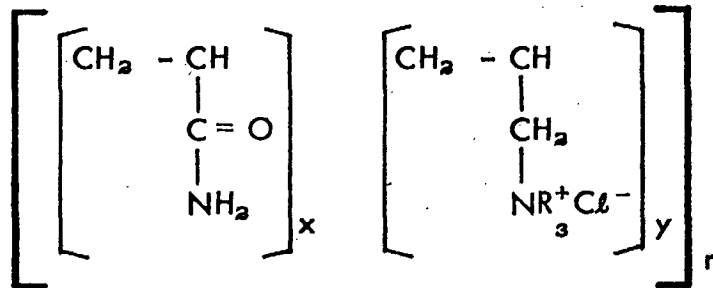


Figure 8(b): Structure of Synthetic Organic Flocculants
Typical Nonionic and Cationics

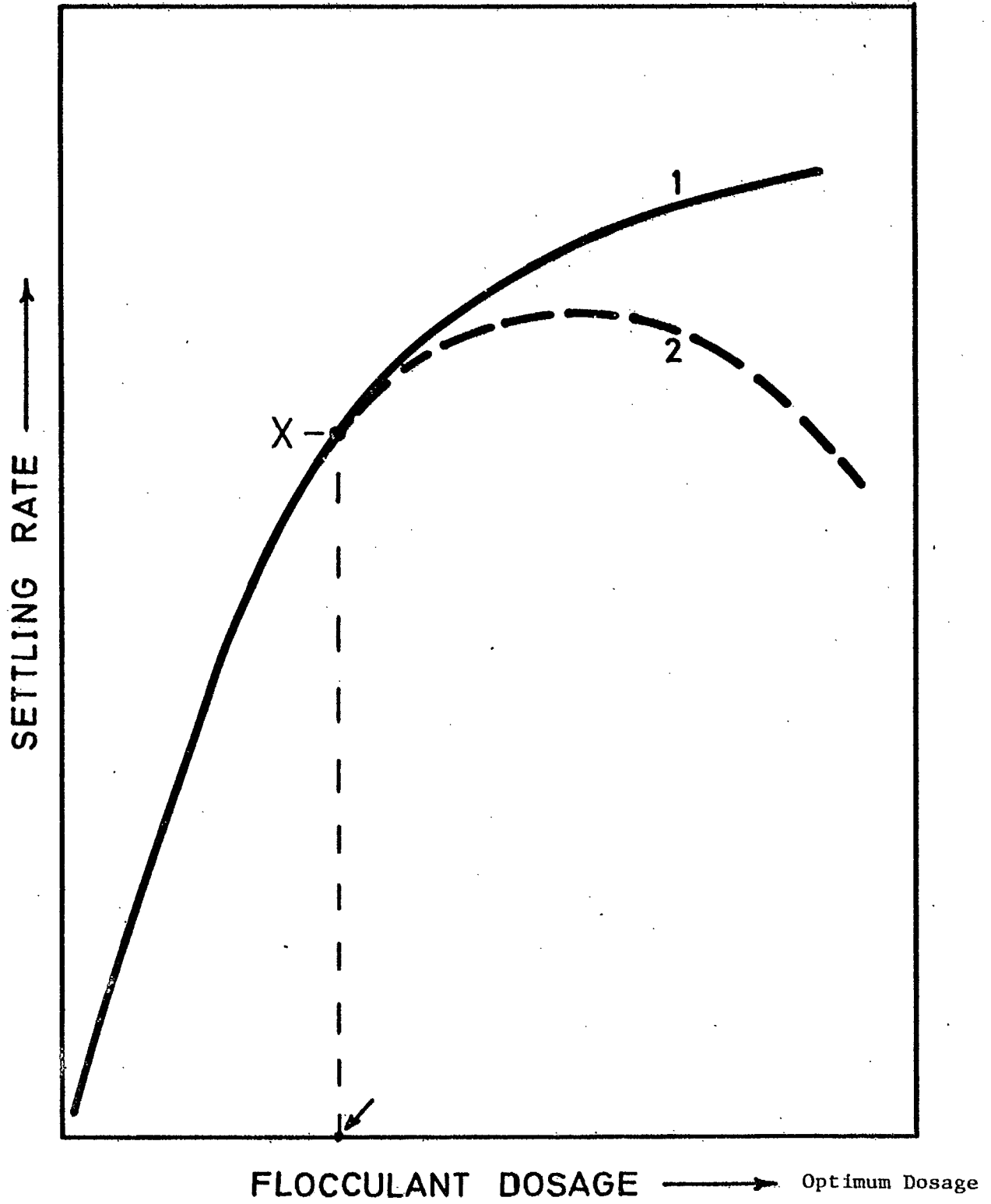


Figure 9 - Typical Settling Rate - Dosage Curves

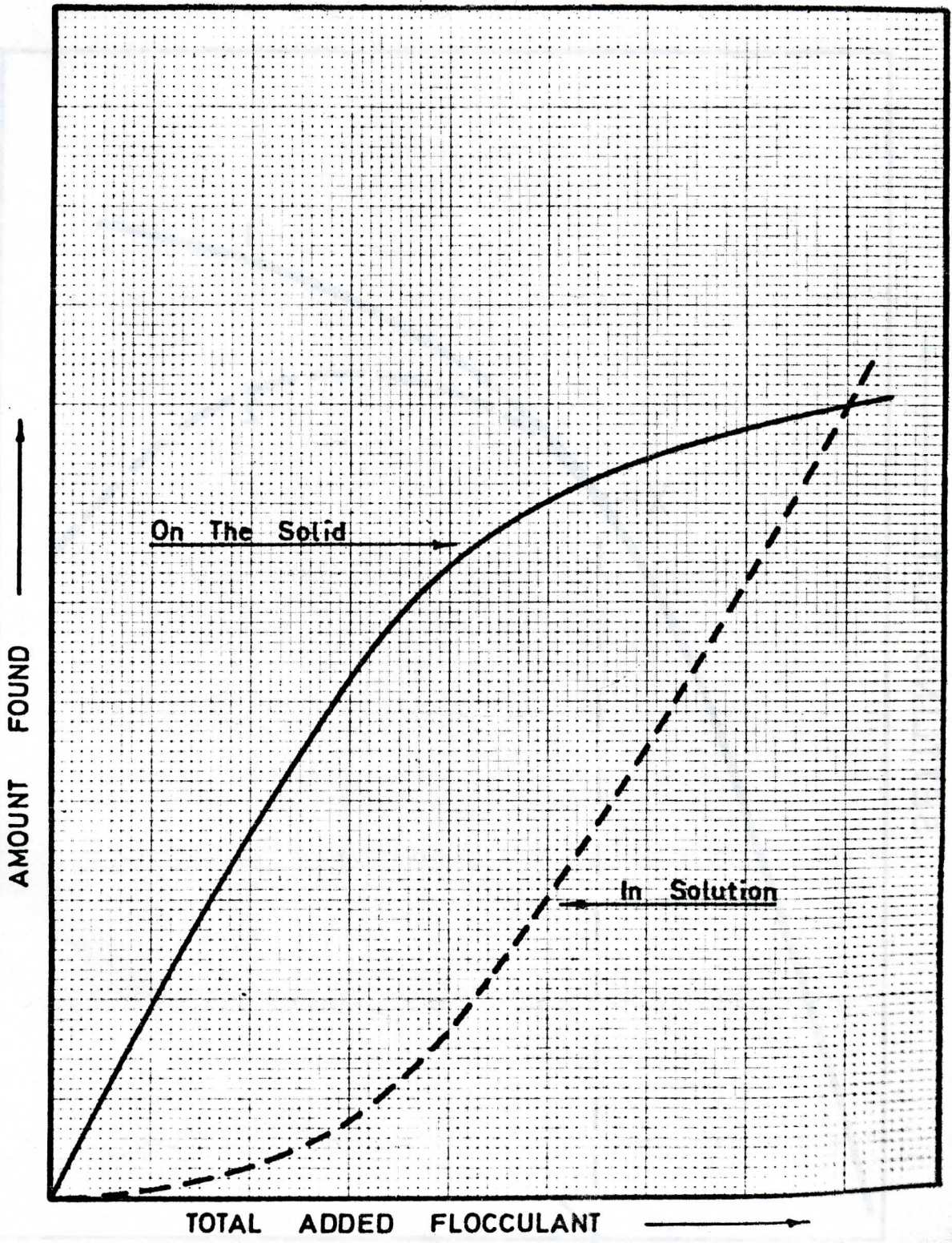


Figure 10 - Distribution of Flocculant Added to Pulp