DEWATERING CHARACTERISTICS OF WASTE WATER TREATMENT SLUDGES

AND

EFFECT OF FLOCCULANTS

A DISSERTATION

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BY

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the Dissertation entitled " **DEWATERING CHARACTERISTICS OF WASTE WATER TREATMENT SLUDGES AND EFFECT OF FLOCCULANTS**" in partial fulfilment of the requirements for the award of the degree of MASTER OF ENGINEERING in PULP AND PAPER ENGINEERING submitted at the Institute of Paper Technology, Department of University of Roorkee, is an authentic record of my own work carried out during the period from April, 1993 to June, 1994 under the supervision of Dr. A. K. Ray and Sri V. K. Mohindru .

The matter embodied in this thesis has not been submitted by me for the award of any other degrees.

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ABSTRACT

Sludge handling and its disposal is one of the major constraints in any chemical industry, pulp and paper industry in particular. The restraints are imposed very recently due to the growing awareness of people for creating clean environment. The major problem relating to sludge handling can be overcome by efficient sludge dewatering techniques for which understanding of sludge characteristics and conditioning of the sludge by flocculants is very much needed. In Indian paper mills, there is no data available on dewatering characteristics of sludge obtained from their Waste Water Treatment plant with and without chemical conditioning by flocculants. It is also a fact that there is not enough information regarding the parametric influence on water drainability from sludge particularly the effect of conventional parameters like pH ,mixing time , temperature, pressure, speed of mixing etc.

An attempt has been made in this present investigation to study indepth, the dewatering characteristics of both primary and secondary sludges of two different mills using different kind of raw materials.

Laboratory scale experiments have been carried out at large scale with various sludges with varying consistencies. The influence of various flocculants, organic and inorganic in

nature, as well as their optimum doses on specific resistance to filteration (SRF) values have been also studied at room temperature. Further , the effect of various parameters like, pH, time of agitation, storage time, pressure on dewaterability of sludge during conditioning with flocculants in terms of specific cake resistance values have been investigated. To evaluate the various parameters like, SRF, compressibility factor, air suction rate, various mathematical correlations have been attempted based on phenomenological concepts available in classical chemical engineering literature.

A non detailed economical feasibility has been studied based on the cost items of the flocculants followed by balancing it against the benefits achieved by fixed charges, power cost and other cost parameters related to reduction of SRF values. The preliminary evaluation of economic viability studies indicates a good promise in near future. Pilot plant/commercial plant application will bring out the success of the project in real sense.

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CHAPTER I

INTRODUCTION

1.0 INTRODUCTION:

With the increasing awareness about the environment cleanliness, it is very much important to look into the every aspects of disposal or profitable use of effluent stream for any industry. Pulp and Paper Industry, in particular discharges huge amount of solid/liquid and gaseous pollutants to environment. Sludge is one of the major streams affecting environment to considerable extent. Sludge from an effluent treatment plant can be mainly classified as under:

1- Primary sludge, also called fibre sludge in paper industry, generated due to settleable solids lost or discarded from the manufacturing process. In addition to the fibres, this may contain materials such as fillers, sand and colloidal materials such as starch, protein and resin etc.

2- Secondary sludge generated due to excess biomass growth and solids accumulation in secondary treatment plant. This result from assimilation of dissolved organic or colloidal matters. It also incorporates suspended matters not settled in primary clarifiers.

In addition, chemical sludges are also generated from chemical coagulation and subsequent separation of dispersed and colloidal suspended matter.

For ecological constraints these sludges require an acceptable means for ultimate disposal into the environment or its reuse for value added products. To achieve the above goal in mind, several process steps are to be followed. The first stage is obviously dewatering. Basically dewatering helps to reduce transportation volume, to make it suitable for landfill, or to prepare the sludge for incineration or other value added byproducts.

Dewatering can be accomplished either by physical means or by mechanical means. Usually mechanical methods are preferred because of compact geometry of the processing equipments and also, they give output most efficiently. The mechanical dewatering equipments include vacuum filter, belt filter press, screw presses, centrifuge, and pressure filter.

Fines capture rate and cake dryness are the two basic parameters indicating the efficiency of all the above dewatering systems. It is necessary to conduct laboratory or pilot scale tests to ascertain relative efficiency of the aforesaid equipments.

Table-1.1 below shows the achievable cake dryness of primary sludge by various mechanical dewatering equipments mostly being used (13).

Table-1.1

ACHIEVABLE CAKE DRYNESS BY MECHANICAL DEWATERING EQUIPMENTS

	Achievable Cake Dryness	
	Mean(%T.S.)	Range(%T.S.)
Vacuum Filter	20	15 - 22
Vacuum Filter and V-press	35	30 - 40
Belt Filter press	35	30 - 40
Screw presses	45	40 - 50

But now various paper mills have installed secondary treatment plants and there is significant increase in generation of secondary sludge. Dewatering of mixed biological and primary sludges have received attention because biological sludge is generally considered more difficult to dewater than primary sludge. There is a growing tendency to dewater more efficiently and thus increasing cake dryness as much as possible for its effective end use.

One important alternative widely being used to improve dewatering efficiency is chemical conditioning of sludges in order to flocculate the sludge and enhance the ease with which water may be removed. Chemical conditioning or flocculation prior to dewatering will improve throughput and cake dryness for all dewatering devices with a few exceptions.

Chemical conditioning results in agglomeration or aggregation of colloidal or finely divided suspended matters by using chemicals. Capillary and intercellular water in the sludges which are difficult to remove, are transferred into easily removable free water. The chemicals most widely used for chemical conditioning are inorganic chemicals e.g. ferric chloride, ferric sulfate, alum and lime and organic polymers. These chemicals are also termed as flocculants.

Flocculation is a two step process. In the first stage, chemicals are mixed rapidly with sludge for a short period to result a homogeneous mixture. In the second stage, this mixture is stirred gently so that aggregation can occur. It is important to note that two criteria must be satisfied, while selecting chemicals and its dose for flocculation. First, the chemicals must condition the sludge to an acceptable low resistance to filteration and second, the resulting cake must be firm and relatively dry. Certainly, there is an optimum dose of chemical, which gives the best economical results. Under dosing or overdosing will affect the performance of dewatering system and its economics. Hence, it is must to carefully select the right flocculant and its dose for conditioning of sludge.

Unfortunately, the performance of a particular flocculant and its optimum dose is dependent on sludge characteristics and vary from sludge to sludge and from mill to mill. Not only the sludge characteristics, but also other operating variables like speed and time of mixing, pH, concentration and type of ions present in sludge, temperature, and storage of sludge greatly influence the performance of chemicals to flocculate the sludge and hence dewatering results. It is therefore, important from both cost and performance considerations, to optimize the addition of flocculant for sludge conditioning. As there are variety of chemicals particularly organic polymers for flocculation of sludge and characteristics of sludges varies widely, so laboratory scale experiments are generally preferred before taking plant scale trials. Even during the routine operation, occasionally laboratory scale tests are performed to get the best results.

A variety of tests are available for this and also to know the dewatering characteristics of unconditioned sludge. These tests are multiple jar test, free drainage test, specific resistance to filteration (SRF) measurement, leaf filter test and capillary suction time measurement. Among these specific resistance to filteration measurement is generally preferred due to its sound theoretical basis.

Specific resistance to filteration controls the rate of flow of filtrate through a sludge cake and is thus related to the performance of full-scale dewatering devices.

The sludges generated from the effluent treatment plant in the Indian Paper Industry will be having different characteristics not only from that of sewage sludges and other industrial sludges, but also from that of sludges generated from effluent treatment plant of paper mills of North America, and other Scandinavian countries, because the raw materials being used by Indian Paper Industry are completely different and also there is some difference in types of end product being produced and process being followed.

Unfortunately, in India no work has been reported till now on dewatering characteristics of sludges generated from waste water treatment plant of paper industries and also on effect of flocculants on conditioning of sludges.

Therefore, plenty of scope exists to carry out laboratory trials of industrial sludges to find out their dewatering characteristics and also the influence of flocculants.

CHAPTER II

LITERATURE REVIEW

2.0 LITERATURE REVIEW:

Plenty of work has been done both at laboratory scale and plant scale on "Study of Dewatering Characteristics of Sludges of Effluent Treatment Plant." Effect of flocculants and operating variables on conditioning of sludge to improve dewatering has also been observed.

However, most of the work has been done on municipal waste water sludges. On the contrary, the work on paper mill effluent sludge is extremely limited. Of late, there has been general awareness of this important aspect and some work has been carried out by the pulp and paper industry of North America and Scandinavia. They have stressed that use of flocculants along with new dewatering equipments is an imperative necessity for drying the cake for landfill or incineration.

Unfortunately, no work has been reported so far by any Indian mill. It is expected that new future Indian mills will also give importance to this aspect and adopt new technique for dewatering system.

Laboratory experiments of the filterability of sludge basically are based on three different methods. Selection of flocculants, dewatering characteristics and finally the optimization of the entire process depends entirely on the technique chosen. The techniques are given as under :

1- Buchner Funnel Filtration Time (Tenney et al. (1))

2- Capillary Suction Time (CST) (Baskerville and Gale (2), Vesilind et al. (3).

3- Specific Cake Resistance (Coakley and Jones; (4); Swanswick and Davidson; (5), and Gale (6); Kavanagh (7).

Since its introduction to sludge dewatering literature in 1956 by Caockley and Jones, specific cake resistance method has been extensively used for characterization of sludges by most of the Investigators. It is generally preferred since it is considered to have a sound theoretical basis. Gale et al. (8) and Baskerville (9) have studied that the specific resistance to filtration (SRF) is a sludge parameter that controls the rate of flow of filtrate through a sludge cake and shown that SRF is related to the performance of full-scale dewatering devices. Cassel et al. (10) - havealso described measurement of SRF for evaluation of dewaterability of sludges. Positive pressure method was used which is similar in operation to the Buchner Funnel method, except that the filteration pressure is provided by positive pressure instead of vacuum. Baskerville et al. (2) has shown that there is co-relation between SRF and CST for a particular sludge in addition to describing the use of CST instruments for measuring dewaterability of sewage sludge. In NCASI Technical Bulletin No.299, (11), it is shown that because specific resistance is computed using a correction for sludge consistency, it tends to be less affected by solids content than CST (Fig.2.1). Further it is suggested that attempts at correlating SRF and CST are generally more successful when a

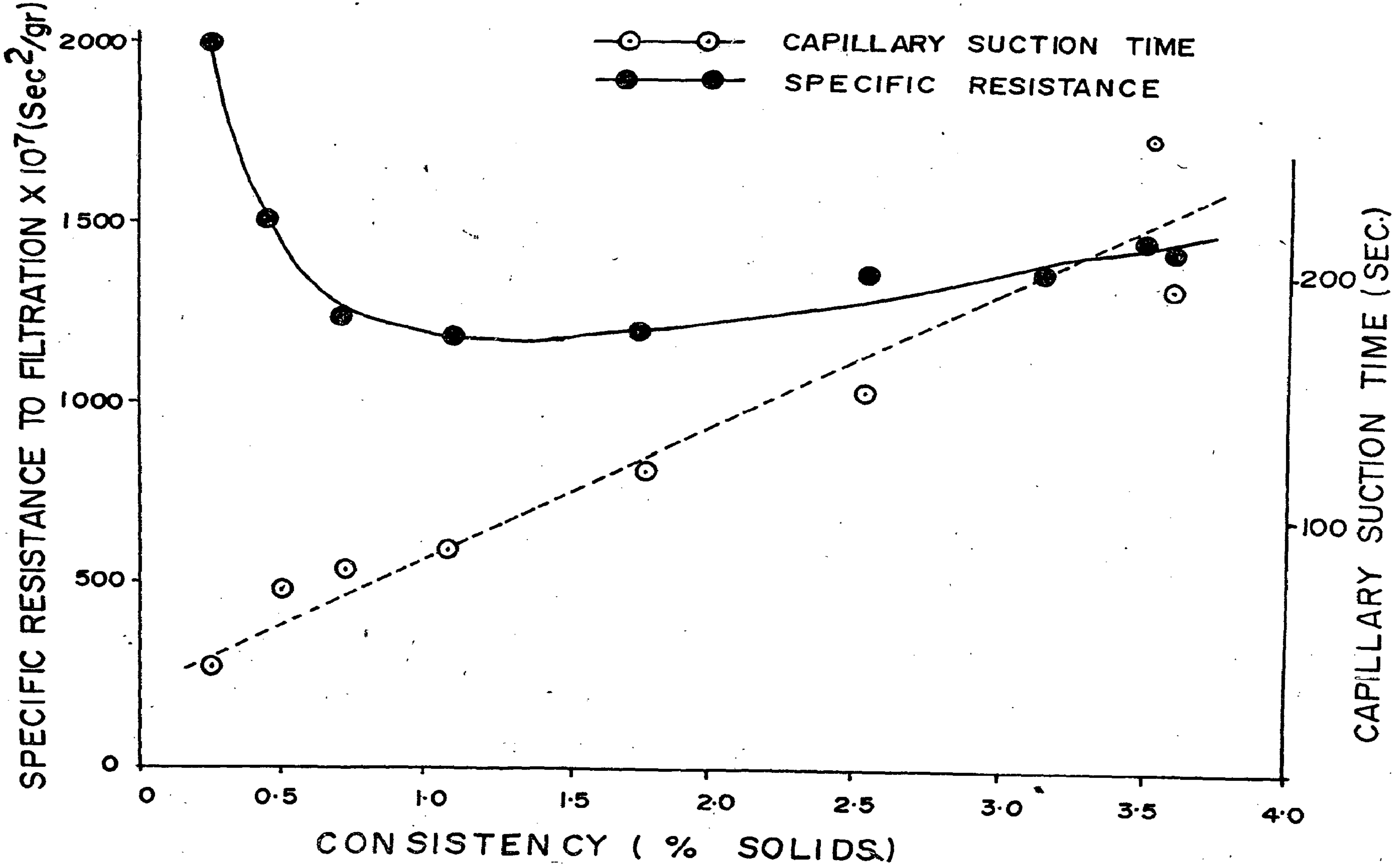


Fig.2.1 : EFFECT OF SLUDGE CONCENTRATION ON CAPILLARY SUCTION TIME (CST) AND SPECIFIC RESISTANCE(11)

correction is included for the sludge consistency for SRF.

In NCASI Technical Bulletin No.315 (12) - it is mentioned that Belt Filter Presses require a free draining floc to perform effectively. This requirement has resulted in the widespread use of polyelectrolytes for sludge conditioning. The types and amounts of polyelectrolytes used are variable. All mills dewatering biological sludge, either separately or in combination with primary sludge use polymer conditioning and costs increases as biological solids % increases. It is further mentioned that under-conditioning results in inadequate dewatering in the initial drainage section and on the other hand, too much conditioning may cause cake doctoring difficulties and aggravate blinding problems. Wilson (13) has shown difficulty in sludge dewaterability as a function of increasing percentage of biological sludge relative to primary sludge. Considerable drop on final cake dryness is noticed. Jerry (14) has stressed the addition of polymers to enhance dewatering of combined sludge (primary plus waste activated sludge). Screw presses have been used with 100% primary sludge and the belt press with a combined sludge after flocculation with polymers. Considerable improvements in efficiencies and performance of sludge handling system has been observed.

Junna et al. (15) mentioned that sludge chemical conditioning and its monitoring has became essential to dewater activated plant sludge in order to dewater the sludge to a solid content of 35-40% w/v in order to reduce transportation expenses or to exploit the heating value.

Reilly et al. (16) on the other hand, suggested separate processing of primary and secondary sludge as the most promising alternative to improve sludge handling. Mill trials proved that using only two filters and presses instead of three primary sludge alone could be dewatered to 45% solids compared to 30% solids in case of combined sludge with three filters and presses. The conditioner used by them (mostly chipper fines) has been found to be reduced. As for self supporting combustion, sludge should be at least 35% solids. Consequently, a substantial portion of the sludge cake which is being landfilled at considerable cost, will be burnt. Further, secondary sludge was dewatered to 10-11% total solids and 99.99% solids recovery with a low speed centrifuge using a cationic polymer. Using dry polymer, maximum solids recovery and cake solids were obtained at polymer dosages of 6-8 Kgs./tonne of secondary solids. Using a liquid emulsion polymer, dosages of 16-20 Kgs./tonne were necessary. However, on cost basis these two kinds of polymers were comparable. Also using no polymer, a 2.2% T.S. feed sludge yield a 3.1% T.S. product with a solids recovery at 34%, emphasizing, the impossibility of secondary sludge centrifugation without chemical flocculation. Three different polymers were used, selected on the basis of laboratory tests, for the purpose of studying and predicting costs at plant scale trials. Further, it has been maintained that an economic analysis of the present system considering items of savings and using a non-details estimate for capital investment indicate a rapid payback.

Tanwir (17) has mentioned the importance of recent generation screw press to improve the dewatering efficiency of paper mill combined sludge, thus burning the sludge. Further, it has been stressed that in addition to use of recent generation screw press, the conditioning of the sludge with the chemicals and the polymer is very important to achieve good results. Alum and anionic polymer were used for conditioning of sludge.

Mc.Cready 18 has mentioned that pulp and paper mills have two options to dewater sludges, either physical or mechanical dewatering methods. The addition and nature of flocculating polymer is determined by the characteristics of the sludge being dewatered and must be established at laboratory scale to reduce the cost. Creek (19) has mentioned that for all dewatering devices, use of flocculants in principle will improve throughput. Use of flocculants represents a very interesting method to improve dewaterability and for many dewatering devices have proved better except in high speed centrifugal devices. Because high rpm in centrifugal devices is accompanied by increased shear of flocs, and thus reducing the benefits. However, low rpm centrifuges resulting in lower risk of shear of flocs can substantiate the shortcoming of high speed rpm centrifuge. It is reported that capillary water and intracellular water in sludges which are difficult to remove, may be transferred into free water by increasing particle size by use of flocculants and thus improving the dewaterability. Liming as flocculant before dewatering has proved success in recent years.

Boivin 20 has mentioned the use of approximately 1.2 Kg. per tonne dry solids of the cationic polymer to improve the dewatering of fibrous primary sludge by screw press. A capture efficiency of 98% and sludge discharge consistency of 48-52% solids were achieved. Tests are being conducted with other flocculants in an attempt to further reduce chemical consumption costs. However, he has suggested that proper flocculant along with operating variables must be closely monitored and regulated in order to operate at maximum.

Okey et al. (21) have stated that inorganic coagulants have widespread use, and in most cases effectively capture solids. However, they have the disadvantage of contributing substantially to the sludge volume, which frequently increases the overall dewatering problem. Organic flocculants are specific in use and effective at low dosages. However, they do not scavenge colloids as well as the coagulants, and under conditions of very high or low pH undergo size degradation, with consequent loss of effectiveness. Bench-scale tests must be used to determine the optimum conditioning agent and other doses.

William et al. (22) has reported plant scale trials by utilizing dual polymer treatment program. A high charge density, short chain cationic polymer was added to the system for charge neutralization, followed by a medium charge high molecular weight cationic polymer for flocculation. This program resulted in a reduction in cost per metric tonne of sludge from $ 20 to less than $ 9.

Parker et al. (23) and Novak et al. (24) has shown by laboratory experiments that anaerobic storage decreases the filterability of unconditioned sludge. Rasmussen et al.(25) found that the decrease in filterability due to anaerobic storage is to be accompanied by an increase in turbidity and dissolved organic carbon (DOC) of sludge bulk water. The increase in turbidity is due to primarily of colloidal particles (e.g. free bacteria) released from the sludge flocs. The increase in DOC is due to bacteria degradation of organic matter releasing waste products such as alcohols and fatty acids as well as hydrolysis of exopolymers on the sludge flocs. Christensen, et al. (26) have shown that lime addition was essential for obtaining good filterability (low SRF value) of anaerobic stored sludges, and that lime requirements increase with increasing anaerobic storage time. They further, showed that an iron dosage of approximately 80 Kg/t T.S. and a ratio of iron : lime equal to 1 : 3 were able to prevent significant changes in SRF of a raw mixed primary and waste activated sludge during a 3 day storage period.

Novak et al. (27, 28) studied that polymer demand increases with increasing stirring time. Karr, et al. (29) have studied the influence of particle size on sludge dewaterability. Dewaterability was measured by CST time and SRF technique. O'Brien and Novak (30) and Novak and Haugan (27) studied the effect of pH and mixing speed on dewaterability of chemical sludges. Smith et al. (31) recognised that ash from sludge incineration could be beneficial in dewatering. Similarly, Newspaper pulp (Carden et al.(32), and Fly ash (Moehle et al. 33) may be used for conditioning of sludge prior to dewatering.

From literature survey it is evident that most of the investigations either laboratory or industry scale have stressed upon the parameters for proper dewatering followed by its efficient end use. Selection of flocculants, optimum doses of flocculant, time for conditioning, speed of agitation, pH, storage time are the main contributing factors for dewaterability of sludge. However, temperature of the slurry and the pressure or vacuum imposed will also influence dewatering. Conditioning of sludge by flocculant has received major attention by most of the investigations. It is also reflected that there is ample scope to work on these aspects, specially for paper mill sludges.

With the above information in hand, the present work has been undertaken to evaluate the dewatering characteristics of primary and secondary sludges collected from wood and non-wood based pulp and paper mills waste water treatment plant. The project focuses the attention on the following distinct objectives:

1- Collection of sludge samples.

2- To evaluate the sludge in terms of fibre fraction and ash.

3- To carry out experiment on dewatering characteristics by Specific Resistance to Filteration (SRF) method without use of flocculants.

4- To evaluate the effect of pressure or vacuum on the filterability and to compute the compressibility factor.

5- To study the effect of total solid concentration sludge on SRF.

6- To examine the effect of different flocculants, inorganic as well as organic.

7- To examine the operating parameters like pH, time of agitation, and storage.

8- To attempt a preliminary economic feasibility of the dewatering process.

CHAPTER III

EXPERIMENTAL EVALUATION

3.0 EXPERIMENTAL EVALUATION:

3.1 MATERIALS AND METHODS:

Primary and secondary sludge samples were collected from waste water treatment plant of two paper mills, Mill A and Mill B. Mill A is a large integrated kraft paper mill producing both bleached and unbleached grade paper using wood and bamboo as raw material. Mill B is a small paper mill using nonwoody raw material for producing unbleached grade paper. The pulping process being used by Mill B is chemical soda process and chemi-mechanical process. The secondary treatment being used is activated sludge process in both the paper mills.

The secondary sludge samples were thickened by sedimentation after bringing to laboratory and primary sludges were used as such.

The flocculants selected for use on study were inorganic chemicals e.g. ferric chloride, ferric sulfate, alum and lime and polyelectrolytes (one cationic and two anionic). However, cationic polymer was used for the rest of the study after preliminary screening, because anionic polymer results were very poor. Fresh 10% w/v stock solutions of inorganic flocculants and 0.1% w/v stock solutions of polyelectrolyte were prepared whenever experiments were conducted in a day. During study of effect of pH on conditioning, hydrochloric acid and sodium hydroxide were used for pH adjustment.

A mechanical stirrer was used to mix sludge samples. After adding the required flocculant dose to the samples, they were mixed for 1 min. at 150 and 250 rpm to generate homogeneous samples and for 2min. at 40 and 70 rpm (lower value for secondary sludge of low total solids concentration and higher value for primary sludge of higher total solids concentration) to promote the floc formation. These parameters of rpm and time have been selected based on preliminary laboratory scale trials and literature information.

Specific resistance to filtration (SRF) was calculated using Buchner Funnel test data. Buchner Funnel test was used to determine the dewatering characteristics of sludge samples. All the experiments were performed at constant vacuum (15" Hg) (≈508 mbar) and using same Buchner funnel i.e. the area remained constant.

Sludge samples with different solids concentration to determine the effect of solids concentration on SRF were obtained as sludge samples were subjected to different levels of thickening, and dilution by supernatant. Effect of storage of sludge on filterability and conditioning was studied by storing the sludge sample in open.

A schematic diagram showing various parameters determined is shown in Fig.3.1.

3.2 LABORATORY DETERMINATION OF SPECIFIC RESISTANCE TO FILTRATION (SRF), COEFFICIENT OF COMPRESSIBILITY AND OPTIMUM FLOCUULANT DOSAGE:

3.2.1 Determination of Specific Resistance to Filteration and Optimum Flocculant Dose:

Laboratory determination of specific resistance r is based on construction of a plot of t/V vs.V and calculation of r from Eq. (1). The laboratory equipment needed is an ordinary Buchner funnel apparatus (Fig. 3.2)

The procedure (35,36) is as follows:

1- Buchner funnel of size 9.5 cm diameter is prepared and whatman filter paper no.2 is put on it.

2- Filter paper is properly set in the funnel by wetting with water. Sludge sample is poured into the funnel and vacuum is adjusted to 15" of Hg (≃508mbar) by using vacuum.pump.

3- Filtrate volumes at selected time intervals is recorded.

4- Solids content in feed slurry and cake are measured by evaporation and weighing. Let these be values c_i (feed solids concentration,%) and c_c(cake solids concentration %). Parameter c is then calculated from Eq. (2).

5- r (Specific resistance to filteration) is calculated from a plot of t/V vs. V utilizing Eq. (1).

6- Steps 1-5 are repeated using various concentrations of flocculants.

7- Specific resistance values of all samples are computed as indicated in Step 5. Optimum flocculant dosage from a plot of specific resistance vs. flocuulant dosage is determined. Optimum dosage corresponds to the minimum on the specific resistance curve.

$$r = (2*P*A^2*s_1)/\mu*c \qquad \text{-----}(1)$$

r = specific resistance (sec^2/g)

P = Vacuum (g/cm^2)

A = Area of filteration (cm^2)

s_1 = slope of curve of t/V vs. V (sec/cm^6)

μ = viscosity of filtrate (poise= g/(cm)*(sec)

c = mass of solids deposited on the filter per unit volume of filtrate($g/ml \approx g/cm^3$)

Where,

$$c = \frac{c_c * c_i}{100*(c_c - c_i)} \qquad \text{-----}(2)$$

c_c= Cake solids concentration, (%)

c_i= Feed solids concentration, (%)

Derivation of Equation (1) and (2) is given in Appendix-I.

3.2.2 Determination of Coefficient of Compressibility:

Most industrial waste water sludges form compressible cakes for which filtration rate and specific resistance are functions of the pressure difference across the cake. This effect is represented by Eq.3 .

$$r = r_0 * P^s \qquad \text{-----(3)}$$

where s is the coefficient of compressibility. The larger is s, the more compressible is the sludge. When s = 0, the specific resistance is independent of pressure and the sludge is incompressible and Eq. (3) yields.

$$r = r_0 = \text{constant.}$$

s is determined by slope of line when a graph is plotted between r and P on log-log scale.

All the values of specific resistance have been computed by using a computer programme which is given in appendix III.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.0 RESULTS AND DISCUSSION :

Based on experiments conducted in the laboratory, Specific Resistance to Filtration (SRF) as a function of various parameters has been calculated. These are shown in various tables. The data have also been interpreted in various figures. These are described in the following paragraphs:

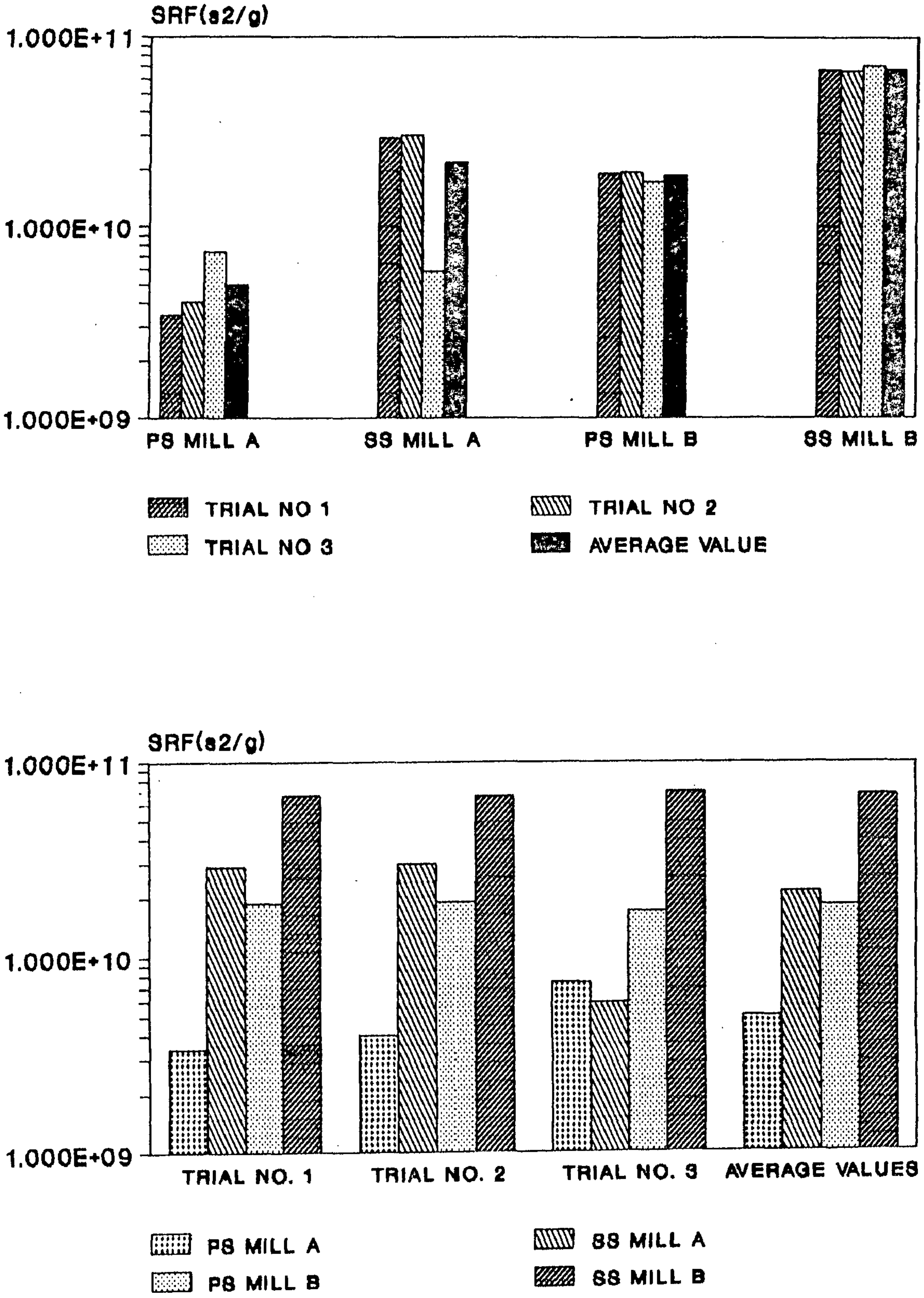
4.1 Specific Resistance of Cake to Filteration for Various Sludges Without Addition of Flocculants :

The values of specific resistance of cake to filteration for primary and secondary sludges of Mill A and Mill B are given in Table-4.1 and are also shown graphically by histogram for better comparison (Fig. 4.1). These values are for the sludges as such i.e. sludges without any addition of flocculants.

On comparing the SRF values of primary sludges for Mill A and B, it is evident that the SRF values of Mill B is found to be relatively large compared to that of Mill A (by almost 4.0 times.). It may be attributed to the more fines content in the sludge of Mill B. The different fibre fraction of the primary sludges of both the mills have been determined for these cases by Bauer-McNett fractionation techniques. The values are shown in Table-4.2. The fines content i.e. material passing through 100 mesh screen are more than 80% (on O.D. material basis) for Mill B compared to only 60% for Mill A. Similarly, the secondary sludge of Mill B is also found to have larger SRF values compared to those of secondary sludge of Mill A (by about 3 times), but the difference is relatively smaller in magnitude . The reason for higher SRF of secondary sludge of Mill B may be the same i.e. more fines are carried into the secondary treatment system resulting in more difficult dewatered sludge.

On comparing the primary and secondary sludges from the same mill, it is clear that secondary sludges are having larger SRF values compared to primary sludges, and thus are found more difficult to dewater. The SRF values of secondary sludge of Mill A is found to be 4.4 times larger than that of primary sludges, while secondary sludge of Mill B is found to be having 3.7 times larger SRF values compared to primary sludge of the same Mill B. The reason for larger SRF of secondary sludges may be due to presence of vary fine biological masses, which are also more hydrous in nature.

Fig.4.1: SPECIFIC RESISTANCE TO FILTERATION (SRF) OF PRIMARY AND SECONDARY SLUDGES OF MILL A AND MILL B



PS: PRIMARY SLUDGE; SS: SECONDARY SLUDGE

SRF: SPECIFIC RESISTANCE TO FILTERATION

4.2 Effect of Pressure Drop (or Vacuum) on SRF Values of Sludges and Estimation of Coefficient of Compressibility :

The effect of change of vacuum on SRF values of unconditioned primary and secondary sludges of Mill A have been estimated. Some experiments are also tried on ferric chloride conditioned primary sludge of the same Mill A. The values are given in Table 4.3a, 4.3b, and 4.3c for unconditioned primary and secondary sludge and ferric chloride conditioned primary sludge respectively. It is clear that there is increase in SRF values with increase in difference of vacuum. Almost linear relationship has been found between average SRF values and pressure drop on log-log scale (see Figs.4.2a,4.2b, and4.2c). The coefficient of compressibility which is a slope of the same above mentioned line has also been determined.

The average values are 0.67, 0.72 and 1.06 respectively for secondary activated sludges, primary sludge and ferric chloride conditioned primary sludge. It reflects that the cakes are compressible in nature.
This primary sludge has been found to be more compressible than secondary activated sludge, however difference is very small. similarly, ferric chloride treated primary sludge is found much more compressible than unconditioned primary sludge. It is interesting to note that the compressibility coefficient exceeds 1.0 for $FeCl_3$ conditioned primary sludge. Though normal value of compressibility coefficient lie between 0-1.0, it has been

mentioned in literature, the value may be greater than 1.0 in quite a few cases.

On the contrary a value of 0.8 has been reported for coefficient of compressibility for pulp and paper activated sludge conditioned with 2.5% ferric chloride (34).

Fig. 4.2a : EFFECT OF PRESSURE DROP ON SRF (PRIMARYY SLUDGE, MILL A)

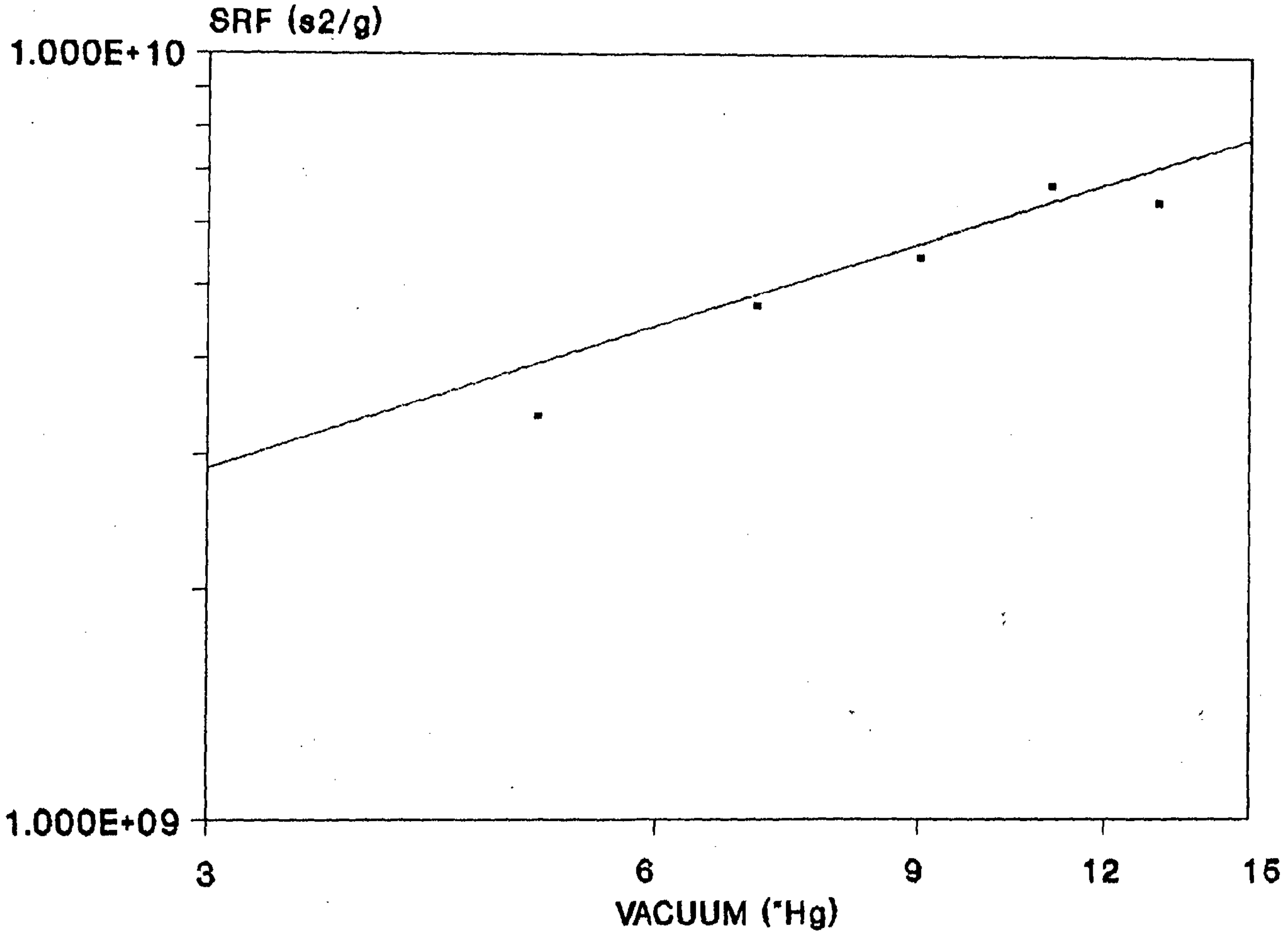


Fig. 4.2b : EFFECT OF PRESSURE DROP ON SRF
(SECONDARY SLUDGE, MILL A)

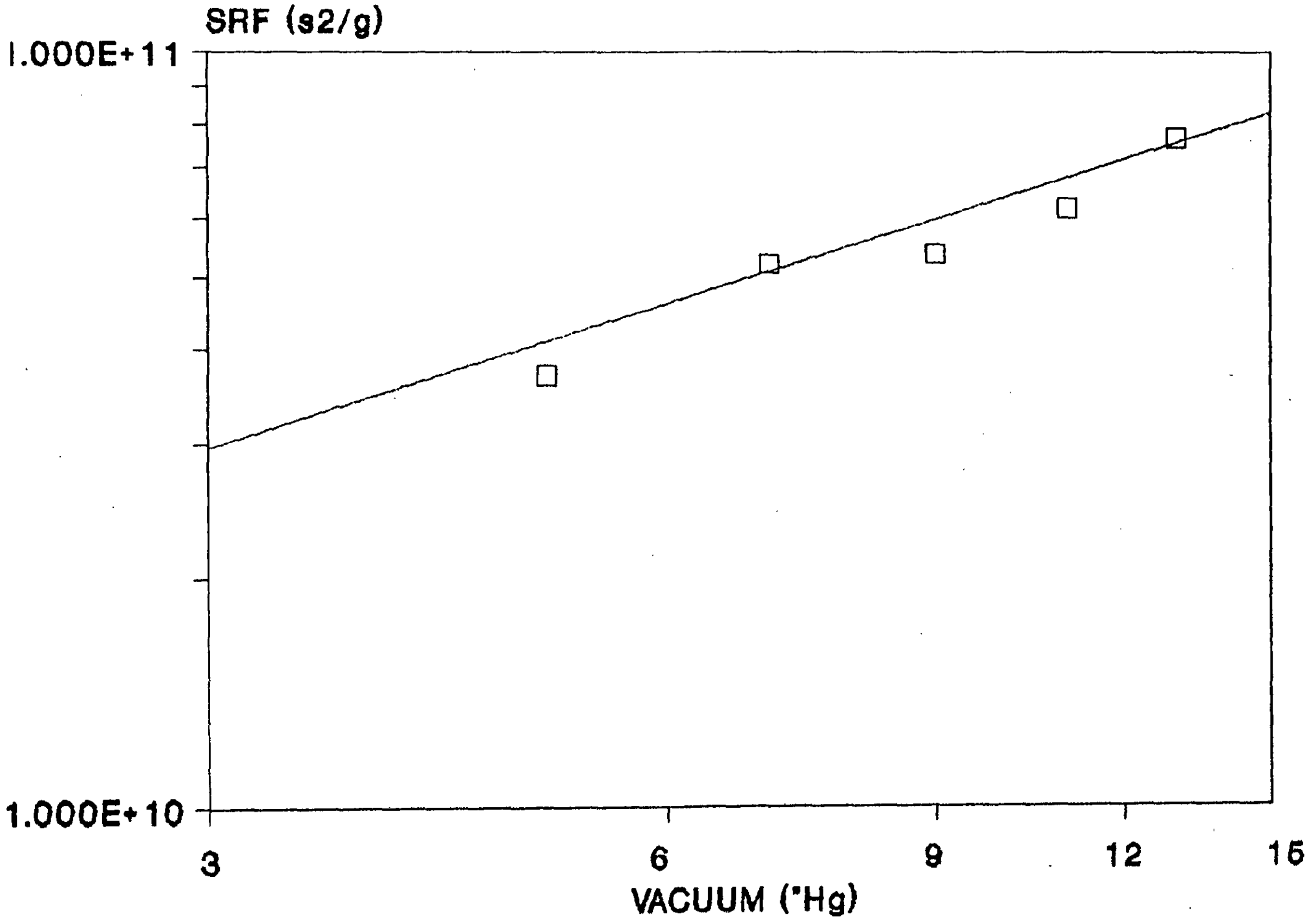
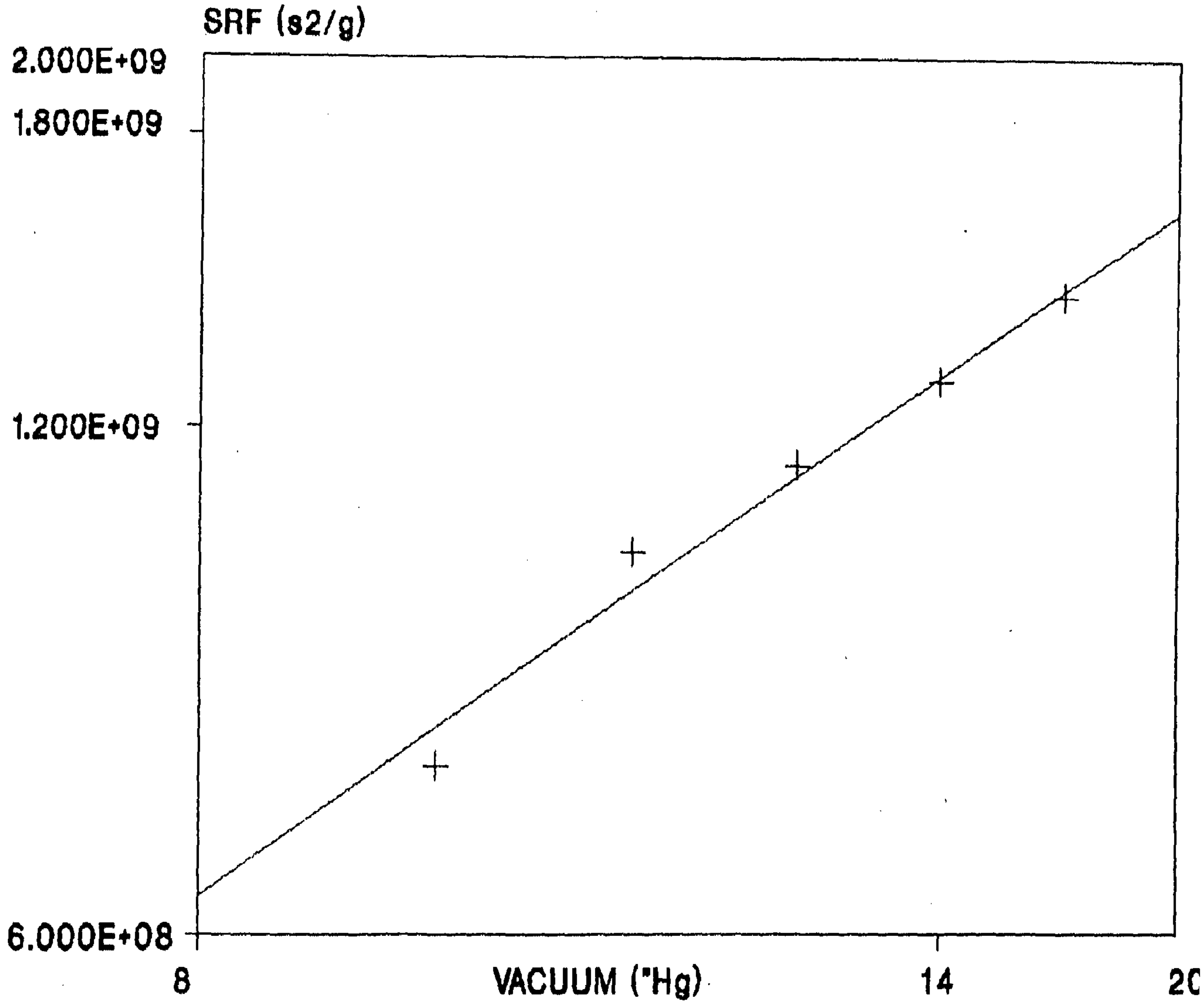


Fig. 4.2c : FFECT OF PRESSURE DROP ON SRF
(FECL3 CONDITIONED PRIMARY SLUDGE)

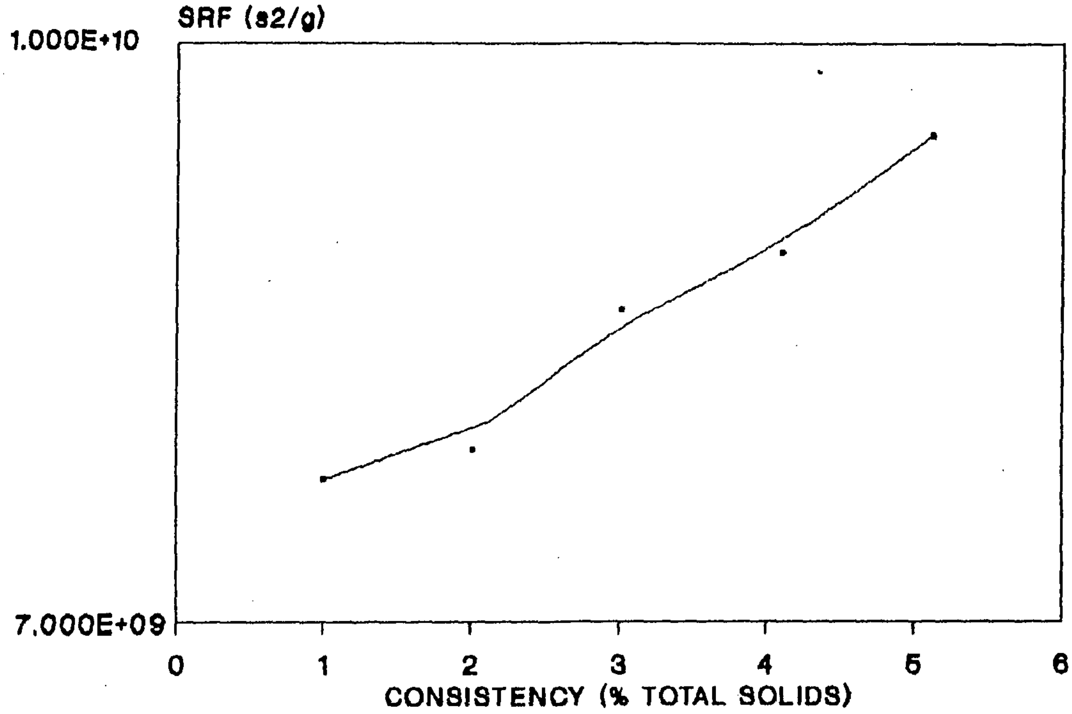


4.3 Variation of SRF With Solids Content of Sludge:

According to theory, specific resistance is independent of solids content of sludge. But, it has been found in actual experiment that SRF increases with increase in solid content. However, the relationship is not an exact linear one as shown in Figs.4.3a and 4.3b, for unconditioned primary and secondary sludges respectively. The values of SRF at different solid content of sludge are also given in Tables 4.4a and 4.4b. The increase in SRF with solid contents may probably be due to the compressible nature of cakes.

The trend of variation of SRF with solid content for secondary sludge agrees to those given in literature (12) for secondary activated sludge (see Fig. 4.3c). Coackley also showed that the SRF decreased with decreasing solids content. It, therefore agrees with the findings with the present investigation.

Fig. 4.3a : EFFECT OF SOLIDS CONTENT OF SLUDGE ON SPECIFIC RESISTANCE TO FILTERATION (PRIMARY SLUDGE MILL A, TRIAL NO. 1)



(PRIMARY SLUDGE MILL A, TRIAL NO. 2)

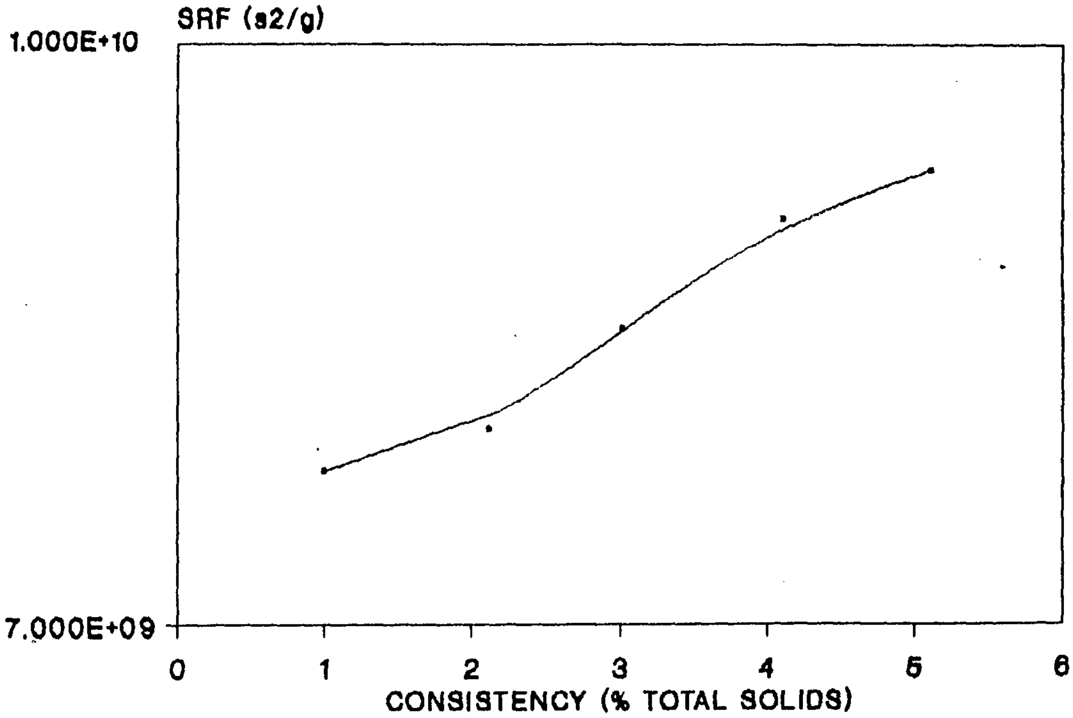
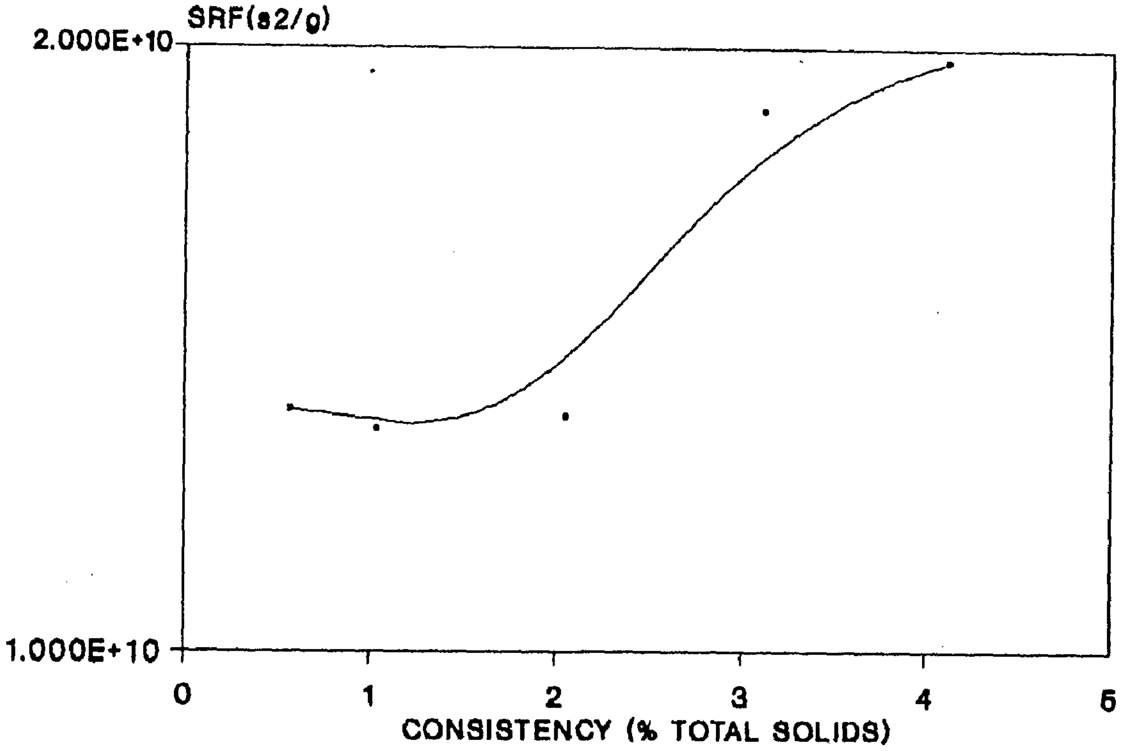


Fig. 4.3b : EFFECT OF SOLIDS CONTENT OF SLUDGE
SPECIFIC RESISTANCE TO FILTERATION
(SECONDARY SLUDGE MILL A,TRIAL NO.1)



(SECONDARY SLUDGE MILL A,TRIAL NO.2)

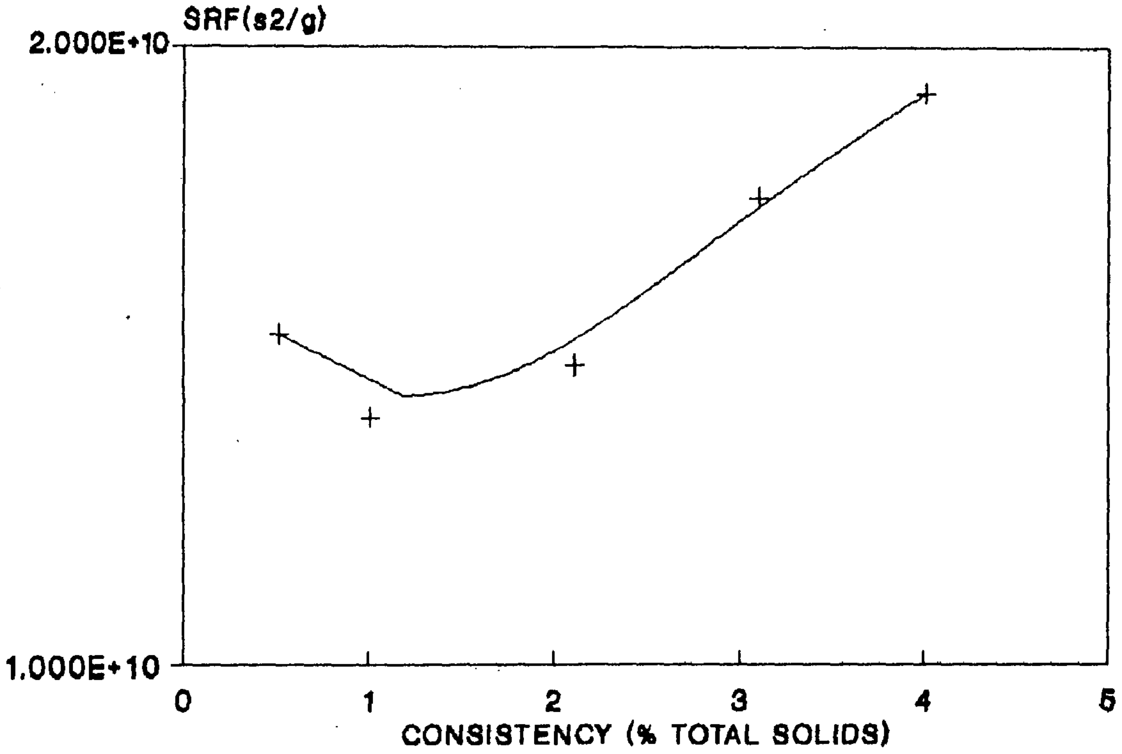
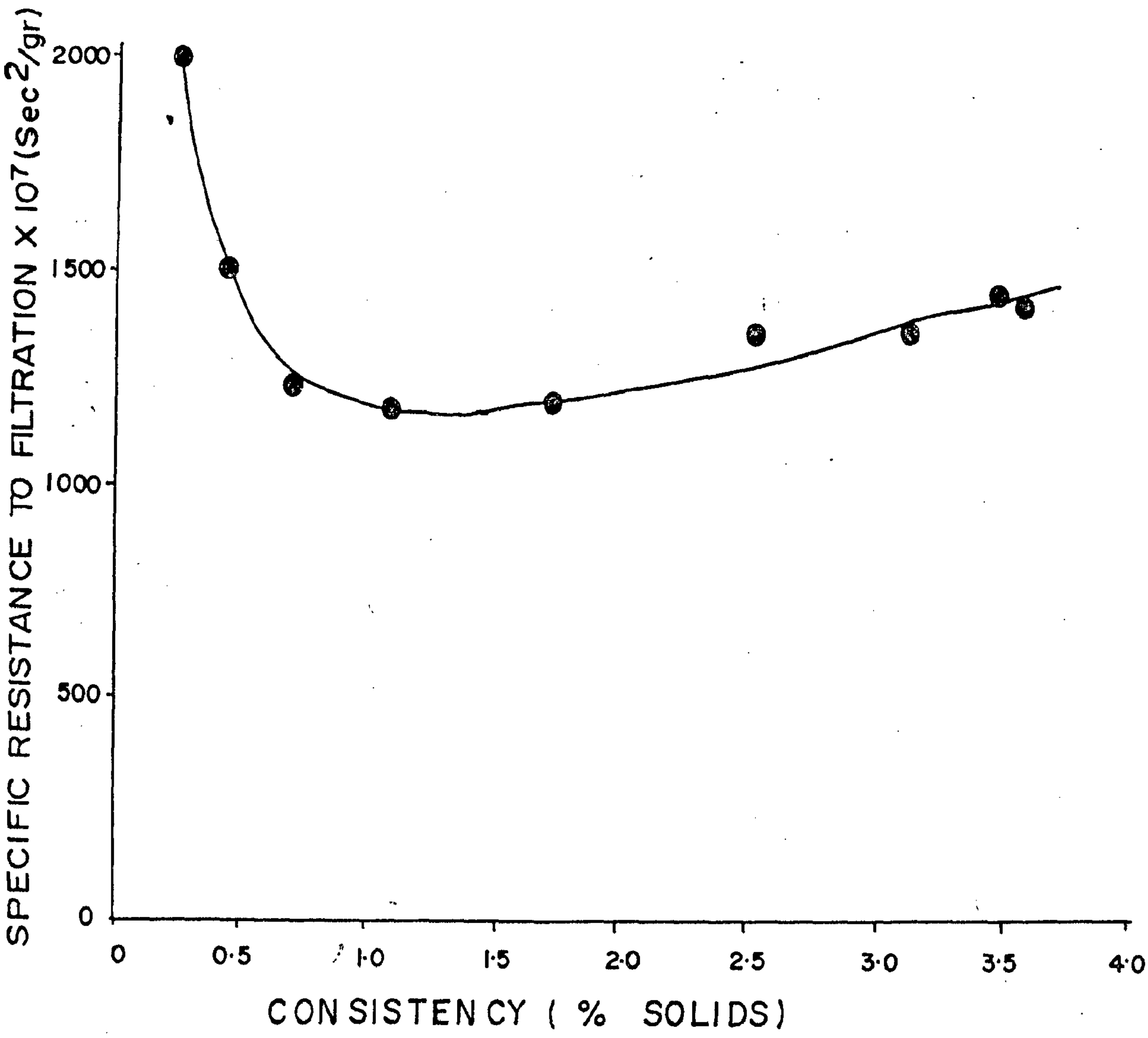


Fig. 4.3c : EFFECT OF SLUDGE CONCENTRATION ON SPECIFIC RESISTANCE (Secondary Activated Sludge)[11]



4.4 Effect of Various Flocculants on SRF:

The effect of various flocculants (both inorganic and polymers) on the SRF values have been obtained for different dosage of flocculants. The experiments have been conducted for both primary and secondary sludge for both the mills. The data on SRF at different dosage of various flocculants are given in Tables 4.5a to 4.12c, and same have been shown on semi-log plot from Figs.4.4a to 4.11c for comparison.

On comparing the data, the effect of inorganic flocculants on primary sludge of Mill A, it has been observed that all the flocculants used improved the sludge dewatering characteristics as indicated by substantial decrease in SRF values of unconditioned sludge. However, the best results have been obtained with ferric chloride and the poorest with lime. The performance with Alum and Ferric Alum sulfate was in between those due to ferric chloride and lime. However, relatively alum gives better results than ferric sulfate. For example in one trial at a dose of 8% and initial SRF value of 3.43×10^9 s^2/g, the SRF values decrease to 4.35×10^7 s^2/g with ferric chloride, 6.45×10^7 s^2/g with alum, 7.01×10^7 s^2/g with ferric sulfate and 2.21×10^8 s^2/g with lime (Table No. 4.5a) . The same trend has been observed with secondary sludge of Mill A. The SRF values at a dose of 8% and initial SRF of 2.90×10^{10} s^2/g decrease to 6.15×10^7 s^2/g with ferric chloride, 1.10×10^8 s^2/g with alum, 1.19×10^8 s^2/g with ferric sulfate and 1.49×10^8 s^2/g with lime (Table No. 4.6a).

Fig. 4.4a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill A,Trial No. 1)

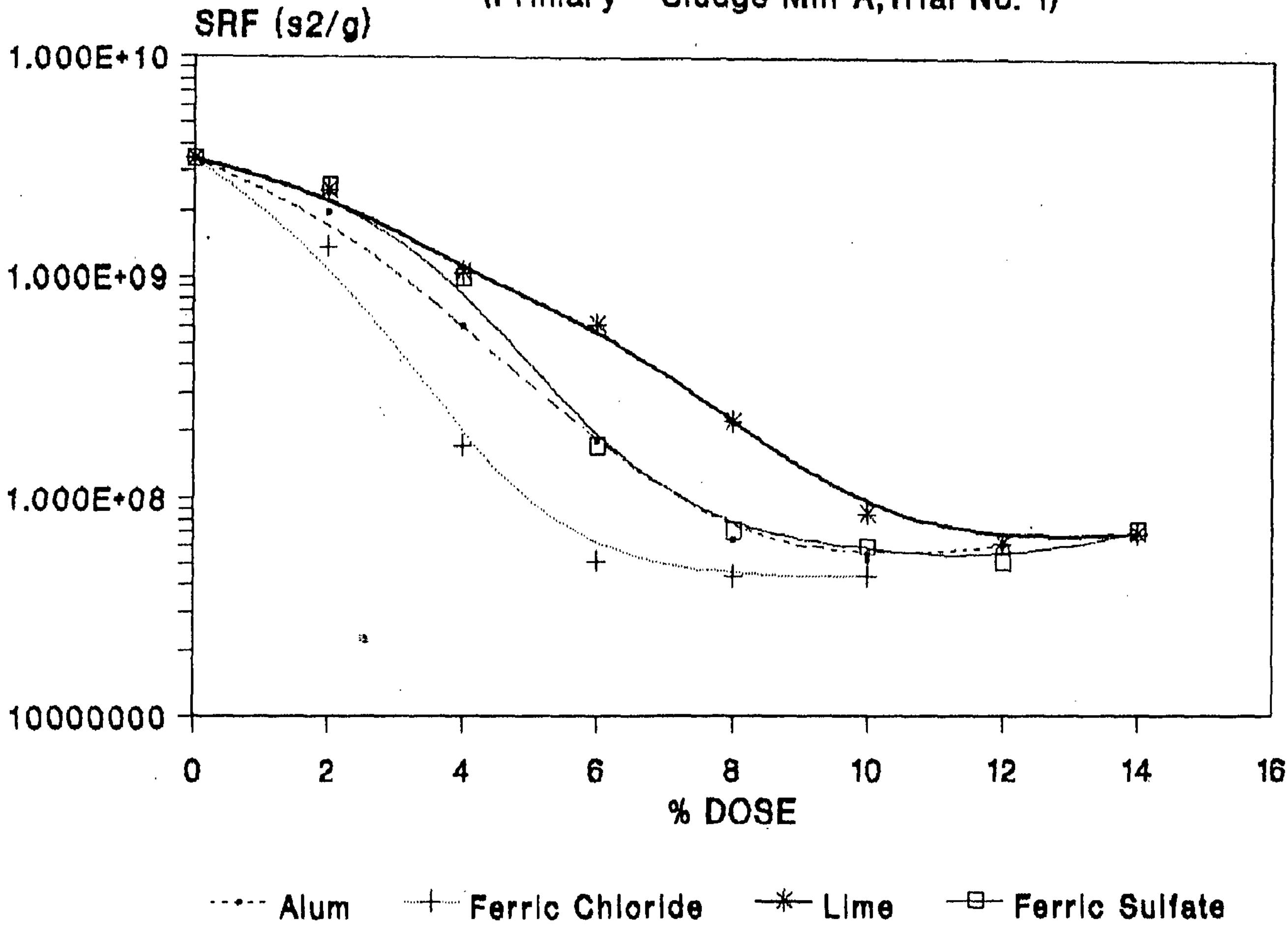


Fig. 4.4b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill A,Trial No. 2)

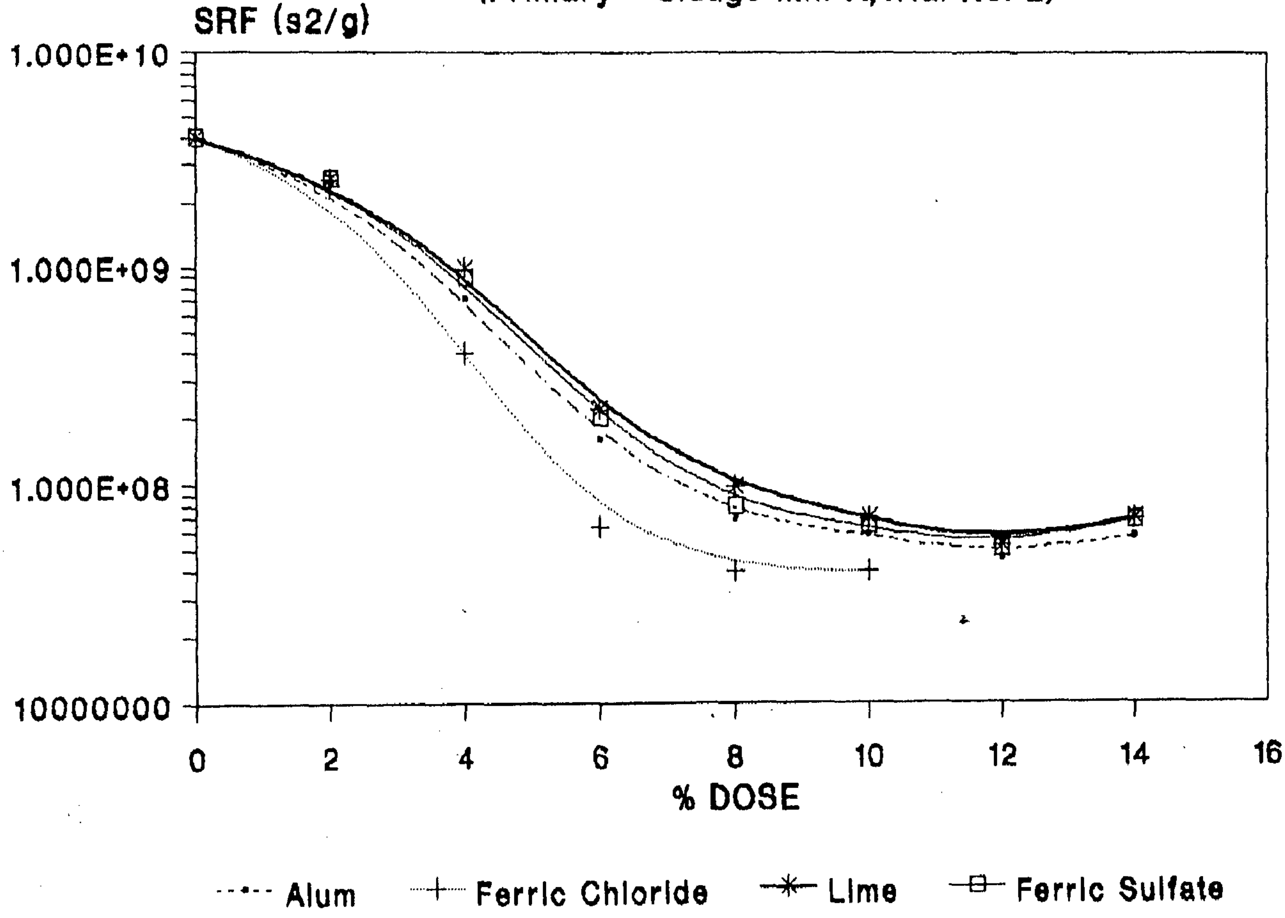


Fig. 4.4c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill A,Trial No. 3)

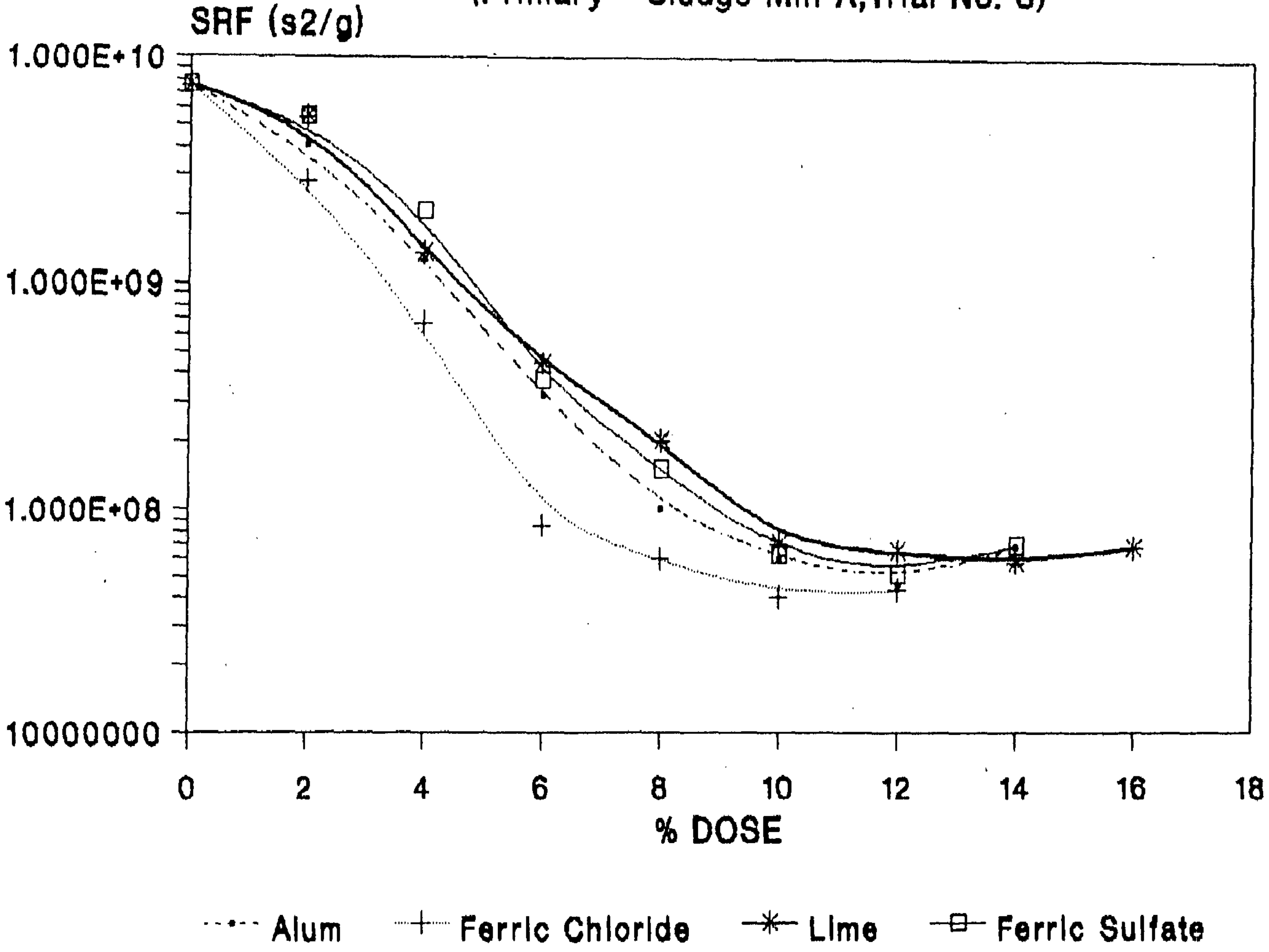


Fig. 4.5a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill A, Trial No.1)

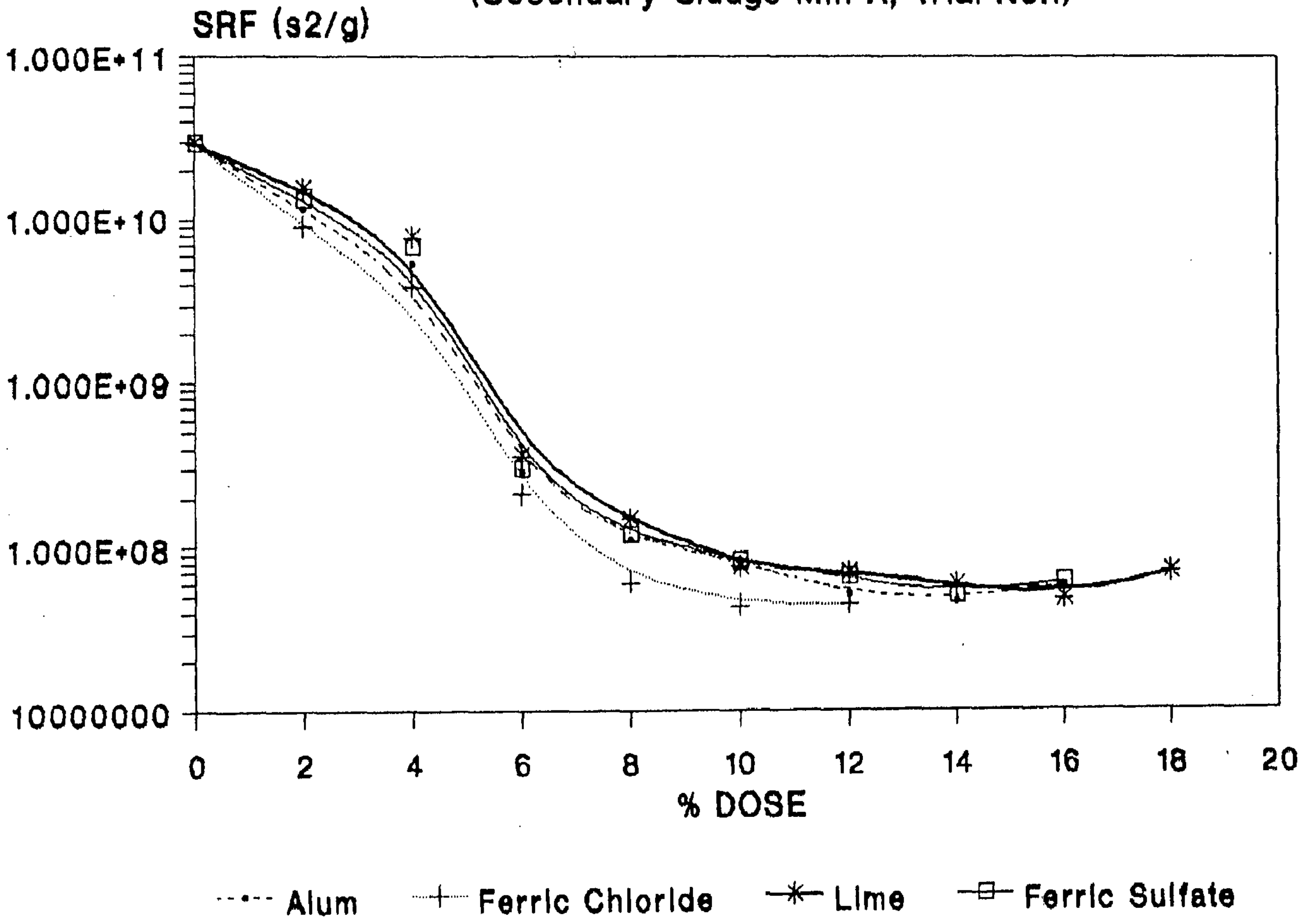


Fig. 4.5b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill A, Trial No.2)

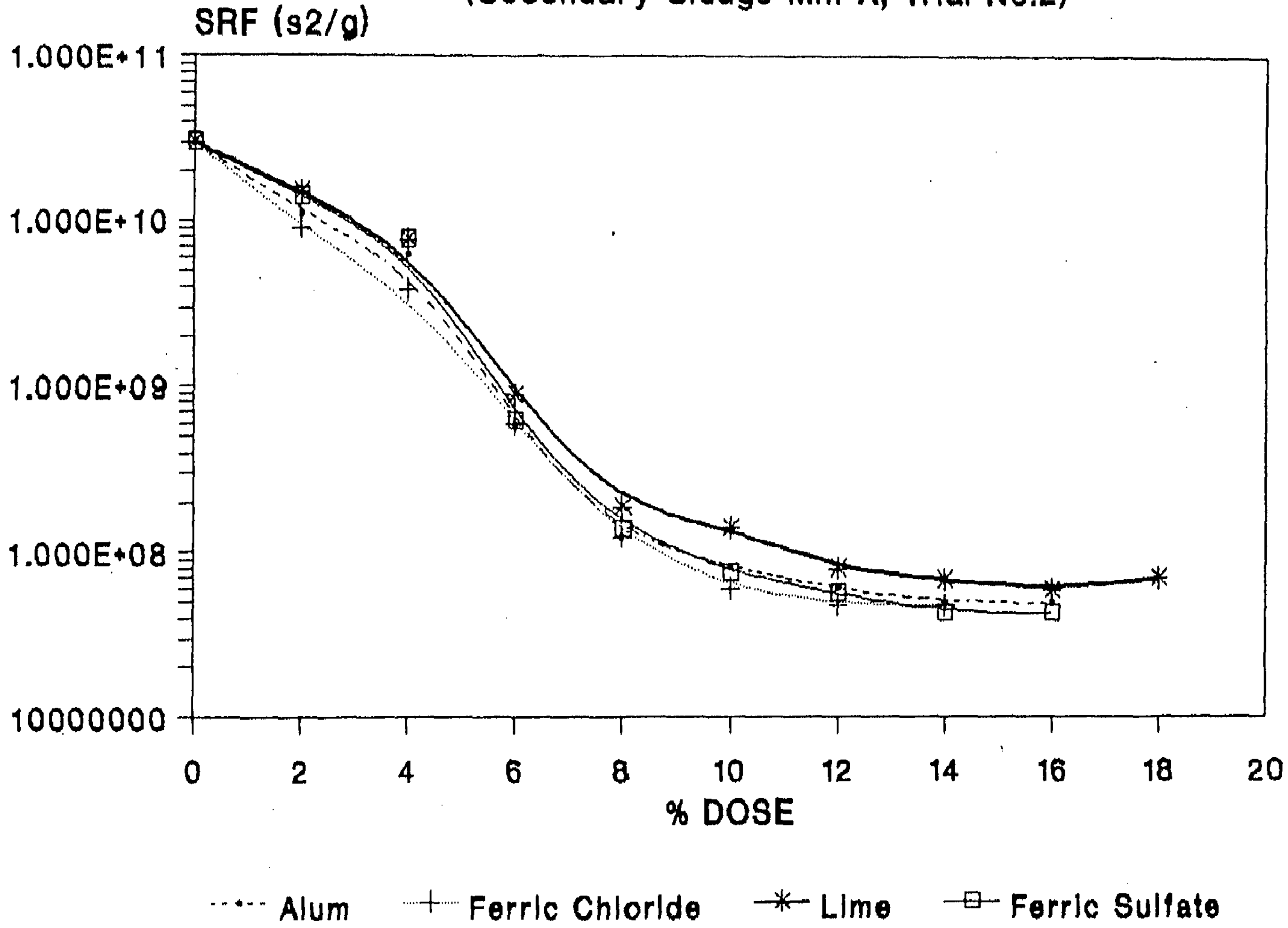


Fig. 4.5c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill A, Trial No.3)

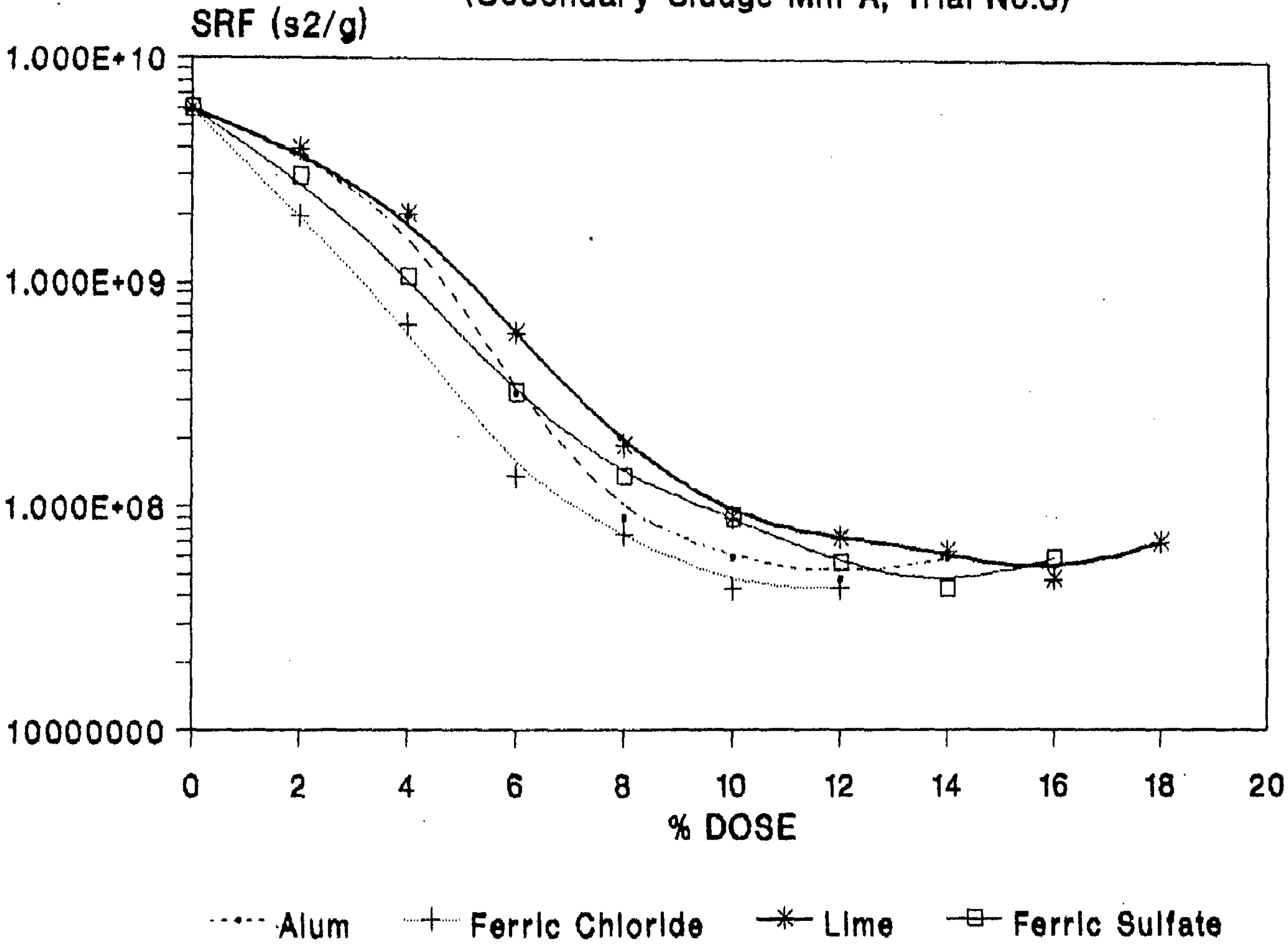
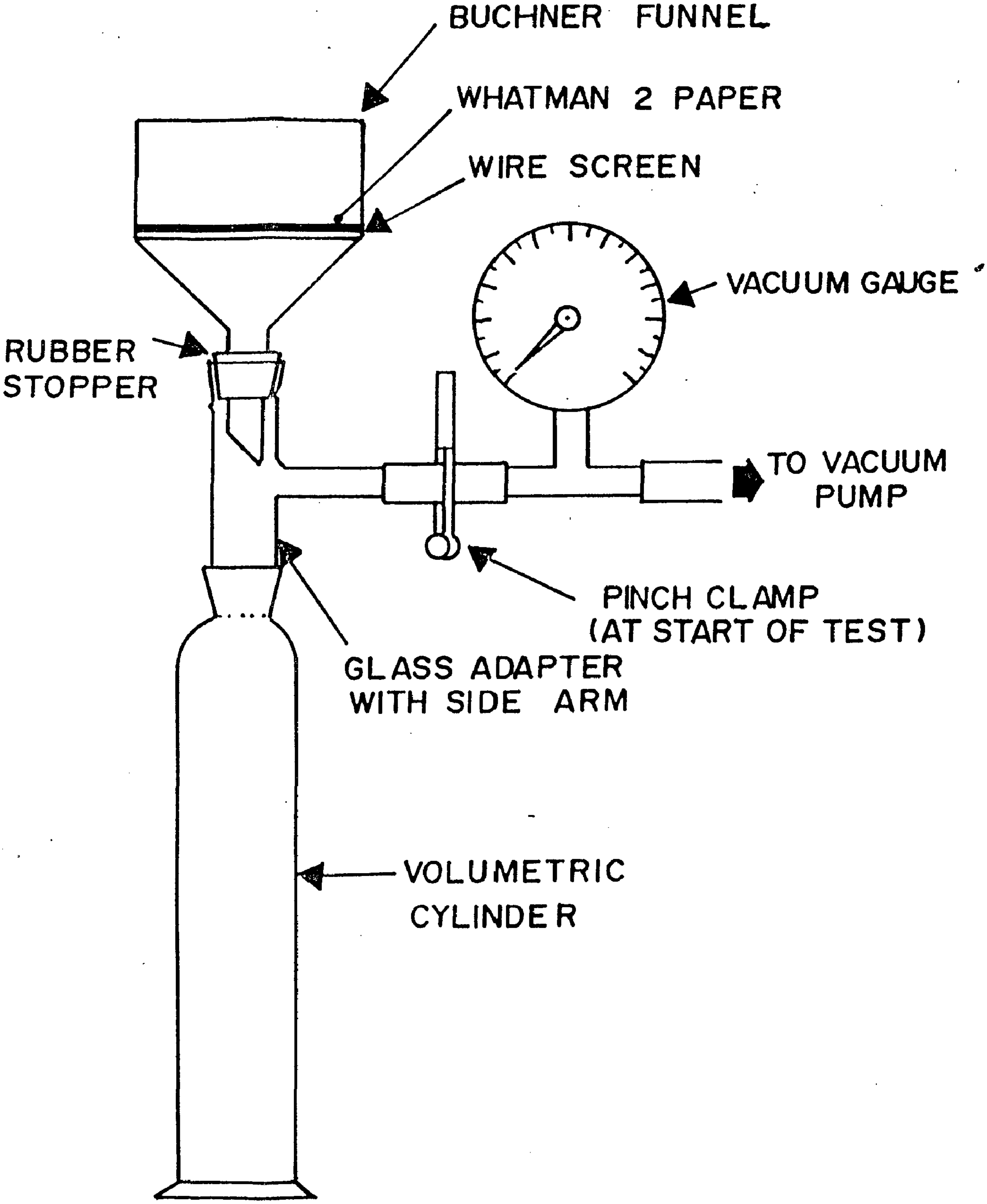


Fig.3.1: SCHEMATIC DIAGRAM SHOWING VARIOUS PARAMETERS DETERMINED FOR SLUDGES OF MILL A AND MILL B

- Mill A
  - Primary Sludge
    1. Fiber Classification and Ash
    2. SRF Without Adding Flocculants
    3. SRF at Different Pressure Drop and Coefficient of Compressibility
    4. SRF at Different Solid Content of Sludge
    5. SRF at Different Dose of Inorganic and Organic Flocculants
       - —a. Alum
       - —b. Ferric Chloride
       - —c. Lime
       - —d. Ferric Sulfate
       - —a. Anionic-A
       - —b. Cationic
       - —c. Anionic-B
  - Secondary Sludge
    1. SRF Without Adding Flocculants
    2. SRF at Different Pressure Drop and Coefficient of Compressibility
    3. SRF at Different Solid Content of Sludge
    4. SRF at Different Dose of Inorganic and Organic Flocculants
       - —a. Alum
       - —b. Ferric Chloride
       - —c. Lime
       - —d. Ferric Sulfate
       - —a. Anionic-A
       - —b. Cationic
       - —c. Anionic-B
    5. SRF at Varying Rapid and Slow Mixing Time During Conditioning With Optimum Dose of Flocculants a)Ferric Chloride b)Cationic Polymer (Effect of Mixing Time)
    6. SRF at Varying Rapid Mixing Time During Conditioning With Different Dose of Flocculant (Optimum and Less than Optimum) a)Ferric Chloride (Interaction of Mixing Time and Dose)
- Mill B
  - Primary Sludge
    1. Fiber Classification and Ash
    2. SRF Without Adding Flocculants
    5. SRF at Different Dose of Inorganic and Organic Flocculants
       - —a. Alum
       - —b. Ferric Chloride
       - —c. Lime
       - —d. Ferric Sulfate
       - —a. Anionic-A
       - —b. Cationic
       - —c. Anionic-B
    - . SRF at Varying pH During Conditioning With Optimum Dose of Flocculants a)Alum b) Ferric Chloride c) Lime d)Ferric Sulfate e) Cationic Polymer (Effect of pH)
    - . SRF at Varying pH During Conditioning With Different Dose of Flocculants (Optimum and Less than Optimum) a)Ferric Chloride b)Cationic Polymer (Interaction of pH and Dose)
  - Secondary Sludge
    1. SRF Without Adding Flocculants
    2. SRF at Different Dose of Inorganic and Organic Flocculants
       - —a. Alum
       - —b. Ferric Chloride
       - —c. Lime
       - —d. Ferric Sulfate
       - —a. Anionic-A
       - —b. Cationic
       - —c. Anionic-B
    3. SRF at Varying Rapid and Slow Mixing Time During Conditioning With Optimum Dose of Flocculants a)Alum b)Cationic Polymer (Effect of Mixing Time)
    4. SRF at Varying pH During Conditioning With Optimum Dose of Flocculants a)Alum b) Ferric Chloride c) Lime d)Ferric Sulfate e) Cationic Polymer (Effect of pH)
    5. SRF Values of Stored Sludge at Different Dose of Flocculants a) Ferric Chloride b)Cationic Polymer c) Lime (Effect of Storage on Dewatering and Conditioning)

Fig.3.2: BUCHNER FUNNEL APPARATUS ARRANGEMENT



$$r = PA^2/[\mu cV(dV/dt)] \qquad \text{--(I-6)}$$

From Eq (I-6) it follows that r is numerically equal to the pressure difference (applied vacuum P) required to produce a unit rate of filtrate flow (i.e. dV/dt=1.0) through a unit mass of cake (i.e. cV=1.0) and a unit filter area (A=1.0), if filtrate viscosity is unity (μ=1) or r=P if dV/dt=1.0, cV=1.0, μ=1.0, and A=1.0. Thus, the specific resistance r measures the ability of the sludge to be filtered; the higher the value, the more difficult is the filteration.In the usual range of operating conditions, the value of r can be related to pressure drop _P by empirical equation

$$r=r_0(\Delta P)^s$$

where, r_0 and s are constants. s is known as coefficient of compressibility of the cake.

Integrating Eq (I-5) assuming constant pressure over time, if at t=0, V=0 and at t=t, V=V, integration of Eq (I-5) yields.

$$(\mu/A^2P)\int_0^V rc(V + V_fA)dV = \int_0^t dt$$

Assuming the specific resistance of cake to be constant.

$$(\mu/A^2P)rc\left[\int_0^V VdV + V_fA\int_0^V dV\right] = \int_0^t dt$$

or

$$(\mu/A^2P)rc((V^2/2) + V_fAV) = t$$

Dividing both members by V and rearranging, and putting $rcV_f=R_m$, medium resistance)

$$t/V = (\mu rc/2PA^2)V + \mu R_m/AP \qquad \text{--(I-7)}$$

From Eq (I-7) it follows that a plot of t/V vs, V yields a straight line, values of specific cake resistance r and medium resistance R_m are evaluated from the slope and intercept of this line, respectively.

$$r = (2PA^2/\mu cV)s_1 \qquad \text{--(I-8)}$$

$$Rm = iAP/\mu \qquad \text{--(I-9)}$$

where s and i denote the slope and the intercept of the straight line. Eq (I-8) is the required equation for specific resistance to filteration.

2.0 Derivation of the Relationship for c (Mass of Cake Deposited per Unit Volume of Filtrate)(36) (Eq 2 Chapter 3)

The cake deposited per volume of filtrate, c, can be approximated by the feed solids concentration in kg/m^3. More accurately, it can be represented as

$$c = c_c c_i \,/\, 100\,(c_c - c_i)$$

where, c_c = cake solids concentration, %

c_i = feed solids concentration, %

This relationship can be derived from materials balance.

Let Q is flow rate and c is solids concentration, and the subscripts i, f and c denote feed, filtrate and cake, respectively.

A liquid balance gives

$$Q_i = Q_f + Q_c \qquad \text{--(I-10)}$$

and a solids balance yields

$$Q_i c_i = Q_f c_F + Q_c c_c \qquad \text{--(I-11)}$$

The weight of dry solids deposited as cake per volume of filtrate, defined as c, is

$$c = Q_c c_c \,/\, Q_f \qquad \text{--(I-12)}$$

Substituting from the liquid balance above(Eq^n.I-10),

$$c = (Q_i - Q_f)\, c_c \,/\, Q_f = (Q_i c_c - Q_f c_c)/\, Q_f \qquad \text{--(I-13)}$$

Rearranging the solid balance (Eq I-11) and substituting from liquid balance Eq (I-10),

$$Q_f c_f = Q_i c_i - Q_c c_c$$

$$Q_f c_f = Q_i c_i - (Q_i - Q_f) c_c$$

$Q_f c_f - Q_f c_c = Q_i c_i - Q_i c_c$

$Q_f = Q_i\ (c_i - c_c)\ /\ c_f - c_c$

Substituting the value of Q_f in Eq (I-13) and rearranging.

$c = c_c\ (c_f - c_i)\ /\ c_i - c_c$ --(I-14)

If the filtrate solids are assumed to be negligible i.e. $c_f = 0$, Eq (I-14) becomes

$c = c_c c_i\ /\ (c_c - c_i)$ --(I-15)

If the solids concentration is expressed in percent, the Eq (I-15) results

$c = c_c c_i\ /\ 100\ (c_c - c_i)$ --(I-16)

3.0 Derivation of the Relationship for L (Filter Yield or Filter Cycle Loading Rate)(36) (Eq III-1)

From Eq I-7,

$t = (\mu rc/2PA^2)V^2 + \mu R_m V/AP$

Assuming resistance of filter medium R_m is negligible, thus

$t = (\mu rc/2PA^2)V^2$

or $V/A = (2Pt/\mu rc)^{1/2}$ = Volume of Filtrate / Filter Area

As known,

c = Weight of Cake / Volume of Filtrate

Therefore

$c(V/A) = (2Ptc/\mu r)^{1/2}$ = Weight of Cake / Filter Area --(I-17)

A drum filter operates so that the time of cake formation , t, is only some fraction, k_f , of the total cycle time t_c (Time for one drum rotation), or

$t = k_f t_c$ (In a rotary drum filter k_f equals the fractional submergence of the drum in the slurry)

Almost same trend has been observed with primary and secondary sludges of Mill B, when comparing the results with all the four flocculants used. However on comparing only alum and ferric sulfate, the performance of later has been observed to be slightly better as compared to previous trend. In one trial, SRF values of primary sludge has been found to decrease from $1.92x10^{10}$ to $4.31x10^{7}$ s^2/g with ferric chloride, to $1.26x10^{8}$ s^2/g with ferric sulfate, to $1.44x10^{8}$ s^2/g with alum, and to $2.37x10^{8}$ s^2/g with lime at a dose of 8% (Table No. 4.7b). Similarly at 8% dose, SRF values of secondary sludge of $6.71x10^{10}$ s^2/g initial SRF values has been found to be $8.31x10^{7}$, $1.50x10^{8}$, $2.00x10^{8}$ and$5.01x10^{8}$ s^2/g with ferric chloride, ferric sulfate, alum and lime respectively (Table No. 4.8a).

On comparing the effect of organic polymer in conditioning primary sludges for dewatering i.e., on SRF values, it has been found that only cationic polymer has improved the dewatering rate by lowering SRF significantly. The power of SRF reduction of sludge by anionic polymer has been observed identical initially (at a dose of 0.2 to 0.4%) with cationic polymer. But, at higher doses of anionic polymer it is found that there has been no change or there has been increase in SRF value. It is important to note that the minimum SRF value obtained has not been significant to appreciably improve the filteration rate as compared to initial rate without flocculant. The reason may be due to the fact that the particles in the sludge are also anionic in nature so there is better flocculation with cationic polymer.

The same is also true with secondary sludges of both the mills. For example; with primary sludge at Mill A of initial SRF value 4.61×10^9 s^2/g, the SRF values obtained at a dose of 0.4 and 0.8% are 4.20×10^8 and 7.01×10^8 s^2/g respectively with anionic polymer A; 3.55×10^8 and 5.82×10^8 s^2/g respectively with cationic polymer; and 3.98×10^9 and 6.45×10^8 s^2/g respectively with anionic polymer B(Table No. 4.9a). Similarly, with secondary sludge of Mill B of initial SRF value 6.71×10^{10} s^2/g , the SRF values obtained at the same dose are 1.65×10^{10} and 4.41×10^8 s^2/g with cationic polymer; 1.48×10^{10} and 2.18×10^9 s^2/g with anionic A; and 1.20×10^{10} and 2.21×10^9 s^2/g with anionic B (Table No. 4.12a). The values of SRF obtained at 0.8% dose with anionic polymers are the minimum values, which are too high compared to minimum SRF value of 5.90×10^7 s^2/g obtained with cationic polymer at a dose of 1.4%.

It is also clear that in comparison to inorganic polymers, the dose required for cationic polymer is much low to reduce the SRF value by same magnitude.

Fig. 4.6a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill B,Trial No.1)

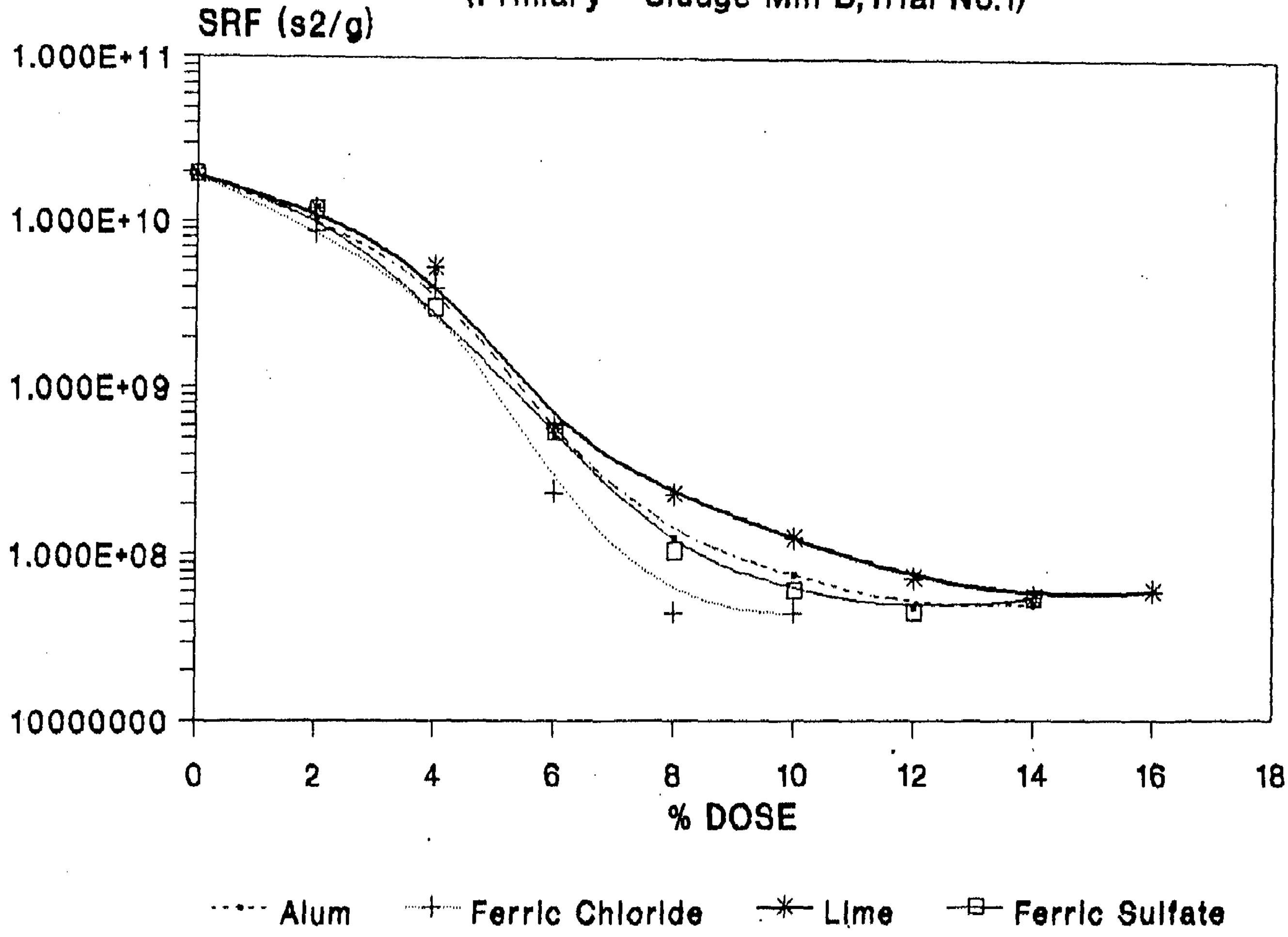


Fig. 4.6b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill B,Trial No.2)

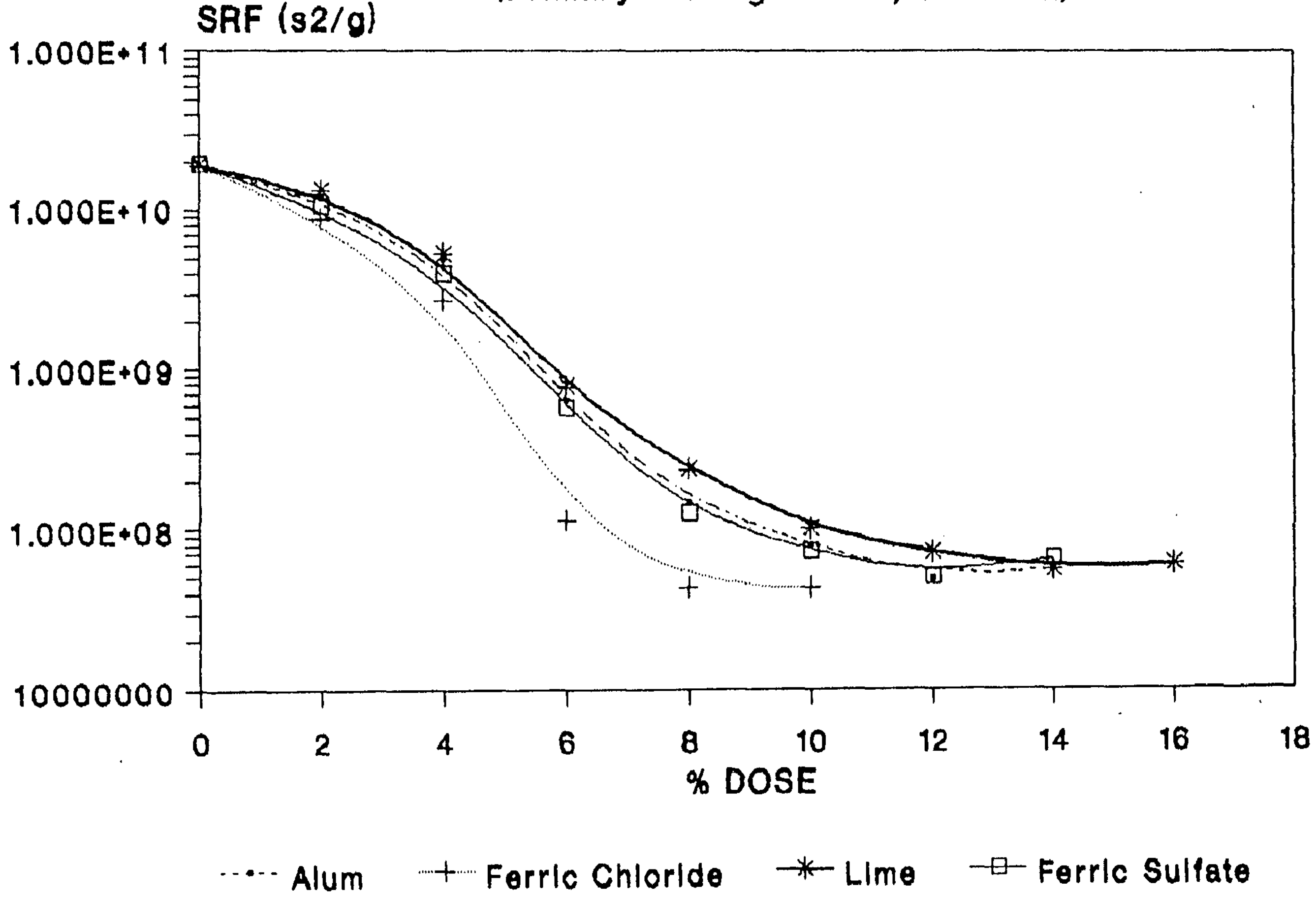


Fig. 4.6c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill B, Trial No. 3)

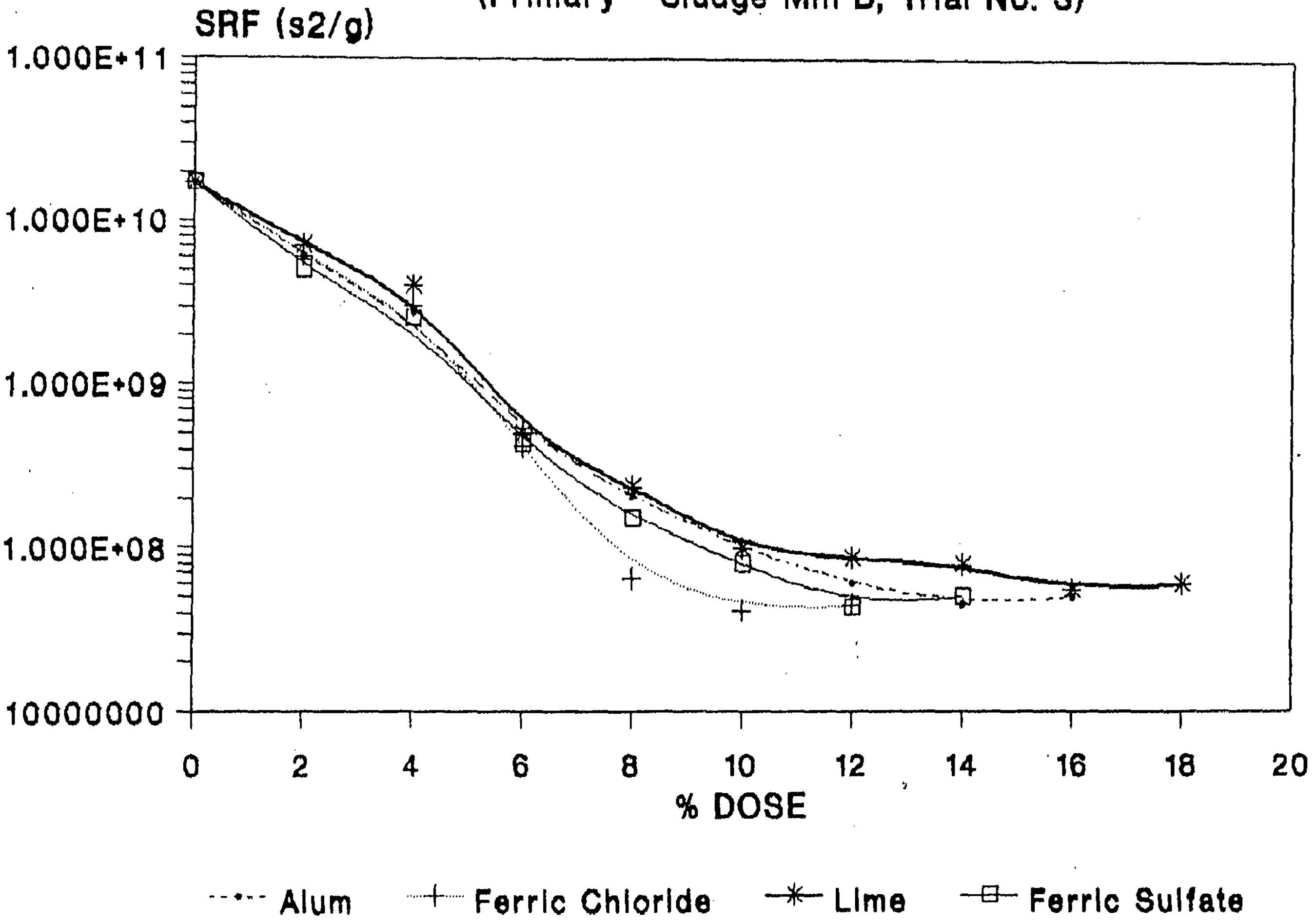


Fig. 4.7a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill B, Trial No.1)

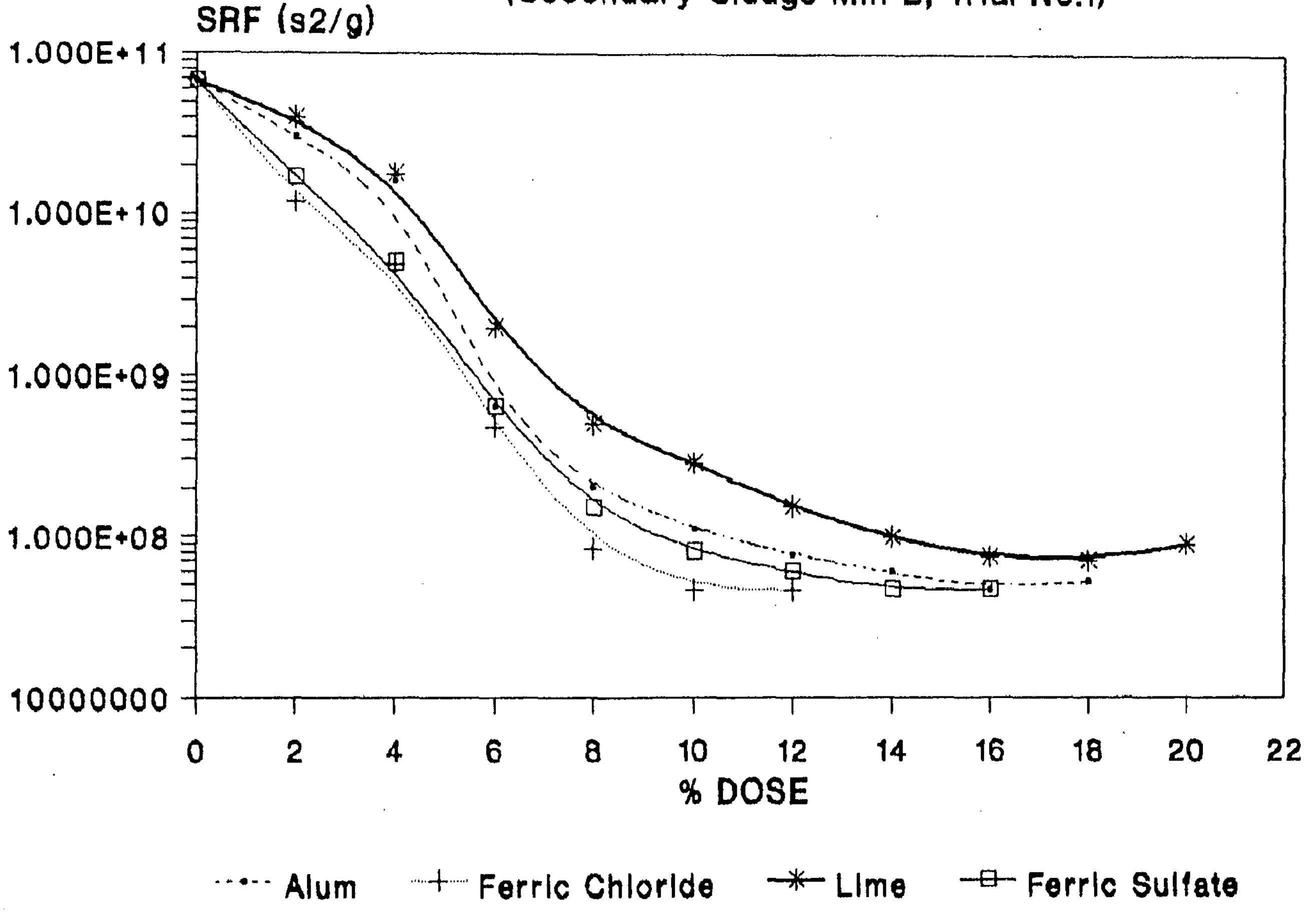


Fig. 4.8a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill A, Trial No. 1)

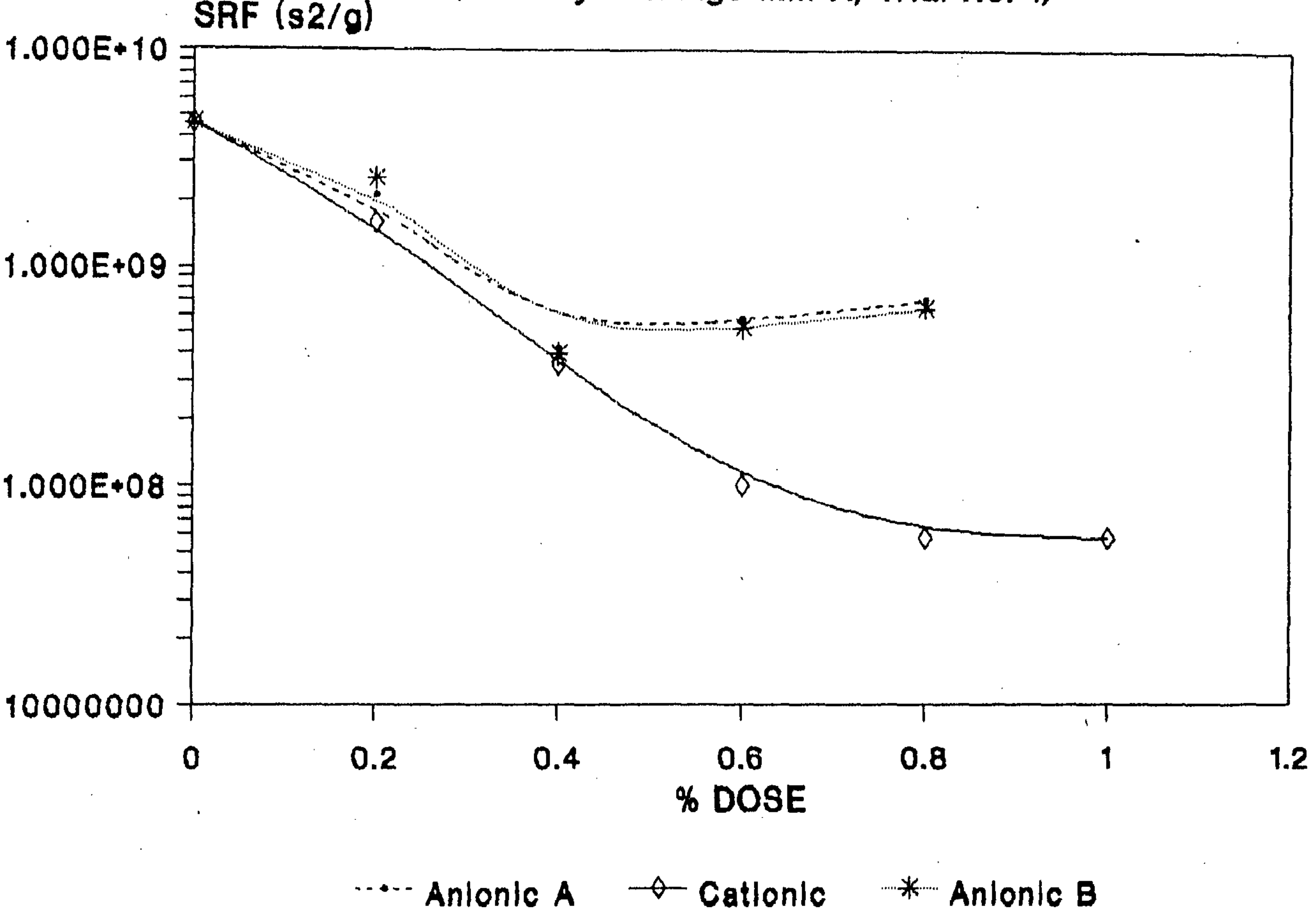


Fig. 4.8b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill A, Trial No.2)

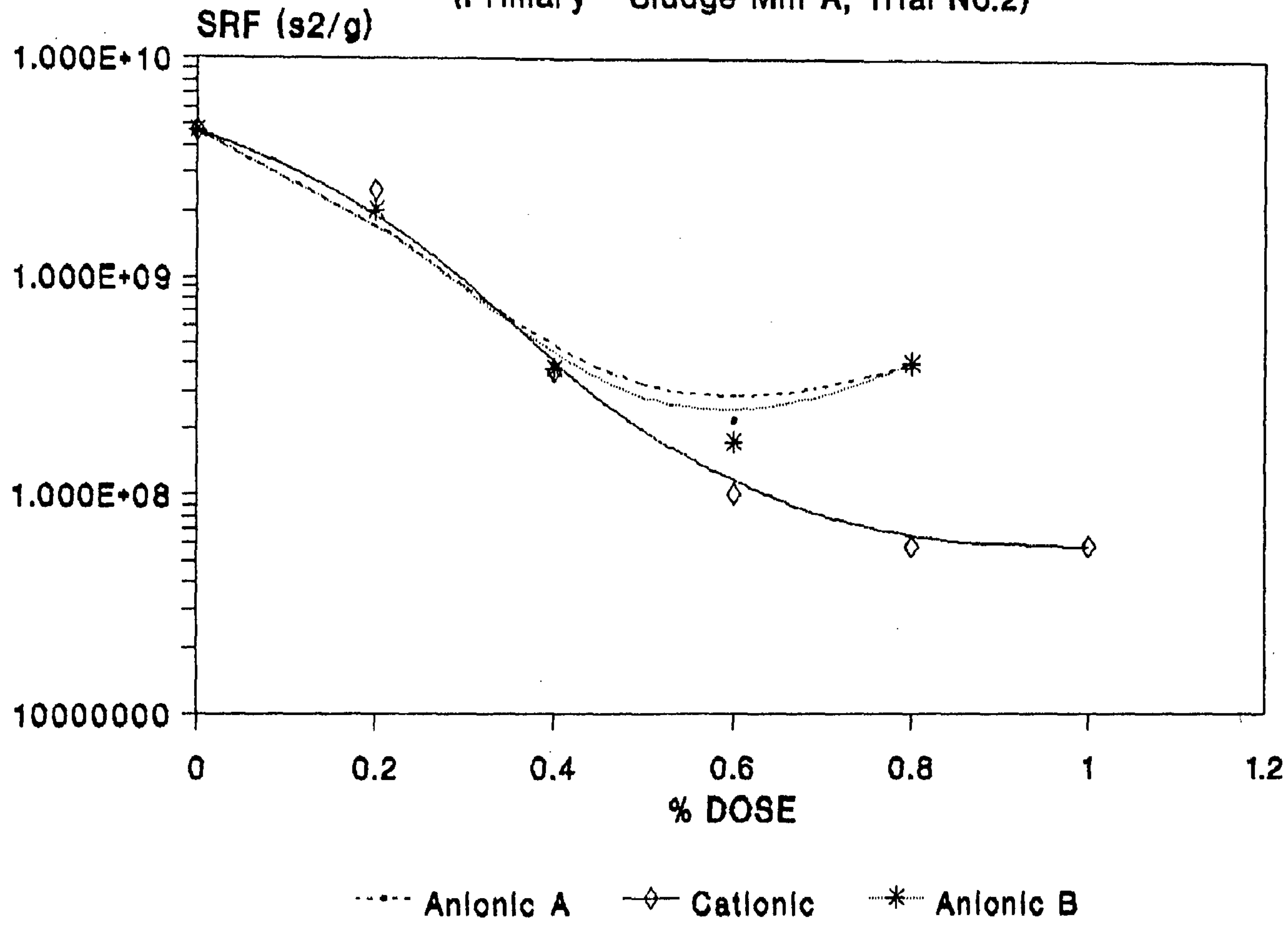


Fig. 4.8c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill A, Trial No.3)

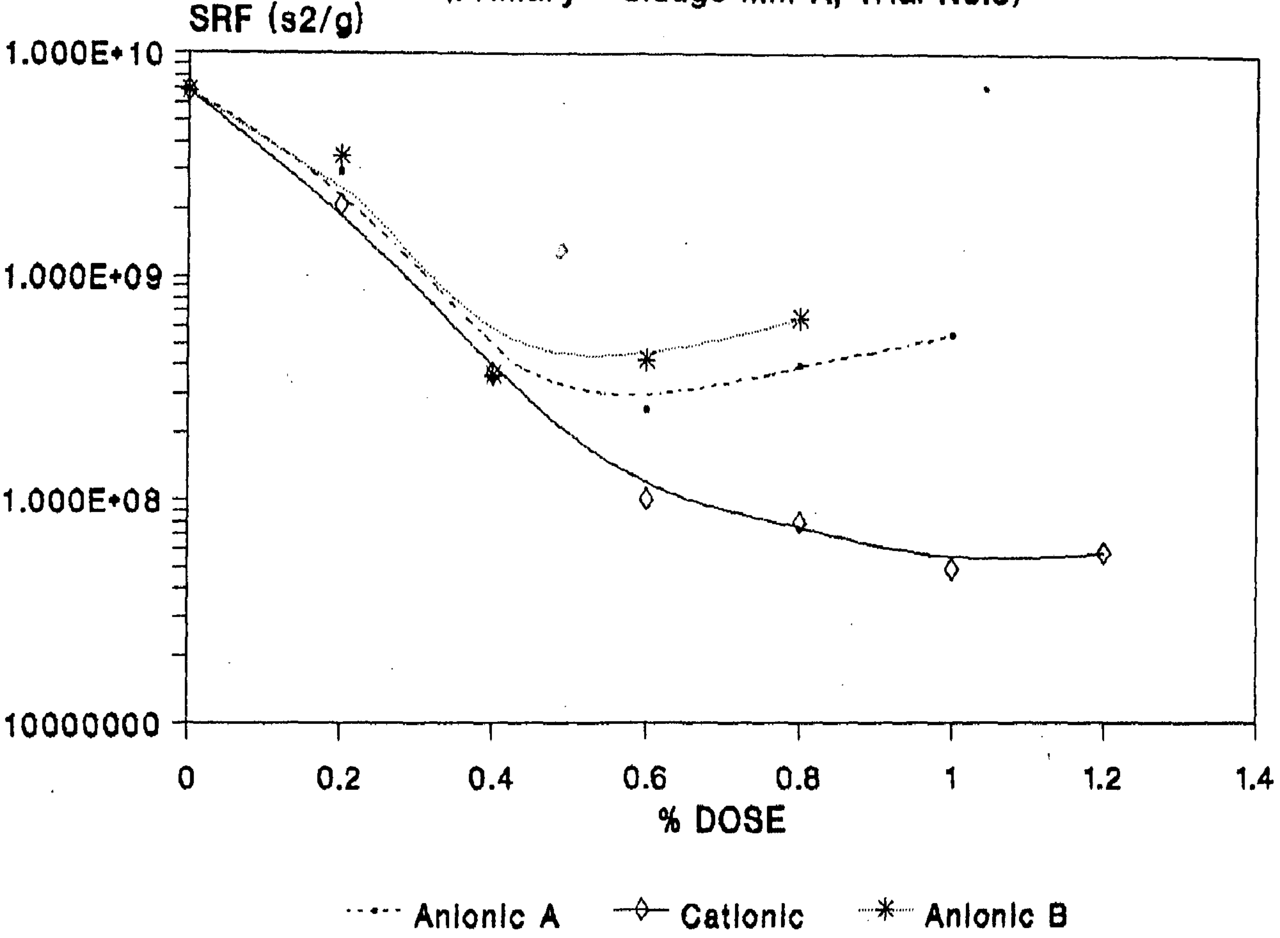


Fig. 4.9a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill A,Trial NO.1)

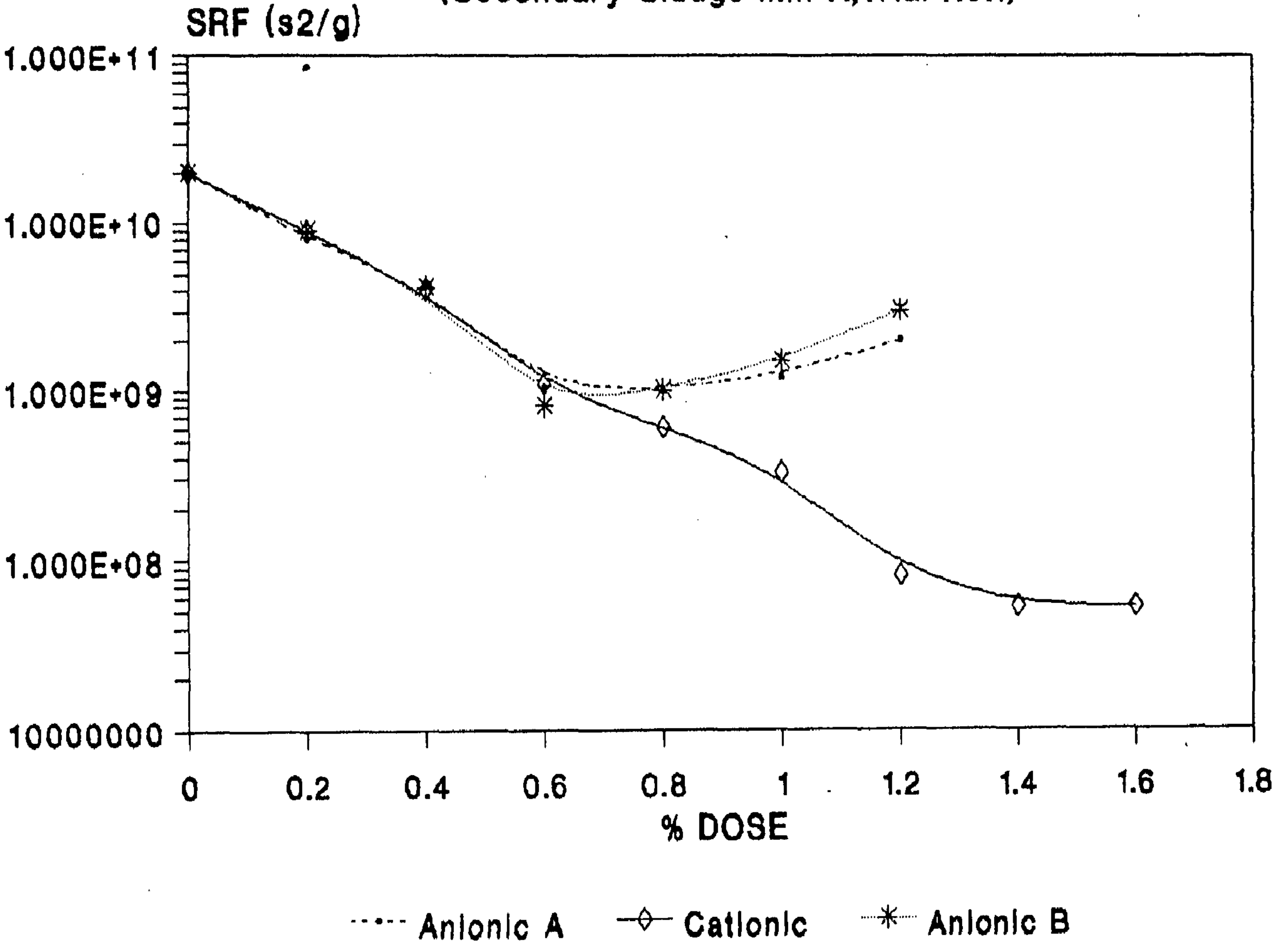


Fig. 4.9b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill A,Trial No.2)

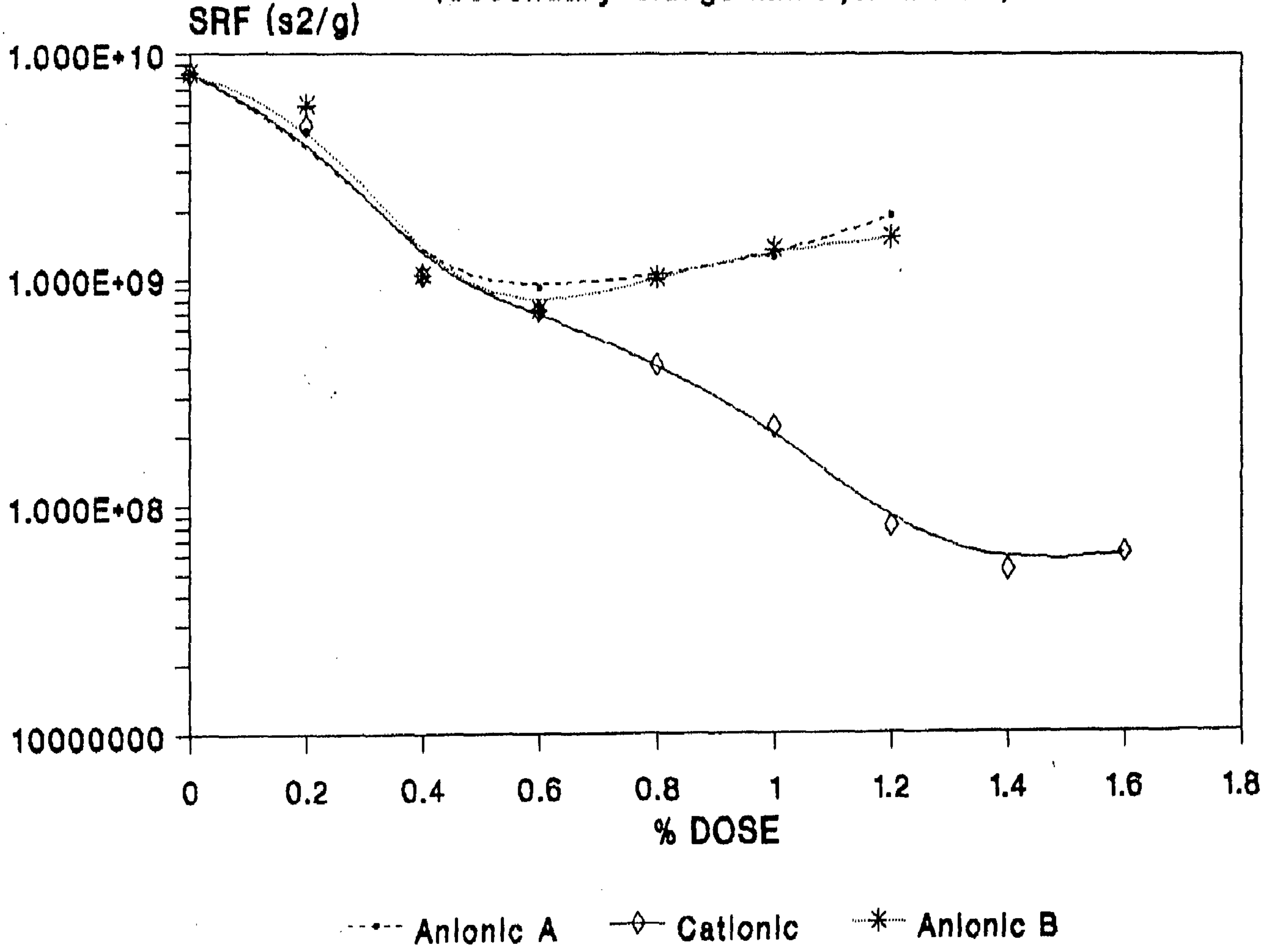


Fig. 4.9c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill A, Trial No.3)

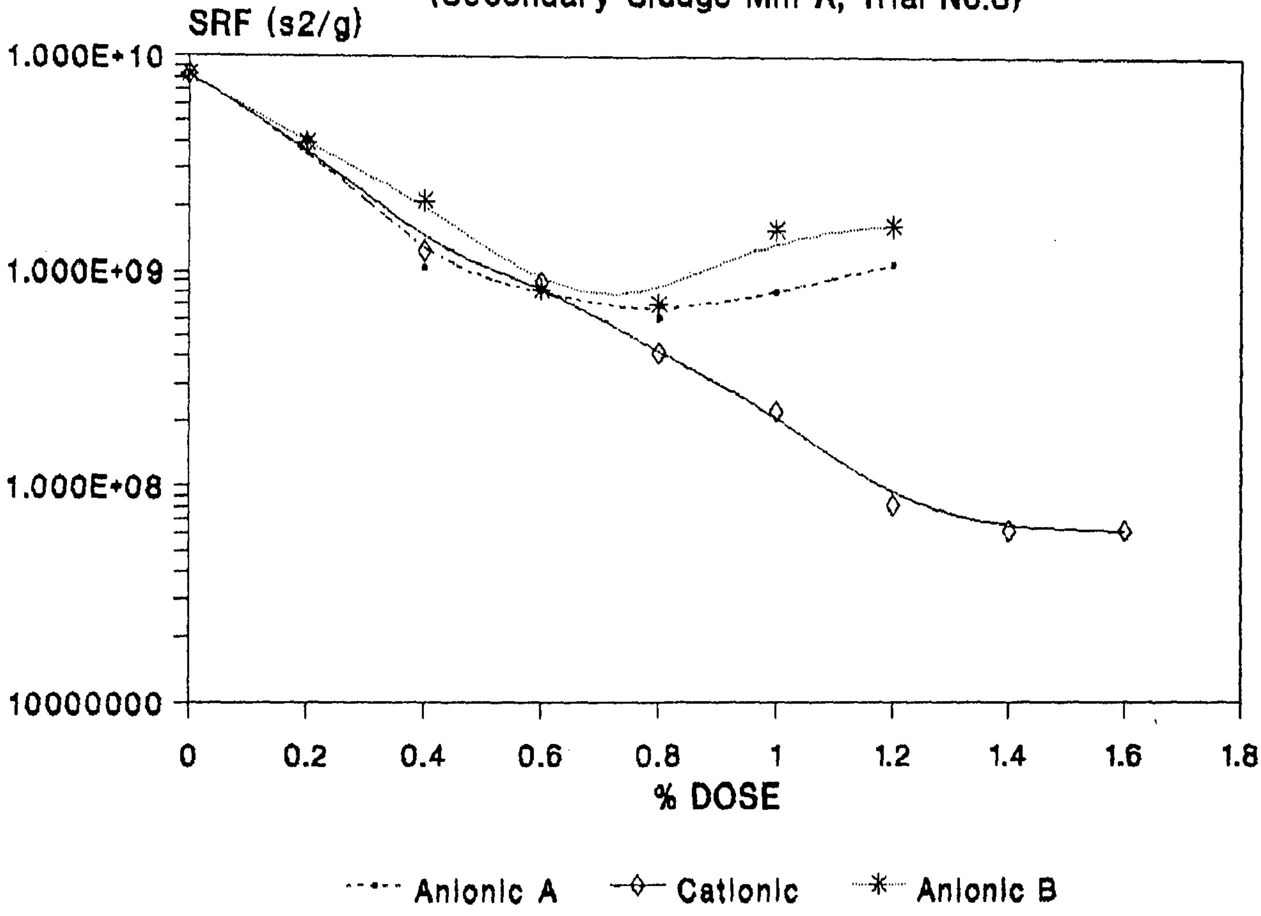


Fig. 4.10a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTÁNCE TO FILTERATION (SRF)

(Primary Sludge Mill B, Trial No.1)

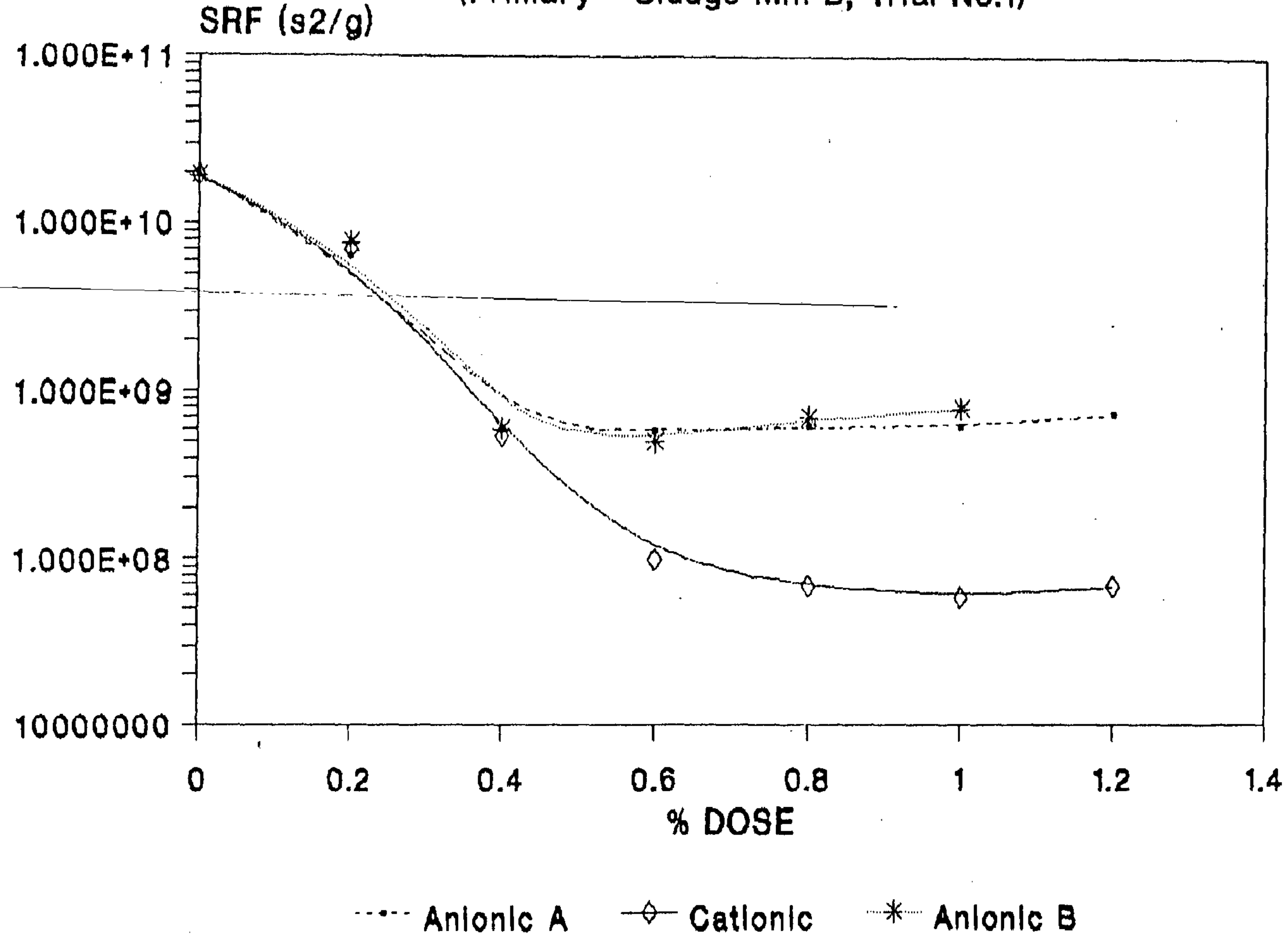


Fig. 4.10b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill B, Trial No. 2)

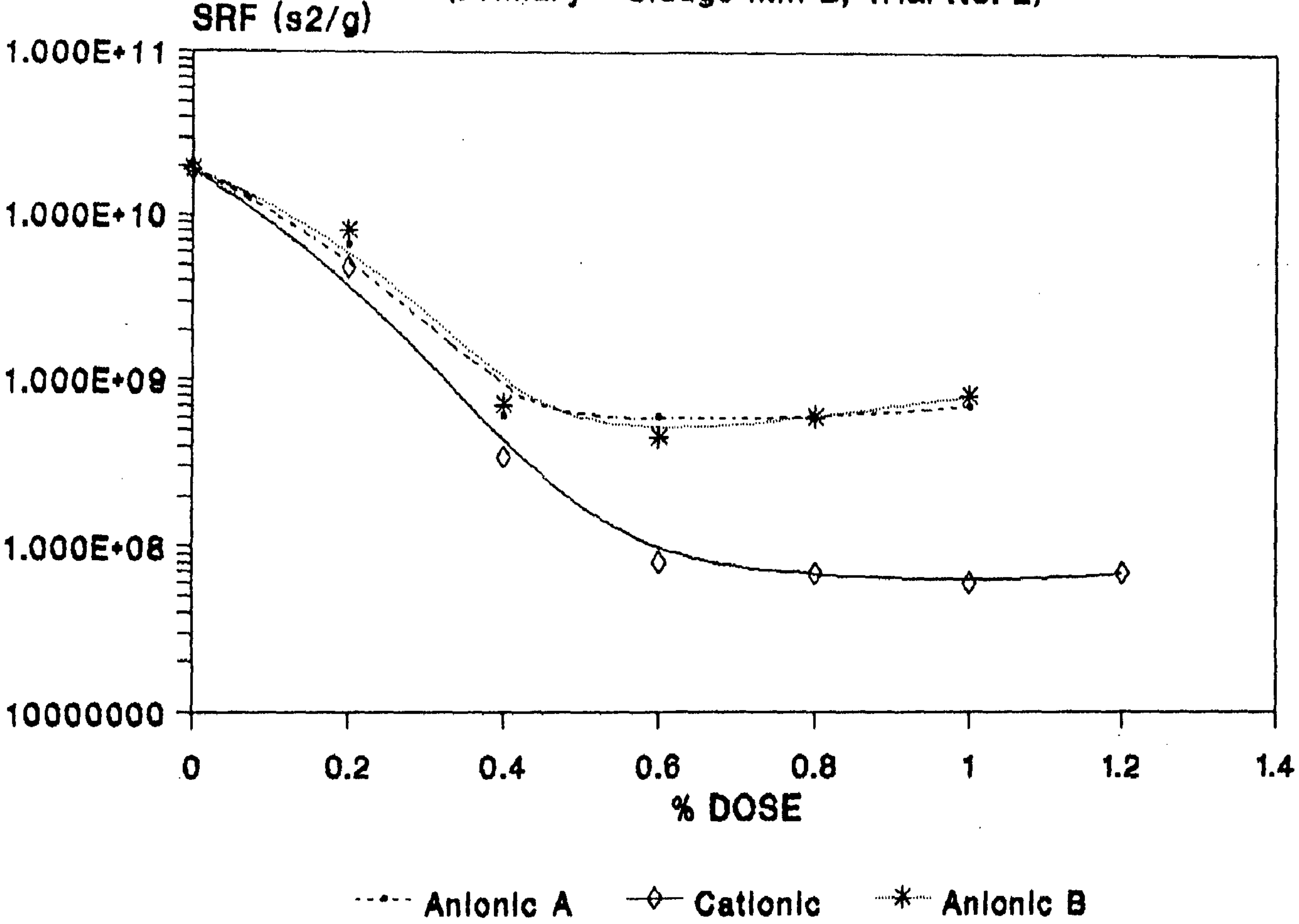


Fig. 4.10c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Primary Sludge Mill B, Trial No.3)

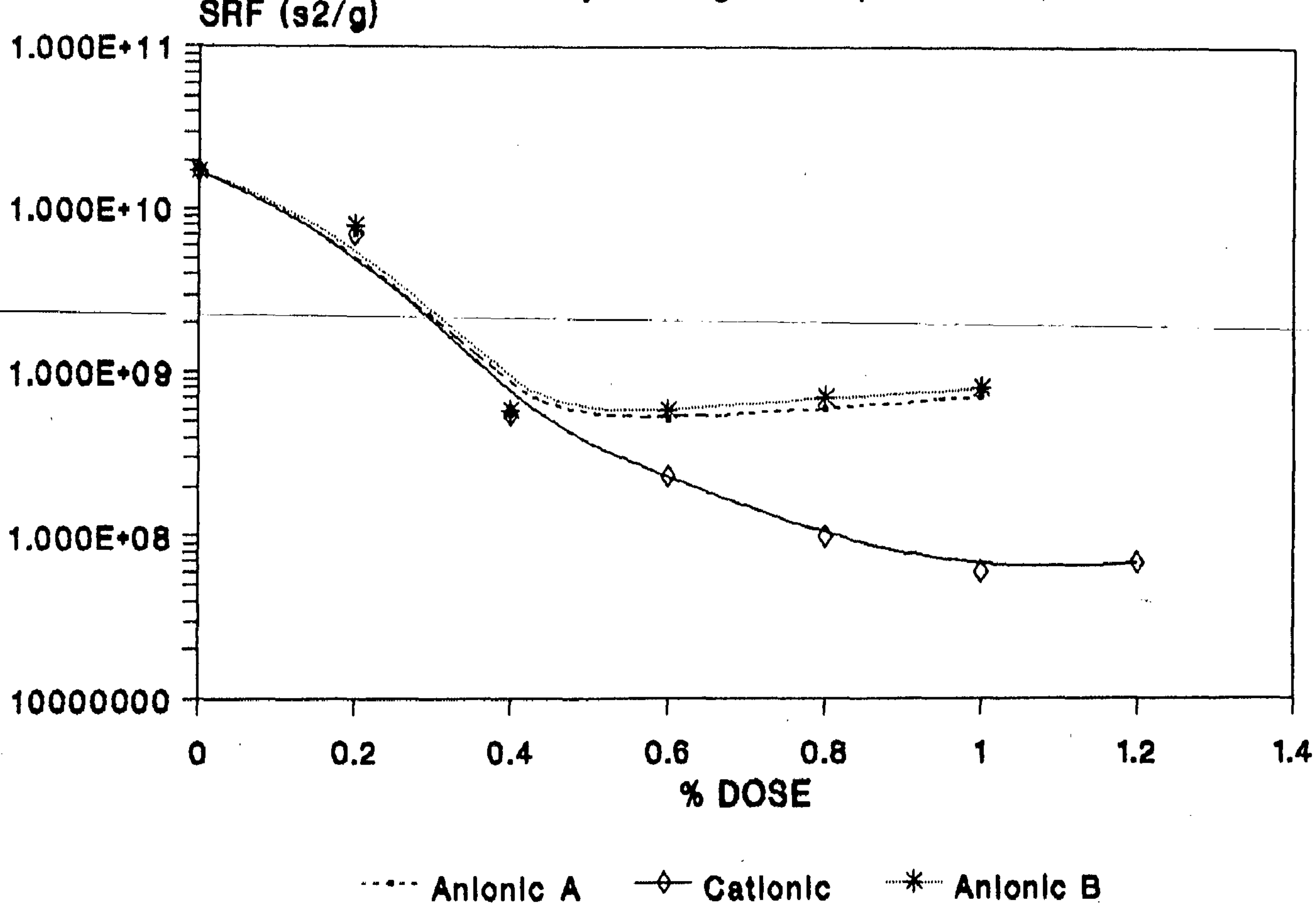


Fig. 4.11a: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill B, Trial No. 1)

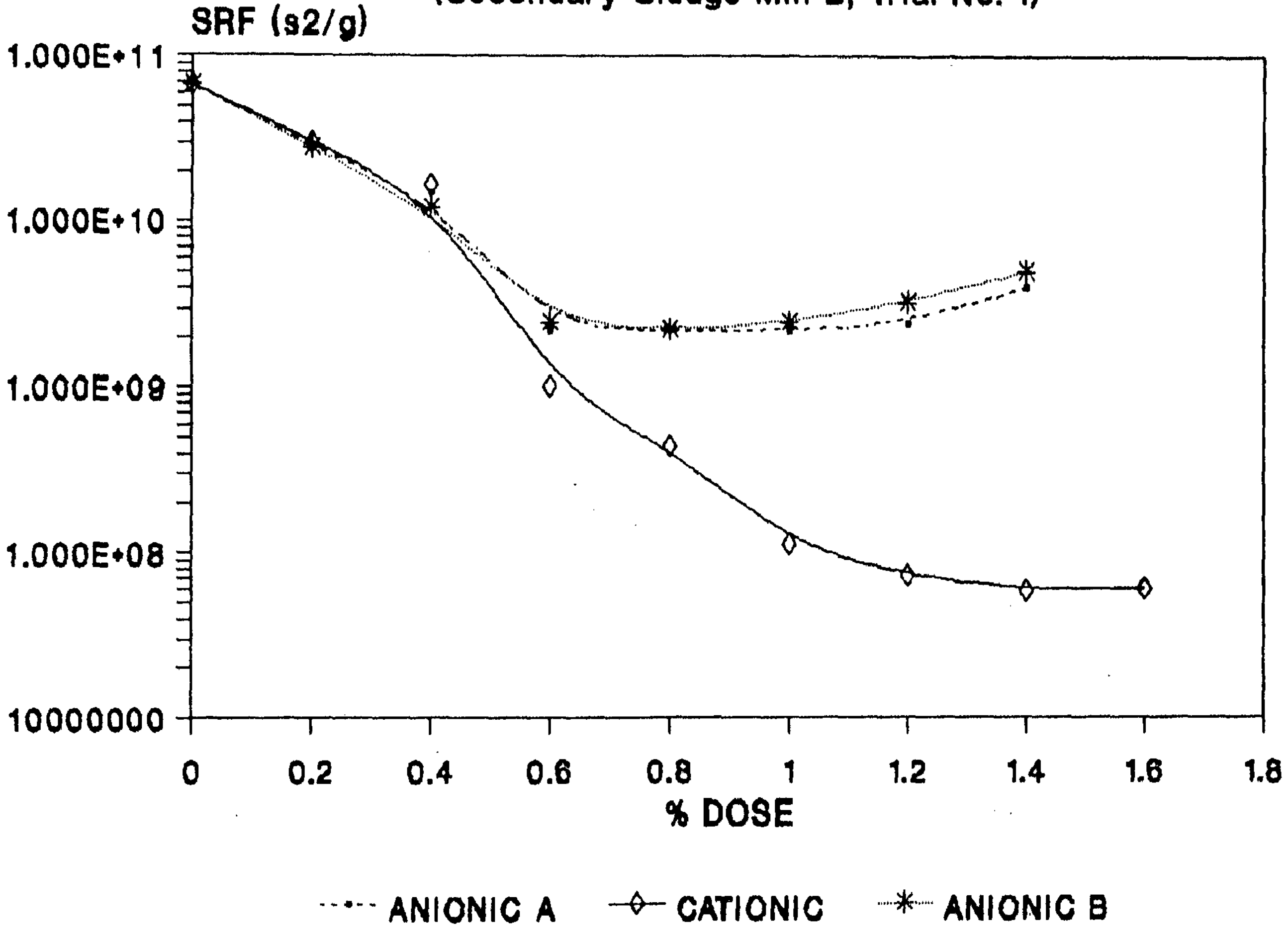


Fig. 4.11b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill B, Trial No.2)

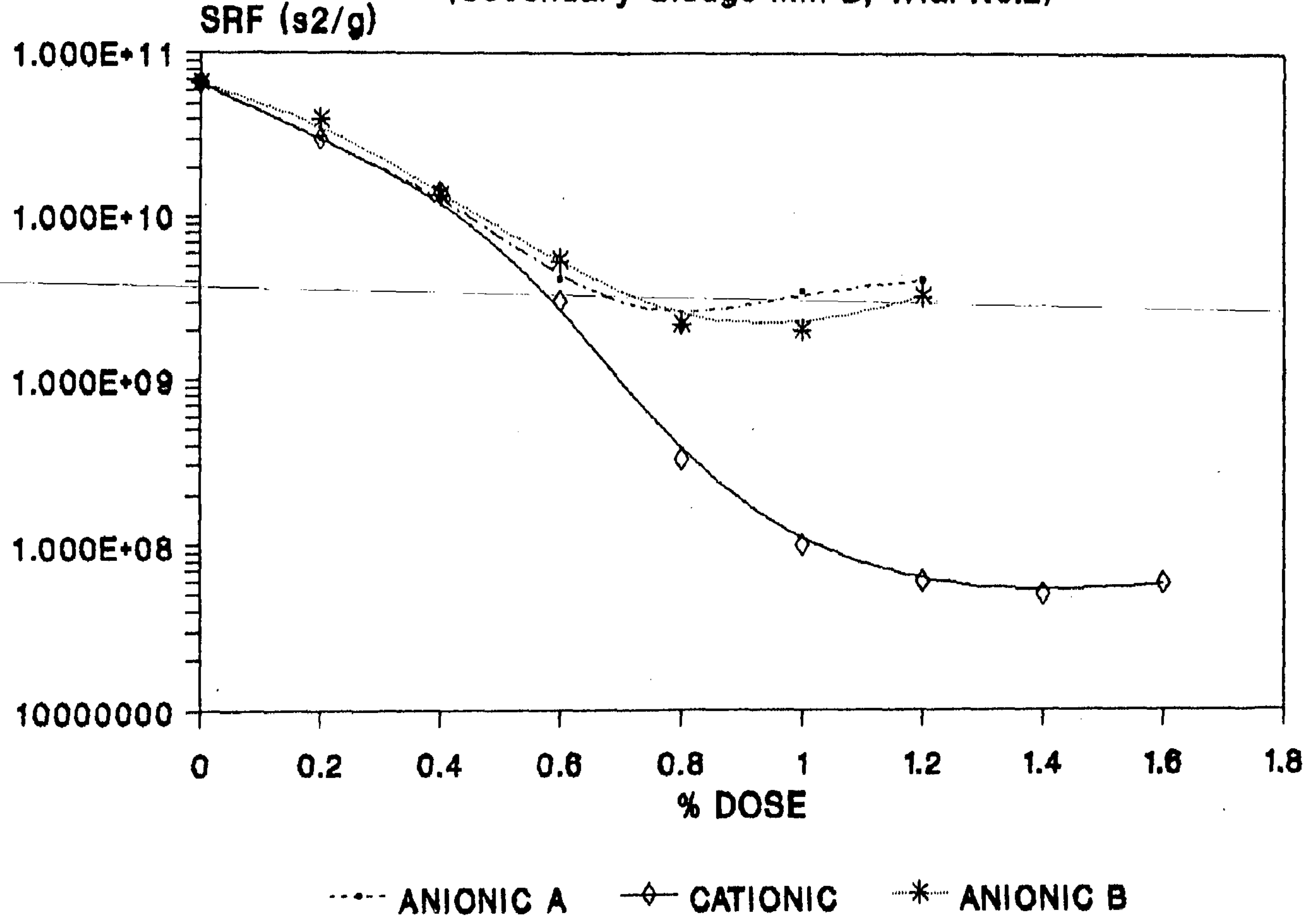
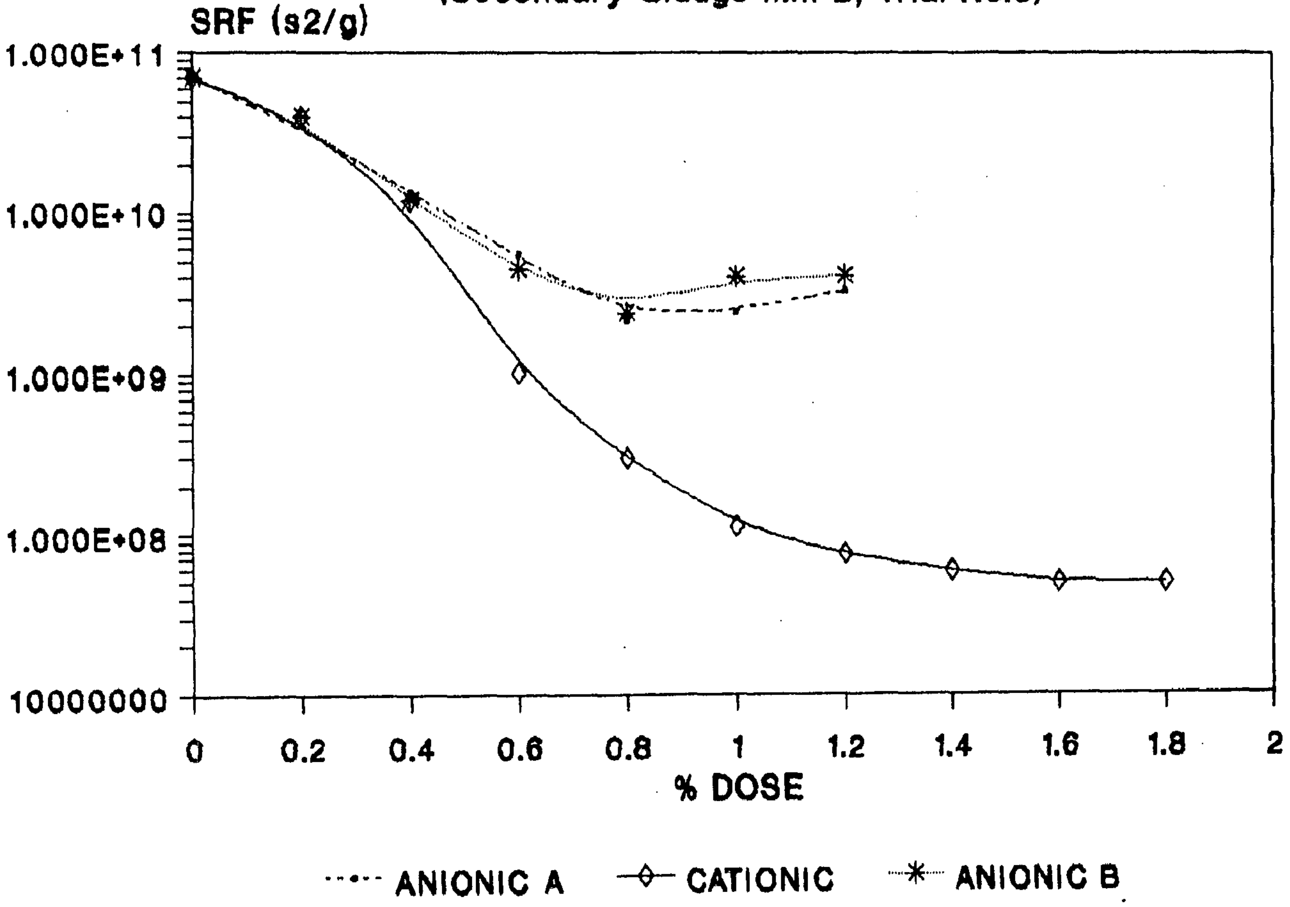


Fig. 4.11c: EFFECT OF DIFFERENT DOSAGE OF VARIOUS ORGANIC FLOCCULANTS (POLYMERS) ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill B, Trial No.3)



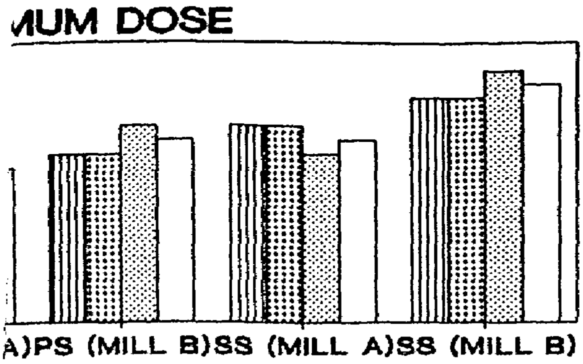
4.5 Optimum Dose of Various Flocculants:

The values of optimum dose of different flocculants for primary and secondary sludges for both the mills have been given in Table 4.13, and the same has been shown in histograms (Fig. 4.12a and 4.12b) for better clarity. The optimum dose has been found to vary with type of sludge and even slight variation has been noticed for same sludge collected at different times.

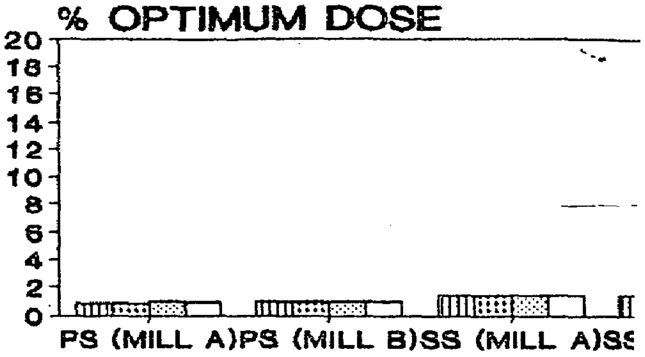
The percent optimum dose of various flocculants for primary sludge of Mill A are 9,11,12,13, and 0.9% for ferric chloride, ~~alum, ferric sulfate, lime and cationic polymer respectively.~~ Similarly, in case of primary sludge of Mill B, the optimum dose has been found to be 9,13,12,15 and 1.0 percent respectively of ferric chloride, alum, ferric sulfate, lime and cationic polymer. It is clear that the optimum dose requirement for primary sludge of Mill B is higher compared to primary sludge of Mill A in the case of all the flocculants used except in case of ferric chloride. Also, the optimum dose requirement is minimum for cationic polymer followed by ferric chloride, alum/ ferric sulfate and lime for primary sludges of both the mills. The similar trend has been observed for secondary sludges of both the mills. However, the optimum dose requirement of secondary sludge is higher than primary sludge of the same mill. For example, the optimum dose of cationic polymer, ferric chloride, alum, ferric sulfate and lime are 1.4,11,13,14, and 16 and 1.5,11,17,15 and 18 respectively for secondary sludges of Mill A and B.

4.13b : OPTIMUM DOSAGE OF DIFF
FOR DIFFEREN

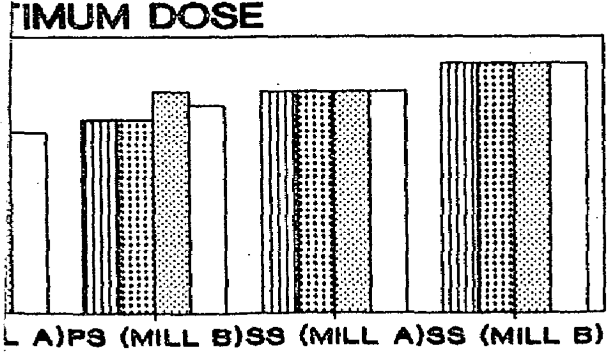
ALUM



CATIONIC POLYME



LIME



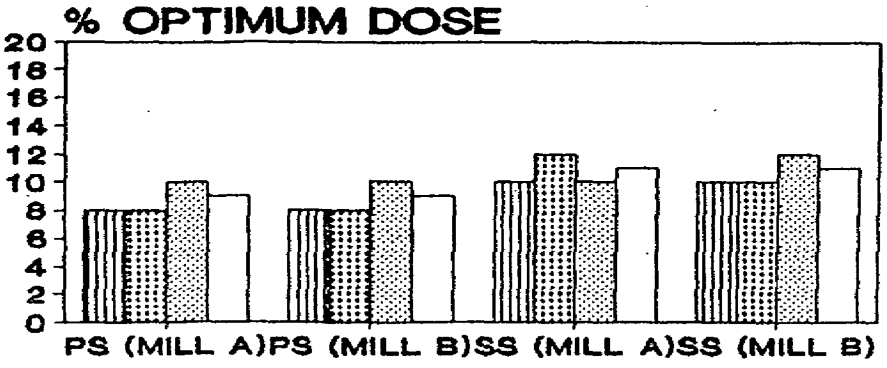
▥ TRIAL No.1 ▦

▨ TRIAL No.3 ☐

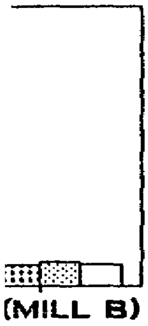
PS : PRIMARY SLUDGE
SS : SECONDARY SLUDGE

ERENT FLOCCULANTS
SLUDGES

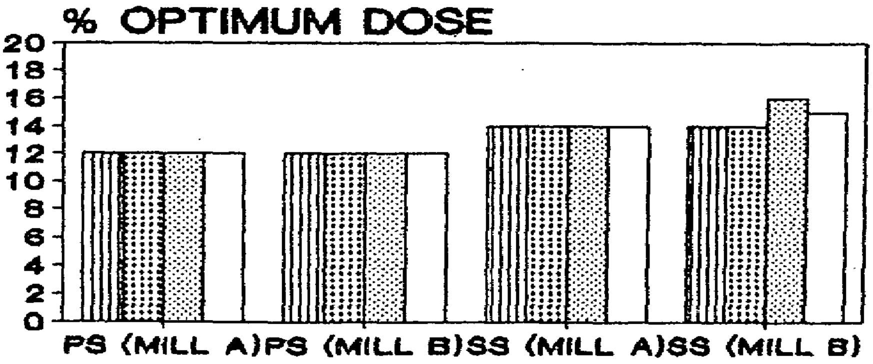
FERRIC CHLORIDE



R



FERRIC SULFATE



▨ TRIAL No.2

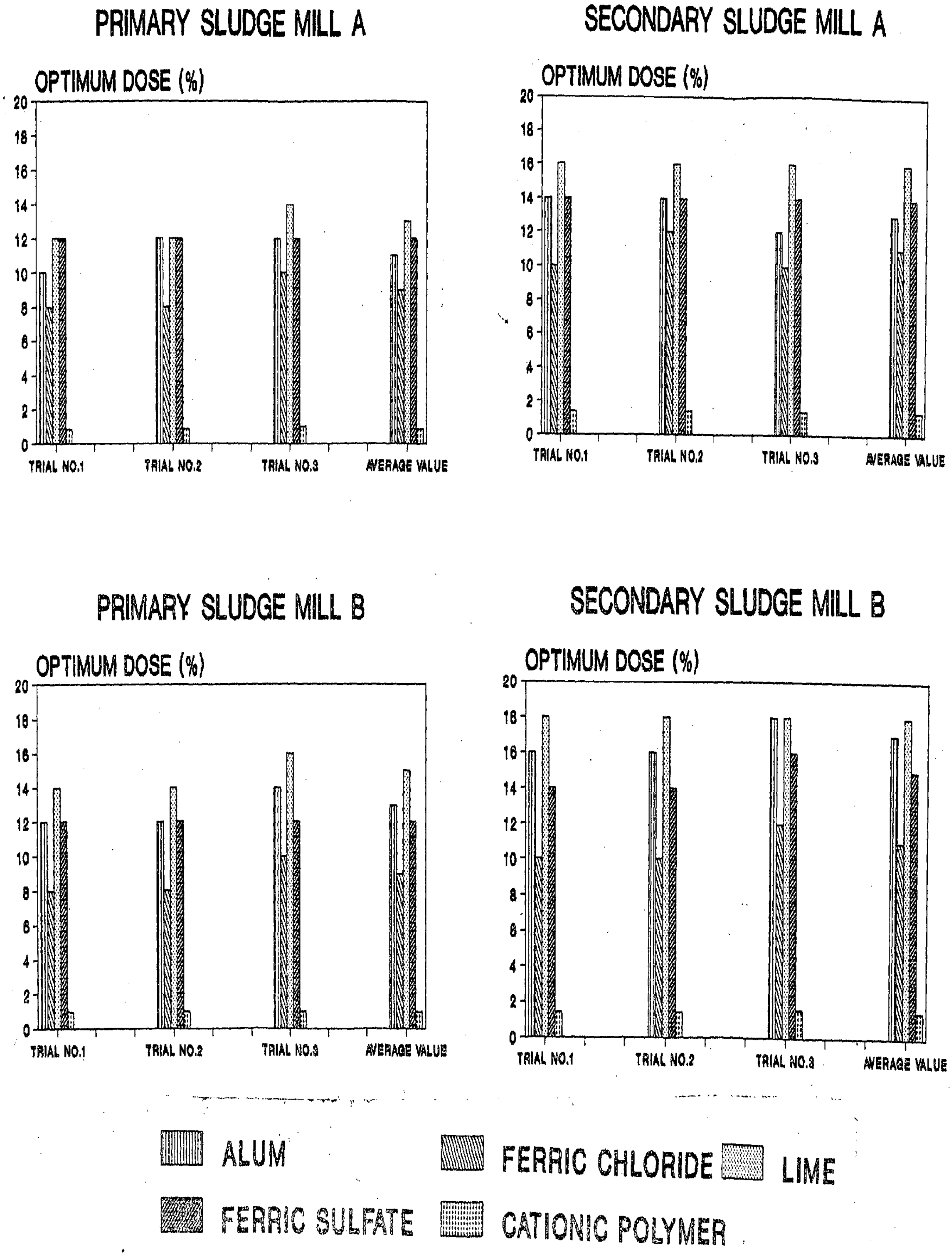
☐ AVERAGE VALUE

4.6 Effect of Mixing Time During Conditioning with Flocculants:

During the course of experiments it has been observed that the optimum mixing speed depends upon total solids concentration (if difference in concentration is appreciable). The main aim during the rapid mixing period must be to disperse the flocculant properly but high rapid mixing should not be for prolonged period. However, just mixing of chemicals will not improve the filterability and slow mixing is must to promote floc formation. Similarly, slow mixing which generally helps in flocculation must be very gentle. This must be for a short period so that floc should not break. The total mixing time has been maintained to 3 min (composed of 1 min. of rapid mixing and 2 min. of slow mixing) in all the cases during the experiments.

The effect of rapid mixing time has been determined by measuring SRF at various mixing times. Total mixing time was equal to rapid mixing time plus 2 min. of slow mixing i.e. the change in total mixing time was due to change in rapid mixing portion of the mixing cycle. Ferric chloride, alum and cationic polymer has been used for study and dose used is around optimum dose which has been found previously (para 4.4). The results shown in Table 4.14a and 4.14b and 4.15a and 4.15b for mill A and B and are also plotted as figure 4.13a, 4.13b, 4.14a and 4.14b. These results indicate that with the increase in rapid mixing time beyond 1-1.5 min or with decrease in rapid mixing time below 1 min, increase

Fig 4.13a : OPTIMUM DOSAGE OF DIFFERENT FLOCCULANTS FOR DIFFERENT SLUDGES

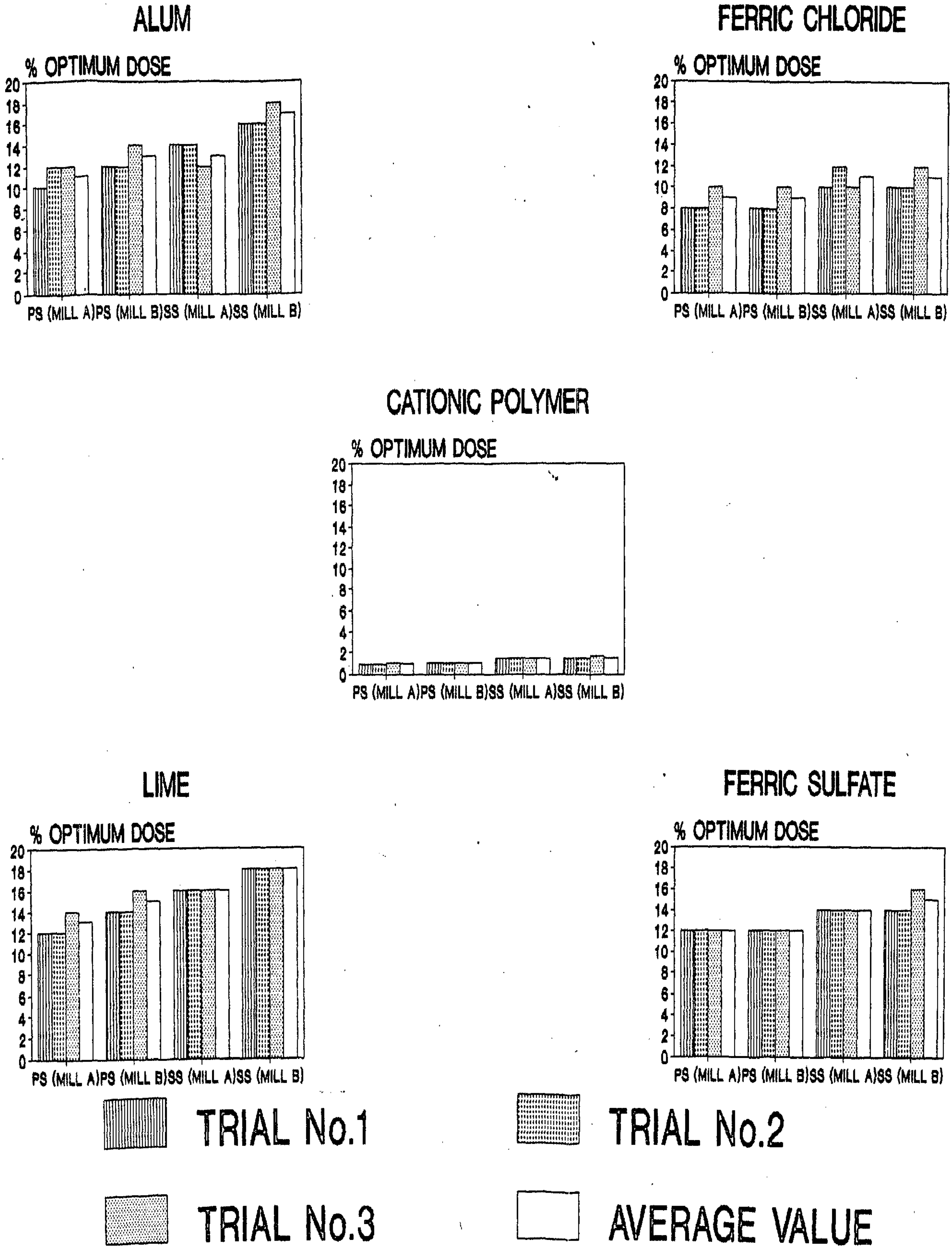

PRIMARY SLUDGE MILL A

SECONDARY SLUDGE MILL A

PRIMARY SLUDGE MILL B

SECONDARY SLUDGE MILL B

Fig. 4.13b : OPTIMUM DOSAGE OF DIFFERENT FLOCCULANTS FOR DIFFERENT SLUDGES



PS : PRIMARY SLUDGE
SS : SECONDARY SLUDGE

4.6 Effect of Mixing Time During Conditioning with Flocculants:

During the course of experiments it has been observed that the optimum mixing speed depends upon total solids concentration (if difference in concentration is appreciable). The main aim during the rapid mixing period must be to disperse the flocculant properly but high rapid mixing should not be for prolonged period. However, just mixing of chemicals will not improve the filterability and slow mixing is must to promote floc formation. Similarly, slow mixing which generally helps in flocculation must be very gentle. This must be for a short period so that floc should not break. The total mixing time has been maintained to 3 min (composed of 1 min. of rapid mixing and 2 min. of slow mixing) in all the cases during the experiments.

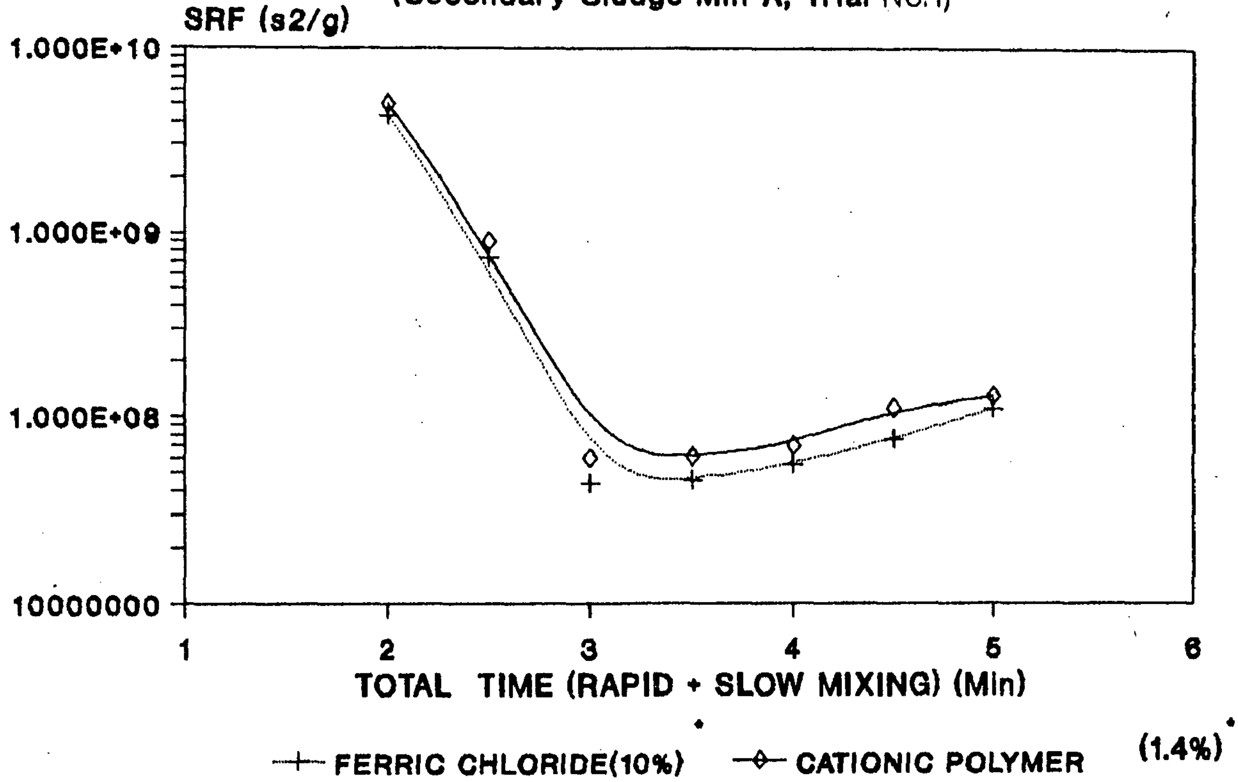
The effect of rapid mixing time has been determined by measuring SRF at various mixing times. Total mixing time was equal to rapid mixing time plus 2 min. of slow mixing i.e. the change in total mixing time was due to change in rapid mixing portion of the mixing cycle. Ferric chloride, alum and cationic polymer has been used for study and dose used is around optimum dose which has been found previously (para 4.4). The results shown in Table 4.14a and 4.14b and 4.15a and 4.15b for mill A and B and are also plotted as figure 4.13a, 4.13b, 4.14a and 4.14b. These results indicate that with the increase in rapid mixing time beyond 1-1.5 min or with decrease in rapid mixing time below 1 min, increase in SRF value has been observed indicating the deterioration of dewatering rate. The optimum mixing time has been found to be 3 min. (composed of 1 minute of rapid mixing and 2 min slow mixing) in this case also.For example, at total cycle time of 2 min (0+2, zero minute rapid mixing, and 2 minutes slow mixing), 3 min (1+2),4 min (1+3) and 5 min (1+4), the values of SRF have been found to be 4.31×10^9 4.34×10^7 , 5.54×10^7 and 1.11×10^8 s^2/g respectively while using 10% ferric chloride to condition secondary sludge of Mill A (Table No. 4.14a).

Similarly, the effect of slow mixing time has been determined by keeping rapid mixing time of 1 min constant and changing slow mixing time. The results are shown in figures 4.15a and 4.15b for mill A and 4.16a, 4.16b for mill B. The values are given in tables 4.16a, 4,16b and 4.17a, 4.17b. The results indicate that if the slow mixing time is very low (less than 2 min) there has been decrease in dewatering rate indicated by high SRF value. However longer time (more than 2 min.) does not affect the results significantly provided gentle mixing is maintained.

For example, at a total cycle time of 1 min((1+0), 1 min. rapid mixing and zero min. slow mixing), 2 min(1+1), 3 min(1+2), 4 min(1+3) and 5 min (1+4), the SRF values of 2% cationic polymer conditioned secondary sludge of Mill B are of the order of 3.01×10^{10}, 2.09×10^8, 4.63×10^7, 4.63×10^7 and 7.02×10^7 s^2/g respectively (Table No. 4.17b).

Fig. 4.13a: EFFECT OF VARYING RAPID MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (SLOW MIXING TIME (2 MIN) KEPT CONSTANT)

(Secondary Sludge Mill A, Trial No.1)



* NEAR ABOUT OPTIMUM DOSE FOUND

Therefore, from Eq (I-17) one obtains

$$(c/t_c)(V/A) = (2Pck_f/\mu rt_c)^{1/2} = L \qquad \text{--(I-18)}$$

Where,

L = Filter loading rate $Kg/m^2/sec$.
(Weight of dry cake per unit time per unit area)

P = Applied vacuum (N/m^2)

c = Mass of dry cake deposited per unit volume of filtrate (Kg/m^3)

k_f= Fractional filter drum submergence

μ = Viscosity of filtrate (Ns/m^2)

r = Specific resistance of cake to filteration (m/kg)

4.0 Derivation of the Relationship for Air Suction Rate in Vacuum Filters and Power Requirement of Vacuum Pump for Vacuum Filters(38,39) :-

Air Suction Rate :

A vacuum pump must be supplied for the operation of a rotary vacuum filter. It is generally required to estimate the size of the pump and power requirement for a given filteration unit for a given throughput capacity . Because air leakage into the vacuum system may supply a major amount of the air that passes through the pump, design methods for predicting air suction rate must be considered as approximate since they do not account for air leakage.

The rate at which air is sucked through the dewatering section of a rotary vacuum filter can be expressed in a form similar to Eq (I-1) as,

$$dV_a/dt = A\Delta P/(R'_c + R'_m)\mu_a \qquad \text{--(I-19)}$$

Where, V_a is volume of air at temperature and pressure of surrounding sucked through cake in time t; μ_a is viscosity of air at temperature and pressure of surroundings; R'_c & R'_m is cake resistance and filter medium resistance respectively

Eq (I-19) is rewritten as,

$$dV_a/dt = A^2\ P/r_a c(V+AV'_f)\mu_a \qquad \text{--(I-20)}$$

(This can be obtained similar to equation (I-5))

where, $r_a = C'/p_c$ and is known as the specific air suction cake resistance

V = Volume of filtrate delivered in time t

V'_f = Fictitious volume of filtrate per unit of filtering area necessary to lay down a cake thickness of l'_f

c = Mass of dry cake solids deposited per unit volume of filtrate

Integrating equation (I-20) assuming constant pressure drop and at $t=0$, $V_a=0$, and $t=t$, $V_a=V_a$

$$V_a = A^2 Pt/r_a c(V+AV'_f)\mu_a \qquad \text{--(I-21)}$$

If the cake is compressible, a rough correction for variation in V_a with change in _P can be made by use of following empirical equation:

$$r_a = r_{ao}(\_P)^{s'}$$

where, r_{ao} and s' are constant.

Therefore, by neglecting the resistance of the filter medium, Eq (I-21) can be simplified to,

$$V_a = A^2 Pt/r_a cV\mu_a$$

If, k_a is fraction of total cycle time t_c available for air suction. Then, $t = k_a t_c$ and thus

Volume of air V_{aR} in time t_c (i.e. per revolution)

$$= A^2 Pk_a t_c/r_a cV\mu_a$$

or volume of air per unit time (cycle time) (V_{aR}/t_c)

$$= A^2 Pk_a/r_a cV\mu_a \qquad \text{--(I-22)}$$

putting value of $V = A[2 Pk_f t_c/\mu rc]^{1/2}$ from equation (I-18)

Volume of air per unit time

$$= [A^2 Pk_a/r_a c\mu_a](1/A)[\mu rc/2\_Pk_f t_c]^{1/2}$$

$$= [Ak_a/r_a\mu_a][\mu r\ P/2ck_f t_c]^{1/2} \qquad \text{--(I-23)}$$

Therefore, from Eq (I-18), weight of cake per unit time is found out as

$$= A[2\_Pck_f/\mu rt_c]^{1/2} \qquad \text{--(I-24)}$$

Combining equation (I-23) and (I-24)

Volume of air per unit time / Weight of cake per unit time

$$= k_a\mu r/k_f\mu_a 2r_a c \qquad \text{--(I-25)}$$

If the constants in the preceeding equation are known for a given filter system and the assumption of no air leakage is adequate, then the total amount of suction air can be estimated. This value, combined with the knowledge of the air temperature and the pressure at the intake and delivery sides of the vacuum pump, can be used to estimate the power requirements of vacuum pump by the methods described below.

Power Requirement :

A vacuum pump is a compressor that takes suction at a pressure below atmospheric and discharges against atmospheric. The power P (in KW) required by the motor of a single stage compressor to compress G kg of gas per hour from initial pressure p_1 to the final pressure p_2 is determined by the equations (I-26) and (I-27)

$$P = G\, W_{ad}/3600 * 1000 \qquad \text{--(I-26)}$$

where, W_{ad} is theoretical amount of work done (in J/kg) by a single stage compressor in the adiabatic (isentropic) compression of 1 kg of a gas and can be calculated by the Eq I-27

$$W_{ad} = [k/(k-1)]p_1V_1[(p_2/p_1)^{(k-1)/k} -1] \qquad \text{--(I-27)}$$

where, k = Adiabatic exponent equal to the ratio C_p/C_v (the specific heat capacities at constant pressure and constant volume)

p_1 & p_2 = Initial and final pressure of the gas (N/m^2)

V_1 = Specific volume of gas in the initial conditions i.e. at a pressure of p_1 and a temperature of T_1 (m^3/kg)

Eq (I-27) can be derived from the relationship between p and V for an ideal gas for adiabatic compression

$$pV^k = p_1V_1{}^k = p_2V_2{}^k \quad \ldots$$

and from equation of theoretical work done for blowers and compressors

$$dW = Vdp$$

Integrating this equation between limits p_1 and p_2 after substituting $V = (p_1/p_2)^{(1/k)} V_1$,one obtains

$$W_{ad} = (p_1)^{(1/k)} V_1 \int_{p_1}^{p_2} 1/(p)^{(1/k)} \, dp$$

$$= (p_1)^{(1/k)} V_1 \, [p_2^{((-1/k)+1)} - p_1^{((-1/k)+1)} / \{(-1/k)+1\}]$$

$$= (k/k-1) \, p_1 V_1 \, \{(p_2/p_1)^{(k-1)/k} - 1\}$$

APPENDIX II

APPENDIX-II

A. SAMPLE DESIGN CALCULATION

1.0 Calculation for Vacuum Filter Loading Rate and Filter Area Required for Conditioned & Unconditioned Sludge:

The following assumptions are used

1. Combined (Primary and secondary) sludge flow rate for a 100 TPD paper plant = 80 m^3/day
2. Consistency of sludge (% T.S.) = 3.5
3. The value of mass of dry cake deposited per unit volume of filtrate(c) is same for both unconditioned / conditioned sludge , estimated based on experimental results (Eq.I-16) = 40 Kg/m^3
4. Total cycle time of filter Q_c = 3 min=180 sec
5. Surrounding temperature and pressure = 25°C and 1 atmosphere
6. Viscosity of filtrate at 25°C (assumed is equal to viscosity of water at same temperature) = 0.008953 poise = 8.953×10^{-4} Ns/m^2
7. Operating time of filter per day = 20 hr
8. Fractional filter drum submergence,k_f = 0.3
9. Specific resistance of unconditioned combined sludge at 15" Hg vacuum, r = $2.00 \times 10^{10} s^2/g$
10. Specific resistance of conditioned sludge (conditioned with

Alum using 15% dose on weight by weight basis) at 15" Hg vacuum) = $5\times10^{7}s^{2}/g$

11. Sludge density(assumed is equal to water density)= 1000 kg/m^3

Case I: Unconditioned Sludge:

Vacuum to be applied, P = 15" Hg

= 5.0766×10^{4} N/m^2

Specific resistance of sludge r = 2.00×10^{10} s^2/g

= 1.962×10^{14} m/kg

Filter cycle loading rate is thus estimated using Eq. I-18

$$L = [(2\times5.0766\times10^{4}\times40\times0.30)/(8.953\times10^{-4}\times1.962\times10^{4}\times180)]^{1/2}$$

= 1.963×10^{-4} $Kg/m^2/sec.$

= 0.71 $kg/m^3/hr.$

Using a scale factor of 0.8 which compensates for that area of filter drum where the cake is removed and the media is washed.

L (actual) = 0.71x0.8 = 0.568 $kg/m^2/hr.$

Solids to be processed per day = 80x35

= 2800 kg/day ≃ 140 kg/hr.

Therefore,

Filter Area required (m^2) = solids to be processed kg per hr./cycle loading rate kg/ m^2/hr.)

= 140/0.568

= 246.5 ≃ 250 m^2

Therefore, Five filters of 50 m^2 area will be required for the purpose.

Case II: Conditioned Sludge:

Vacuum to be applied(assumed), P = 8" hg

= 2.7075×10^4 N/m^2

Specific resistance r at P = 8"Hg = 3.22×10^7 s^2/g

= 3.16×10^{11} m/kg

(using relationship $r = r_o (\Delta P)^s$ and using s = 0.7

(coefficient of compressibility)

Therefore,

Filter loading rate $L = [(2 \times 2.7075 \times 10^4 \times 40 \times 0.3)/(8.953 \times 10^{-4} \times 3.16 \times 10^4 \times 180)]^{1/2}$

= 3.572×10^{-3} kg./m^{-3} kg/m^2/sec.

= 12.86 kg/m^2/h

Using a scale factor of 0.8

L (actual)= 10.29kg/m^2/h

Total solids to be processed per day

= sludge + Alum

= 2800 + 0.15x2800

= 3220 kg/day

= 161 kg/hr.

Therefore,

Filter area required = 15.64 m^2 $\simeq$ 20 m^2

Hence, one vacuum filter of 20 m^2 area will be required in this case

2.0: Calculation for Storage Tank Requirement:

In both the cases (conditioning and without conditioning) storage tank will be required for buffer capacity. Let a provision for sludge storage is maintained for 2 days.

Therefore,

Volume of storage required

$$= 80\ m^3/day \times 2$$

$$= 160\ m^3$$

3.0: Calculation for Conditioning Tank Requirement:

In case of sludge conditioning, one additional conditioning tank will be required for slow mixing. Let a in line conditioning tank is provided with a retention time of 4 min.

Total volume to be handled per day (in 20 hrs.)

= Sludge volume + 15% Alum (10% Alum solution)

$$= 80 + 2800 \times 0.15 \times 0.1$$

$$= (80 + 42)\ m^3$$

$$= 122\ m^3$$

Therefore,

Size of the conditioning tank $= 122 \times 4\ min/20 \times 60$

$$= 0.407\ m^3$$

By providing 40% extra volume, actual volume required

= $0.5568\ m^3$

= $0.55\ m^3$

4.0: Power Requirement of Pump, required for Transportation of Sludge from Storage Tank:

In both the cases a pump will be required for transportation of sludge from storage tank (to conditioning tank, in case of conditioning and to vacuum filter headbox in case without conditioning system.)

Capacity of pump (assuming 150% of average sludge flow rate per day = $80 \times 1.50\ m^3/day$

= $1.66 \times 10^{-3}\ m^3/s$

$((80 \times 1.50)/(20 \times 3600))$

Power requirement of the motor of pump can be given by

= $(Q p_d g H)/(1000 \times \eta)$ kW

Where

Q = Volume of output (delivery) through pump

= $1.66 \times 10^{-3}\ m^3/s$

Density of slurry being pumped, p_d

= $1000\ kg/m^3$

Acceleration due to gravity, g

= $9.81\ m/s^2$

Total head developed by the pump (m), H

= 10

Overall efficiency n = 50%

Therefore,

Power required (at 50 % efficiency)

$$= (1.66\text{x } 10^{-3}\text{x}1000\text{x}9.81\text{x}10)/(1000\text{x}.5)$$

$$= 0.32 \text{ kW} \simeq 0.4 \text{ kW}$$

5.0: Power Requirement of Pump Required for Transportation of Sludge from Conditioning Tank:

In case of sludge conditioning system, one pump will be required for transportation of sludge from conditioning tank to vacuum filter head.Its capacity will be same as that of pump required for transportation of sludge from storage tank. Assuring a same dynamic head of 10 meter.The power requirement at 50% efficiency will be 0.4 Kw.

Sludge pump must be self priming , centrifugal and nonclogging type. It must be suitable for handling the maximum solids concentration anticipated in the sludge.

6.0: Power and Area Required for Flocculation Paddle:

The following two equations are commonly used equations for design of flocculation paddles(37):-

Pcwer requirement $P = G^2 \mu V_t$

Area required $A = 2\ P/C_d\ P_d v^3$

where,

P = Power requirement for mixing, (watts)

G = Mean velocity gradient, (sec^{-1}), Typical

Fig. 4.7b: EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill B, Trial No.2)

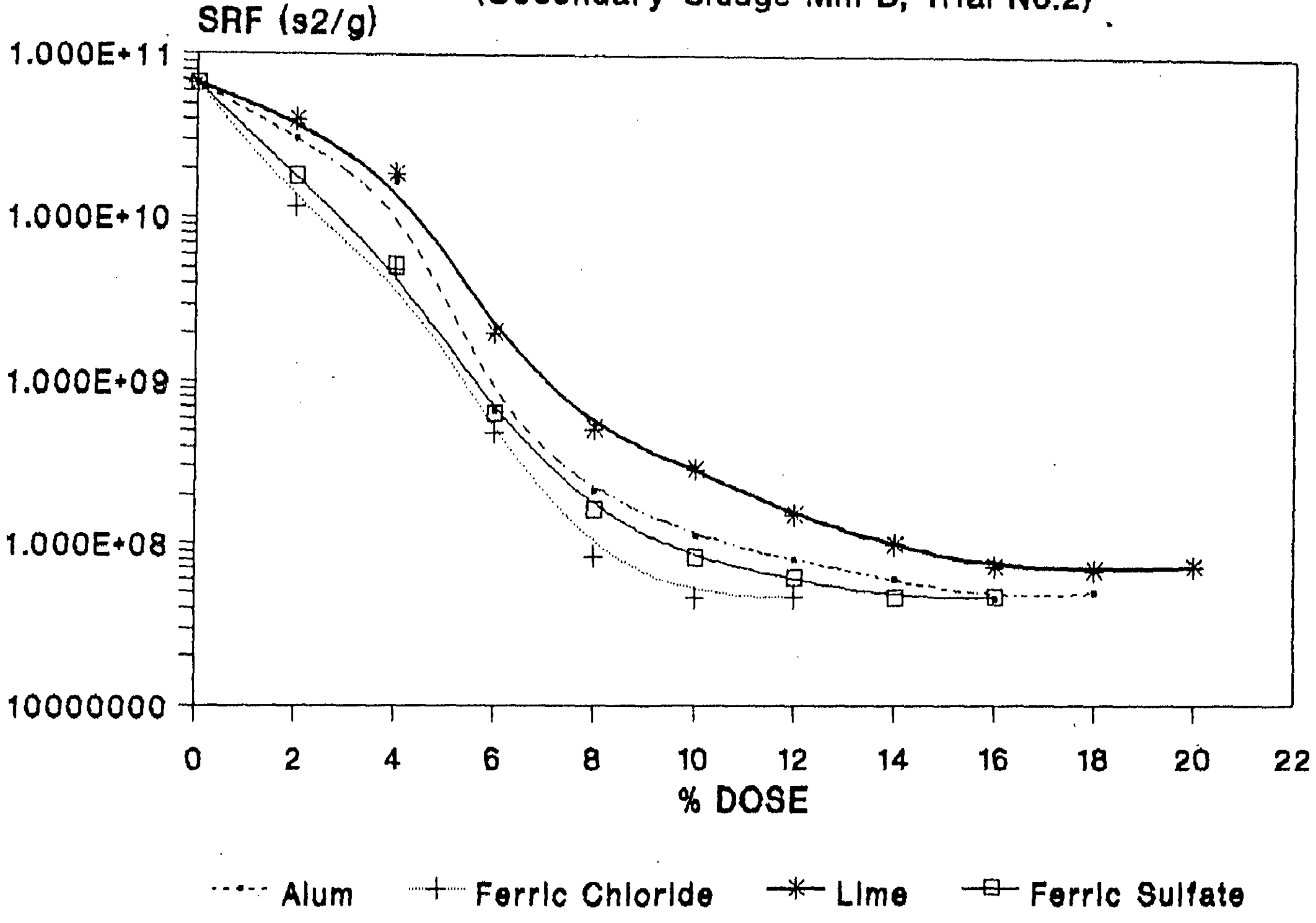


Fig. 4.7c : EFFECT OF DIFFERENT DOSAGE OF VARIOUS INORGANIC FLOCCULANTS ON SPECIFIC RESISTANCE TO FILTERATION (SRF)

(Secondary Sludge Mill B, Trial No.3)

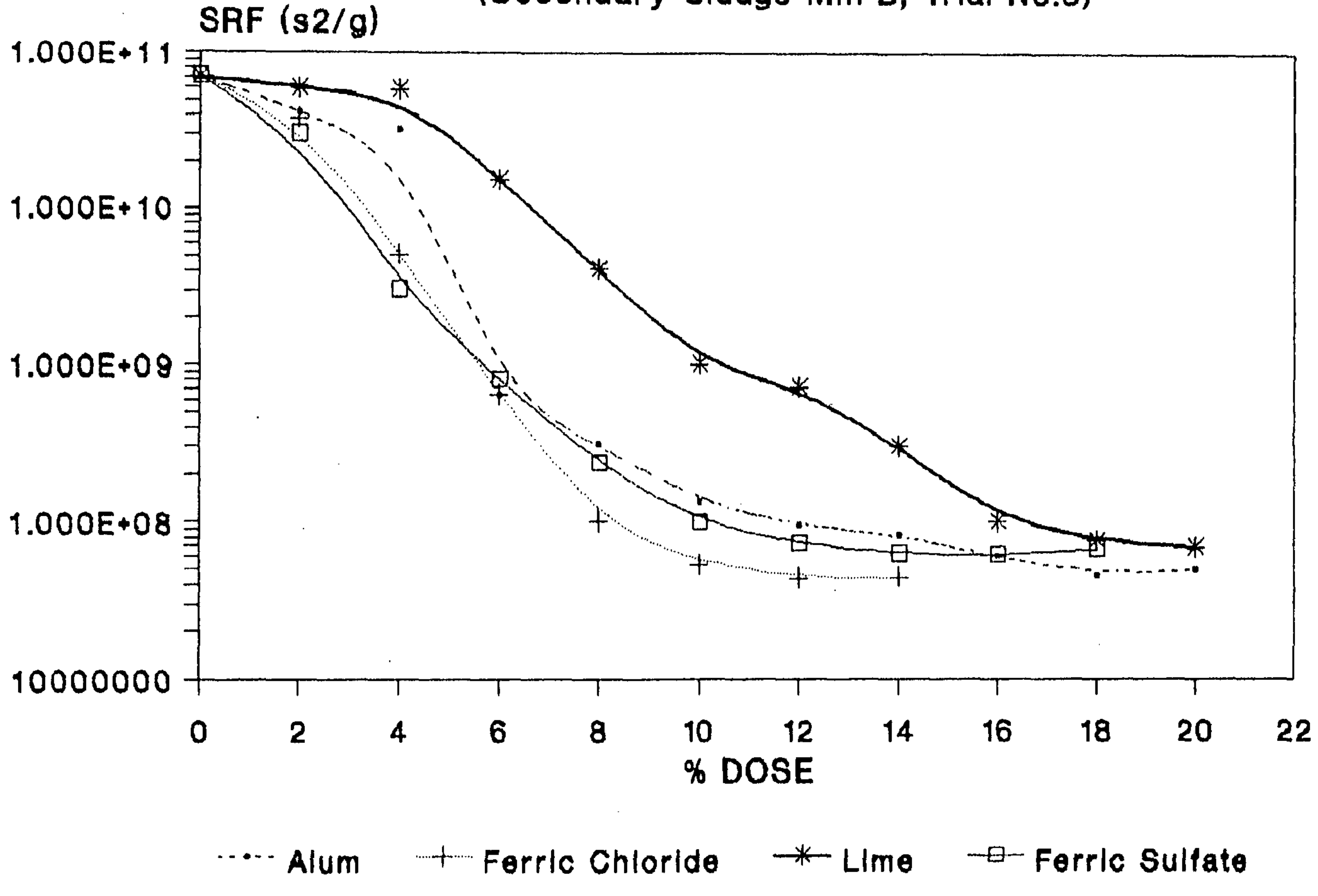
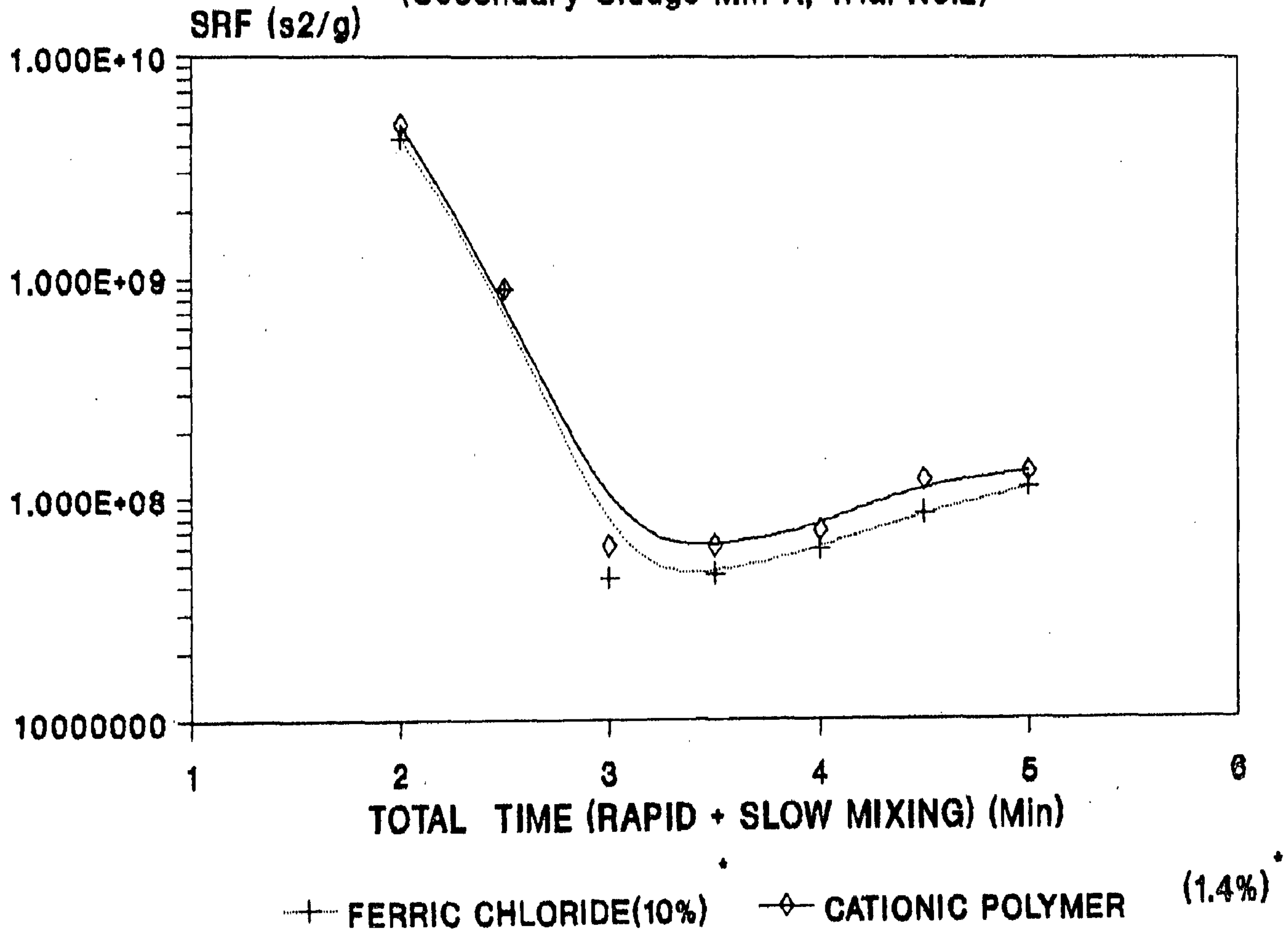


Fig. 4.13b : EFFECT OF VARYING RAPID MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (SLOW MIXING TIME(2 MIN)KEPT CONSTANT)

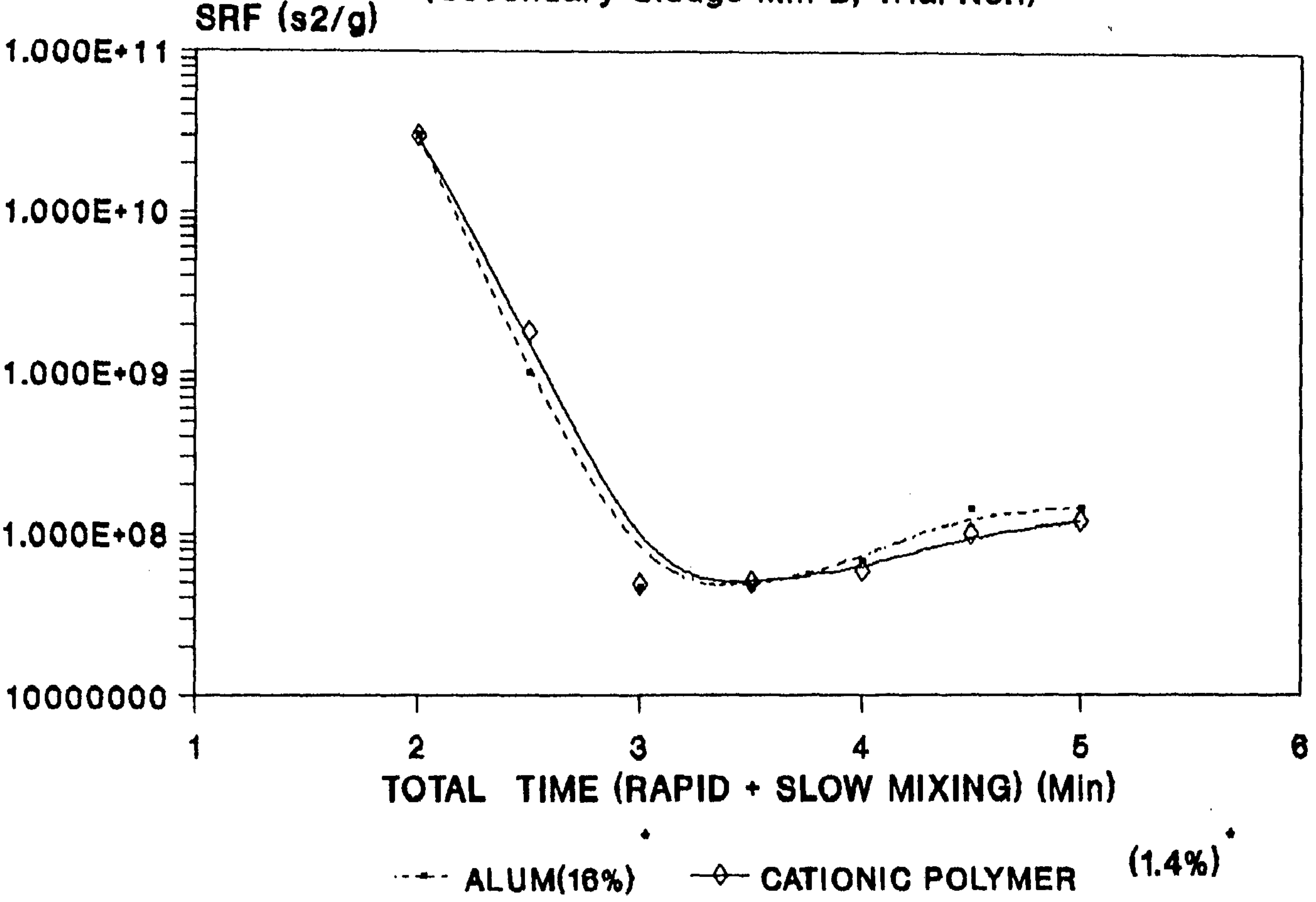
(Secondary Sludge Mill A, Trial No.2)



* NEAR ABOUT OPTIMUM DOSE FOUND

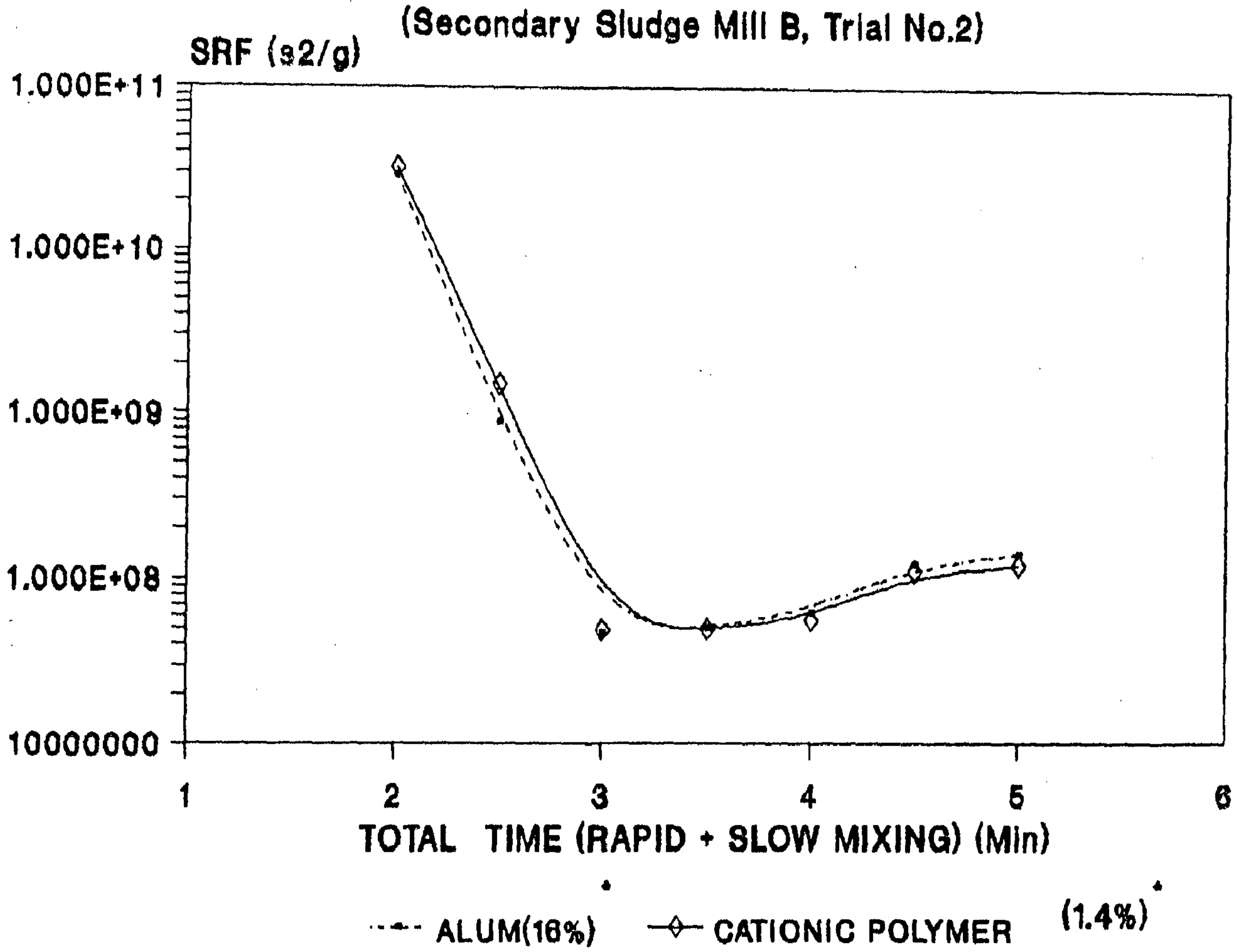
Fig. 4.14a: EFFECT OF VARYING RAPID MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (SLOW MIXING TIME (2 MIN) KEPT CONSTANT)

(Secondary Sludge Mill B, Trial No.1)



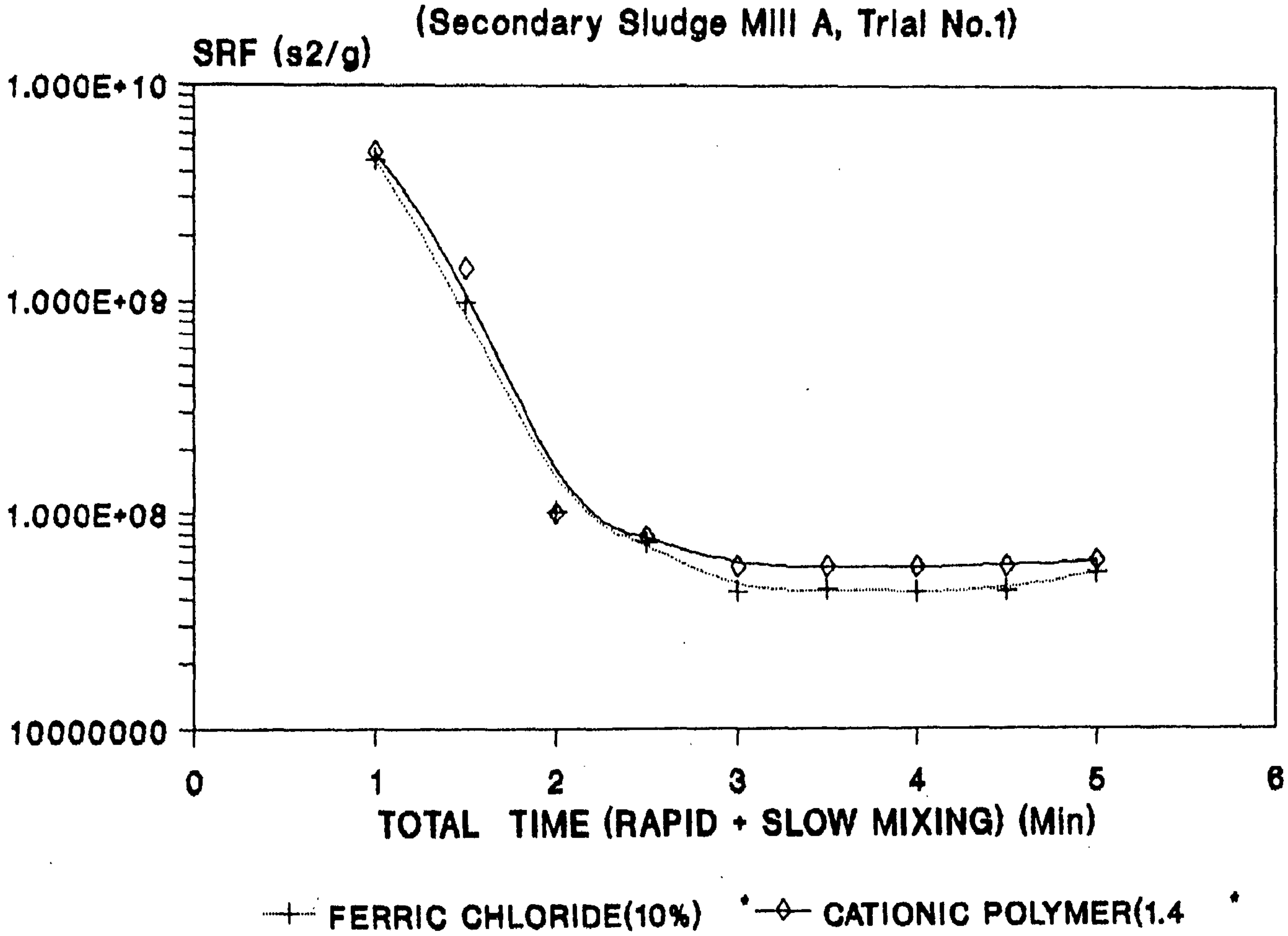
* NEAR ABOUT OPTIMUM DOSE FOUND

Fig. 4.14b: EFFECT OF VARYING RAPID MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (SLOW MIXING TIME (2 MIN) KEPT CONSTANT)



• NEAR ABOUT OPTIMUM DOSE FOUND

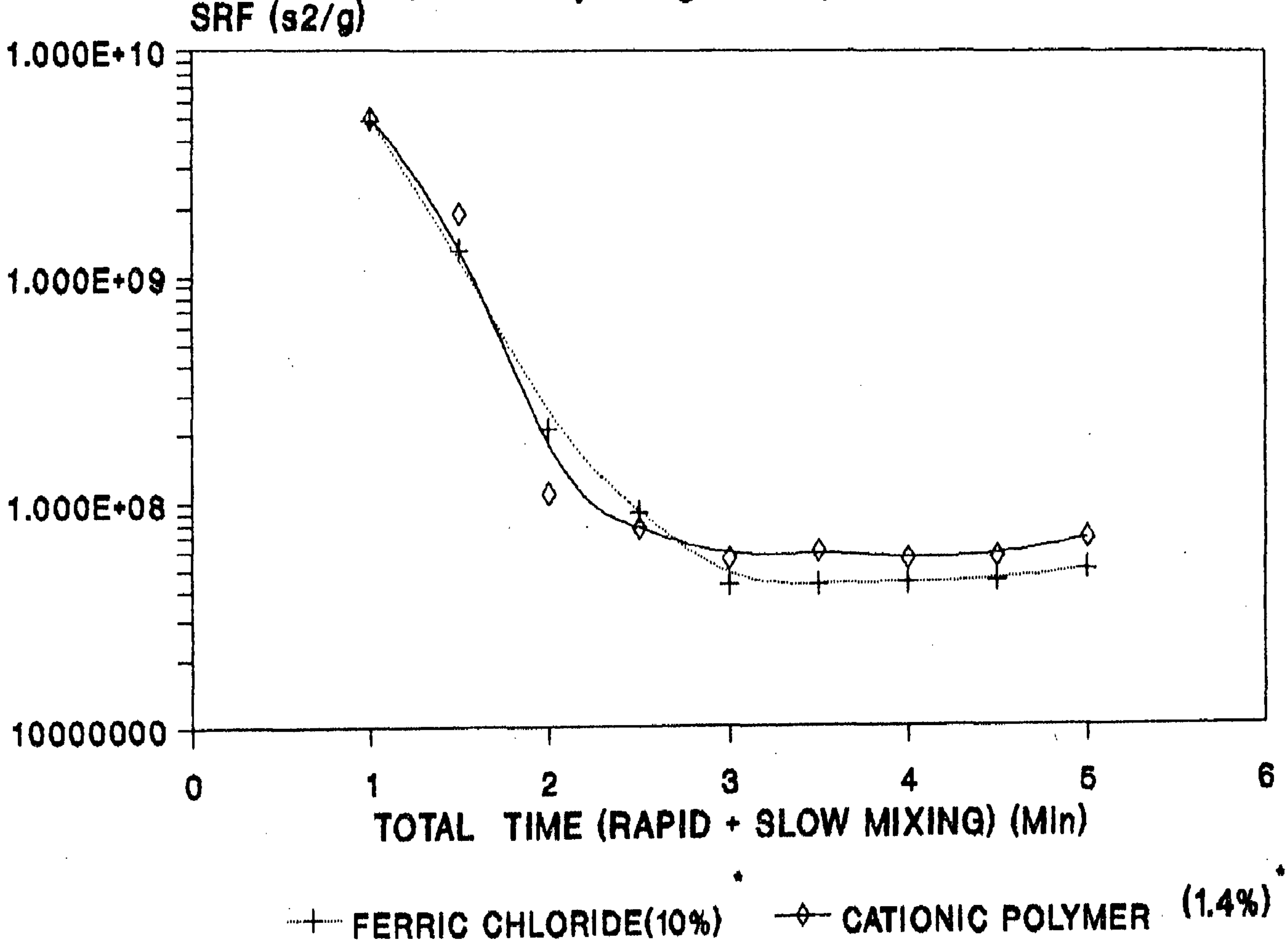
Fig. 4.15a: EFFECT OF VARYING SLOW MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (RAPID MIXING TIME(1 MIN) KEPT CONSTANT)



• NEAR ABOUT OPTIMUM DOSE FOUND

Fig. 4.15b: EFFECT OF VARYING SLOW MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (RAPID MIXING TIME(1 MIN) KEPT CONSTANT)

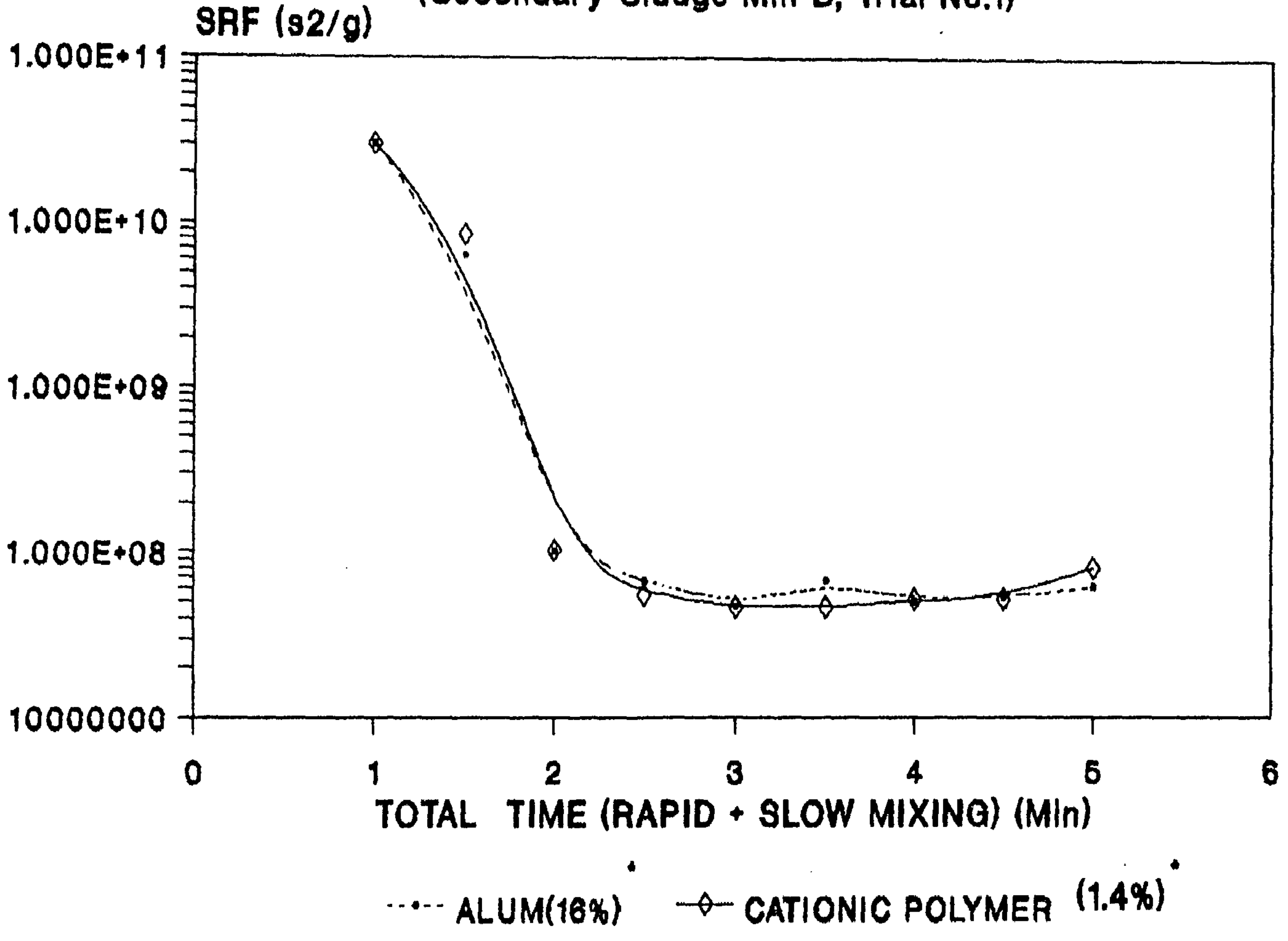
(Secondary Sludge Mill A, Trial No.2)



* NEAR ABOUT OPTIMUM DOSE FOUND

Fig. 4.16a: EFFECT OF VARYING SLOW MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (RAPID MIXING TIME(1 MIN) KEPT CONSTANT)

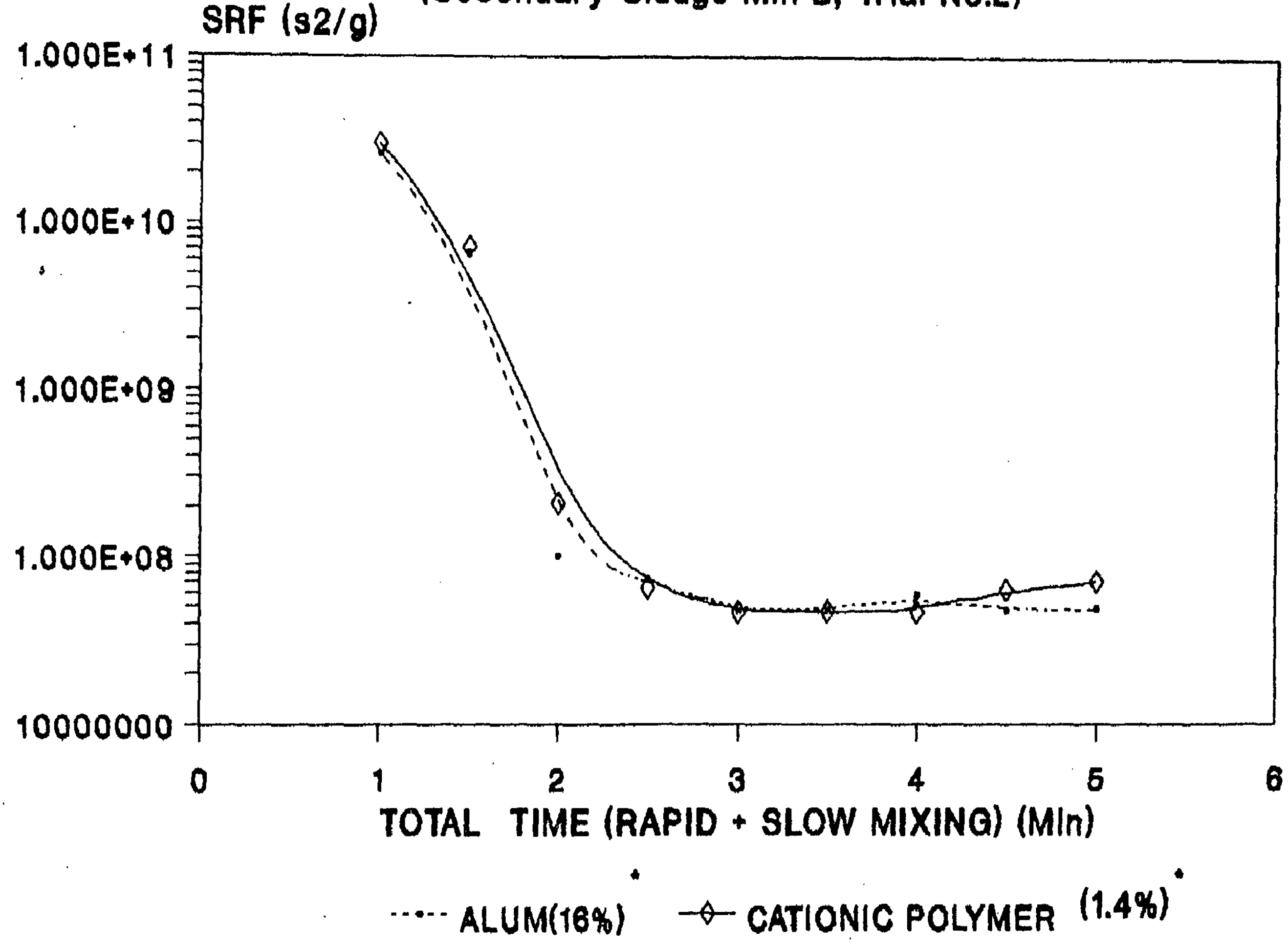
(Secondary Sludge Mill B, Trial No.1)



NEAR ABOUT OPTIMUM DOSE FOUND

Fig. 4.16b: EFFECT OF VARYING SLOW MIXING TIME ON *SRF* DURING CONDITIONING WITH FLOCCULANTS (RAPID MIXING TIME(1 MIN)KEPT CONSTANT)

(Secondary Sludge Mill B, Trial No.2)



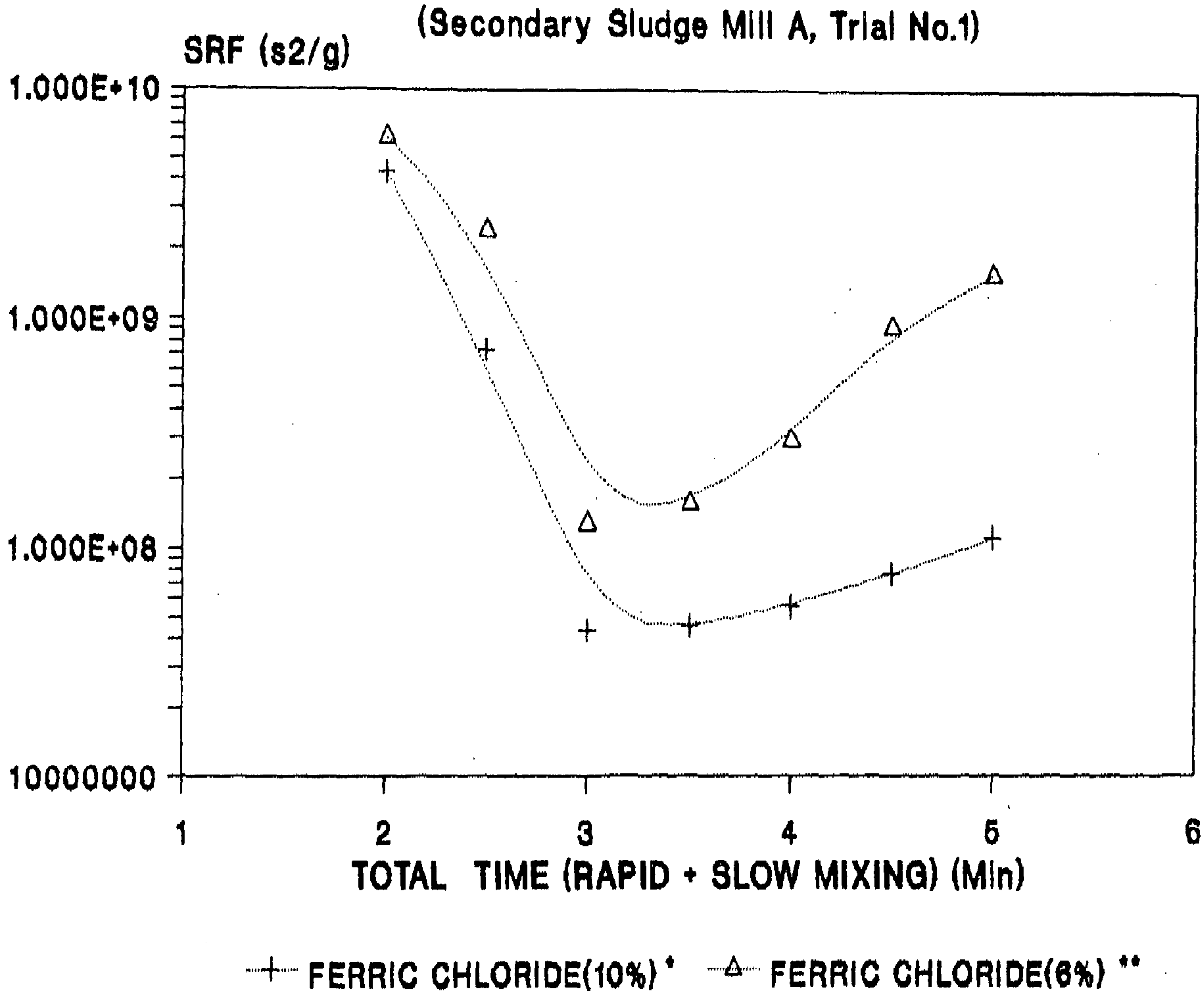
* NEAR ABOUT OPTIMUM DOSE FOUND

4.7 Effect of Varying Rapid Mixing Time During Conditioning with Different Dose (Less Than The Optimum and Optimum) of Flocculants (Interaction of Dose and Mixing Time) :

The experiments have also been conducted at low dose (less than optimum dose already found) of ferric chloride with varying fast mixing time. The results have been compared with the results obtained at optimum dose of ferric chlorides with varying fast mixing time. The results are given in tables 4.18a and 4.18b and are plotted in figures 4.17 and 4.17b. It is clear that at low dose (underdose) there is more pronounced effect of mixing time on SRF values compared to values obtained at optimum dose i.e. there is more increase in SRF values at less than or more than 3 min mixing time with underdosage.

For example, for secondary sludge conditioned with 6% and 10% ferric chloride, the values of SRF at 5 min total cycle times have been found to be around 12.5 times and 2.6 times more of SRF value at 3 min cycle time respectively (Table No. 4.18a).

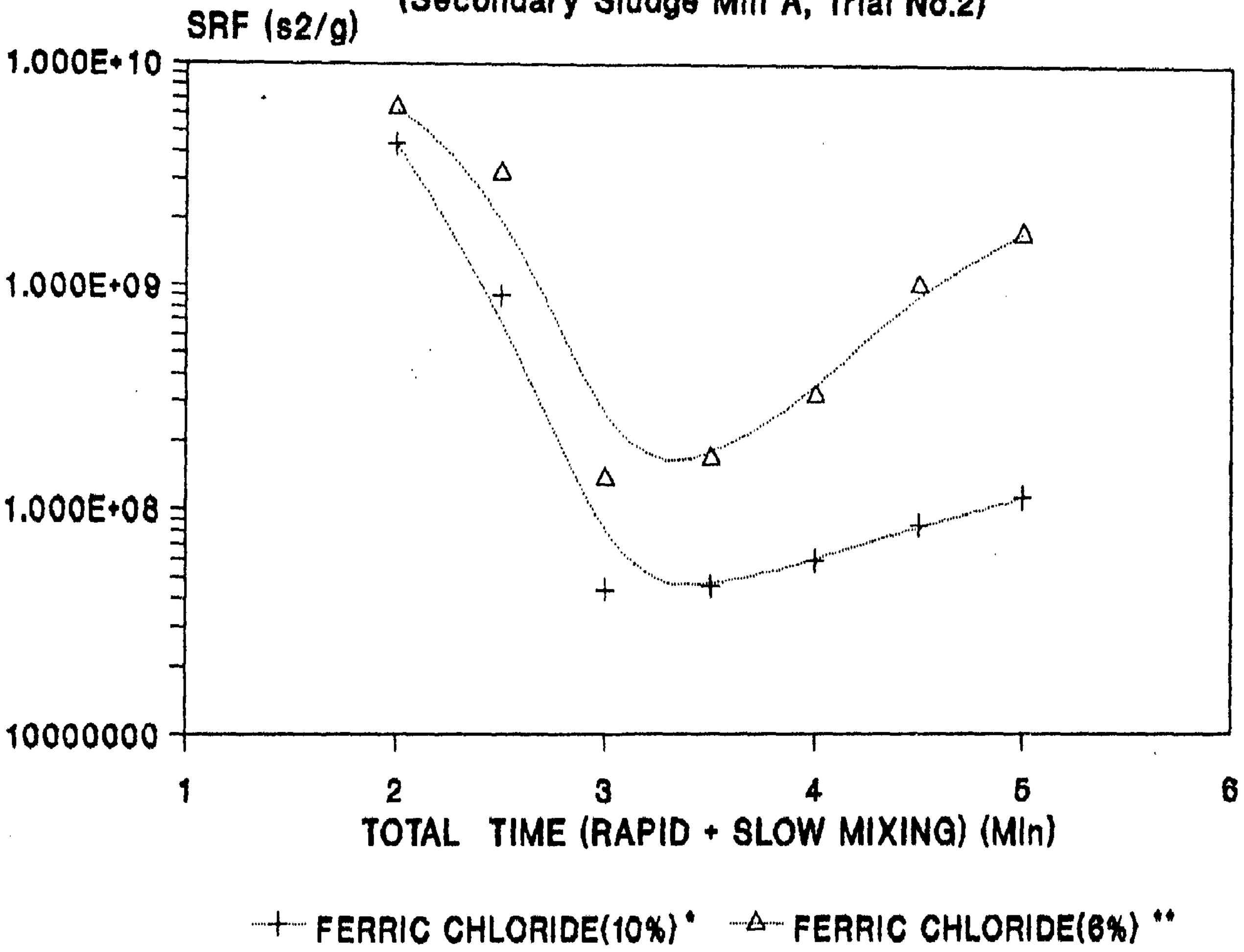
Fig. 4.17a: EFFECT OF VARYING RAPID MIXING TIME ON *SRF* DURING CONDITIONING WITH DIFFERENT DOSE OF FLOCCULANTS (OPTIMUM* AND LESS THAN OPTIMUM**)


(Secondary Sludge Mill A, Trial No.1)

(SLOW MIXING TIME (@ MIN) KEPT CONSTANT)

Fig. 4.17b: EFFECT OF VARYING RAPID MIXING TIME ON *SRF* DURING CONDITIONING WITH DIFFERENT DOSE OF FLOCCULANTS (OPTMUM* AND LESS THAN OPTIMUM**)

(Secondary Sludge Mill A, Trial No.2)



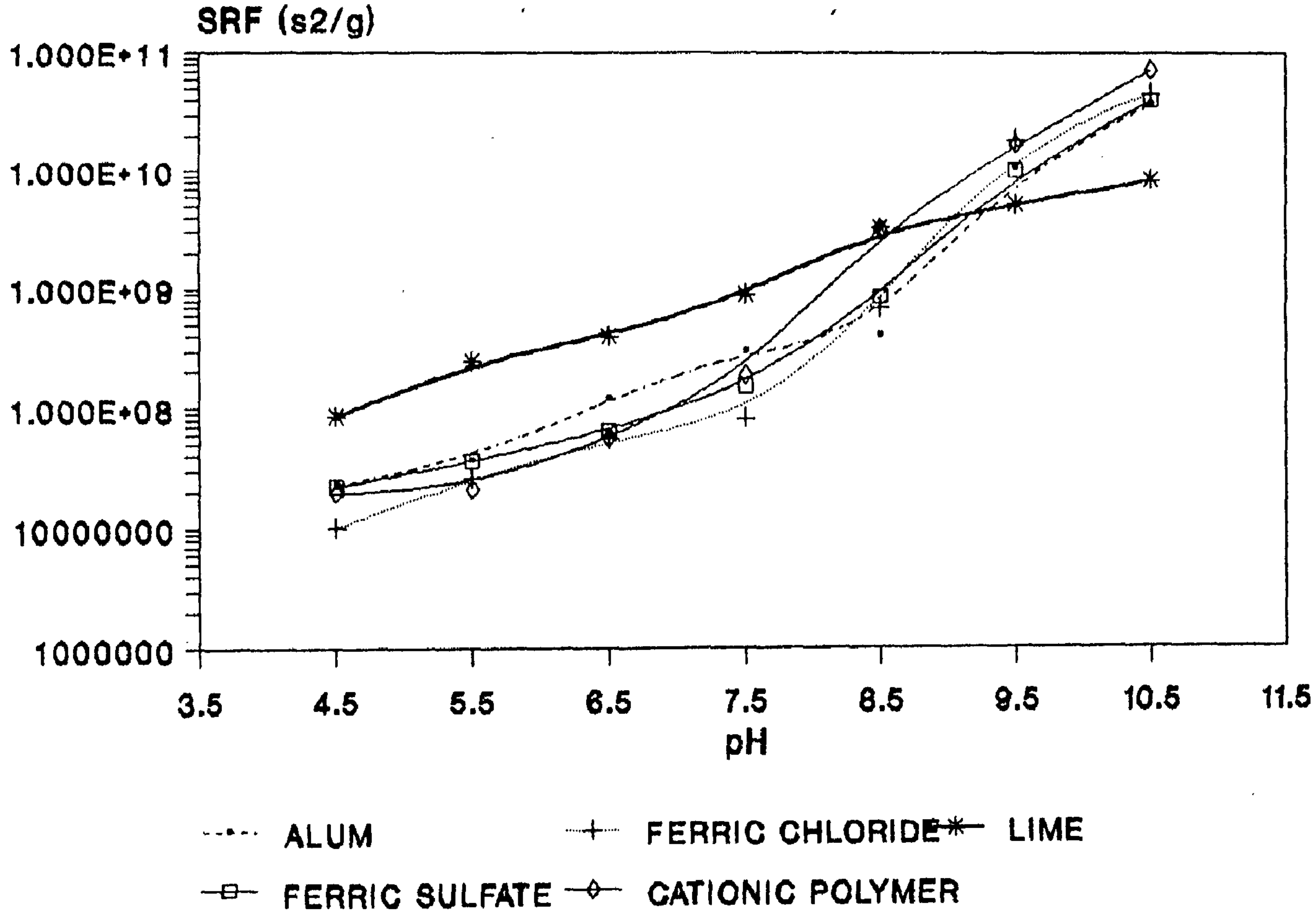
(SLOW MIXING TIME (1 MIN) KEPT CONSTANT)

4.8 Effect of pH Variation During Conditioning With Flocculants:

The effect of pH on SRF has determined for different flocculants and the results are shown in Fig. 4.18a to 4.18c and 4.19a to 4.19b for secondary and primary sludges of mill B respectively. The results are shown in tables 4.19a-4.19c to 4.20a-4.20b. The dose of flocculent used is optimum flocculant dose previously found. It has been observed that there has been increase in SRF with increase in pH, and this increase is very sharp after pH of 7.5, but very less from 5.5 and 7.5 pH. Results of lime was exceptional in case of primary sludge.

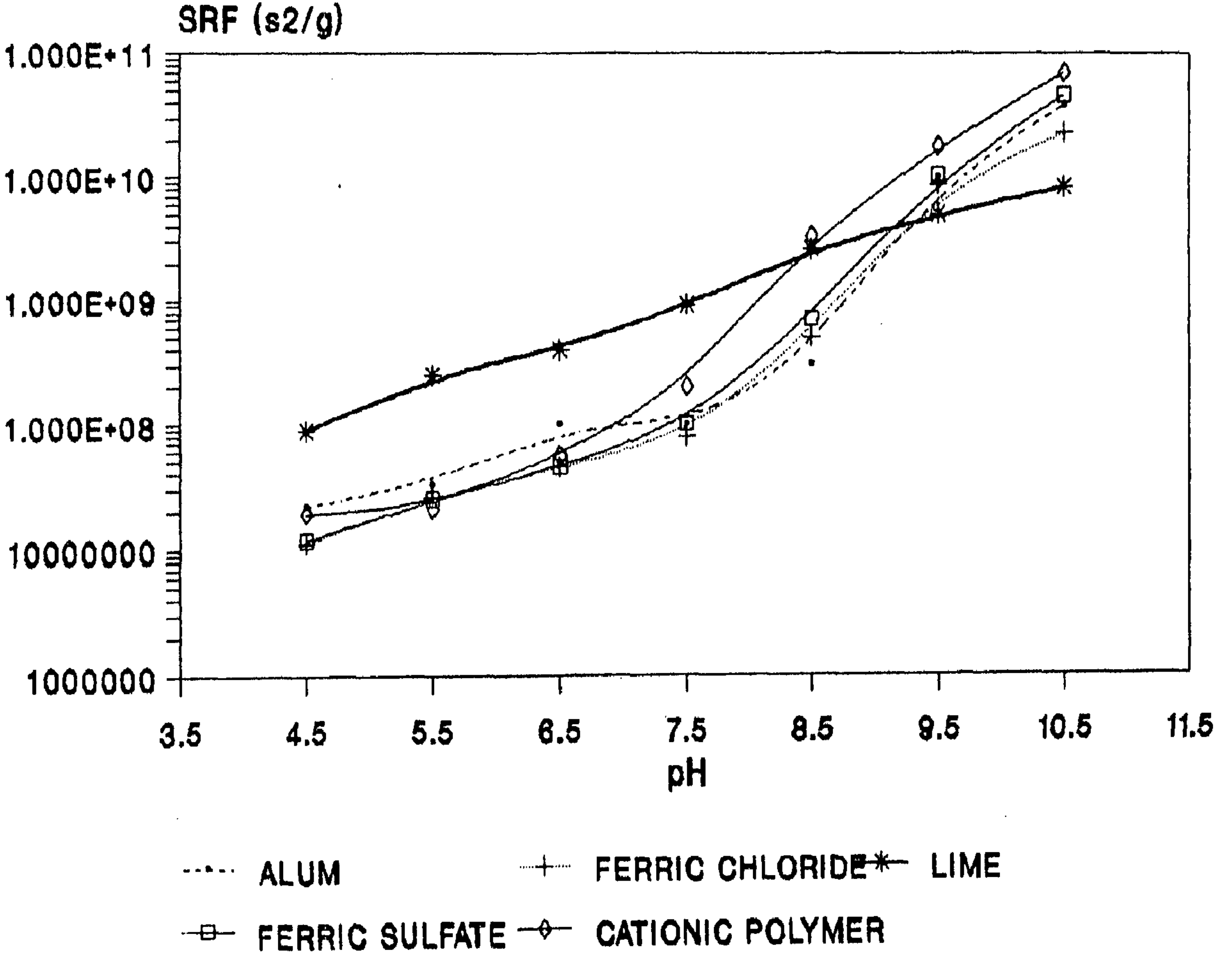
For example in case of secondary sludge conditioned with cationic polymer the values of SRF at a pH of 6.5, 8.5 and 10.5 have been found to be respectively 2.9 , 166.5, and 3726.8 times more than SRF values at 4.5 pH (Table No. 4.19a). In case of lime conditioned, the values at same pH are respectively 4.7, 38.9, and 98.7 times more of SRF value at 4.5. While in case of primary sludge conditioned with lime, SRF values at above mentioned pH has been found 0.4, 1.6, and 2.88 times more of SRF values at 4.5 pH. Similarly, in case of cationic polymer treated primary sludge, the values are 2.1, 11.2, and 308.8 times more respectively compared to SRF value at 4.5 pH (Table No. 4.20b).

Fig. 4.18a: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH FLOCCULANTS*
(Secondary Sludge Mill A, Trial No.1)



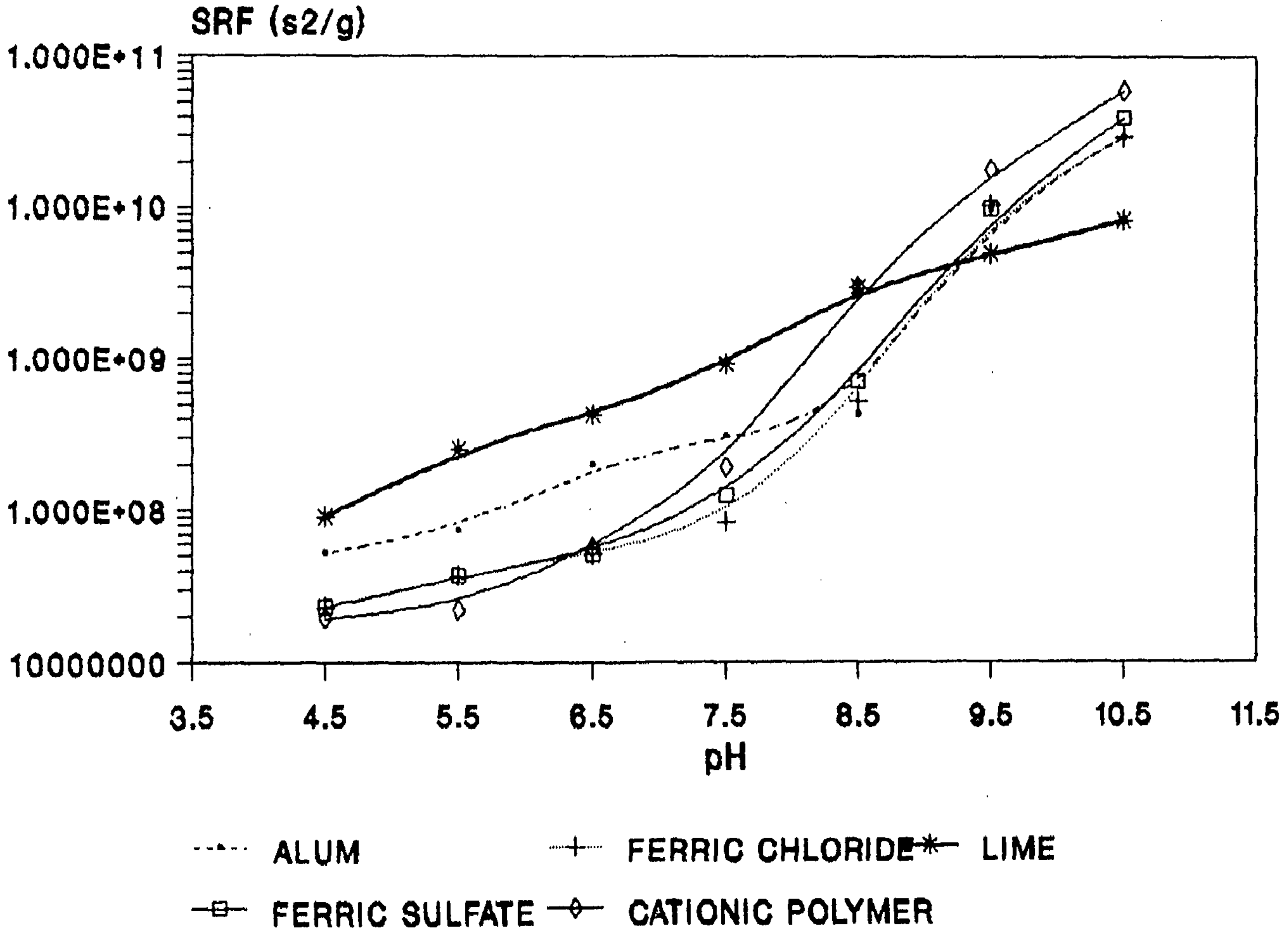
PTIMUM DOSE OF FLOCCULANTS WAS USED
OR CONDITIONING

Fig. 4.18b: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH FLOCCULANTS*
(Secondary Sludge Mill A, Trial No.2)



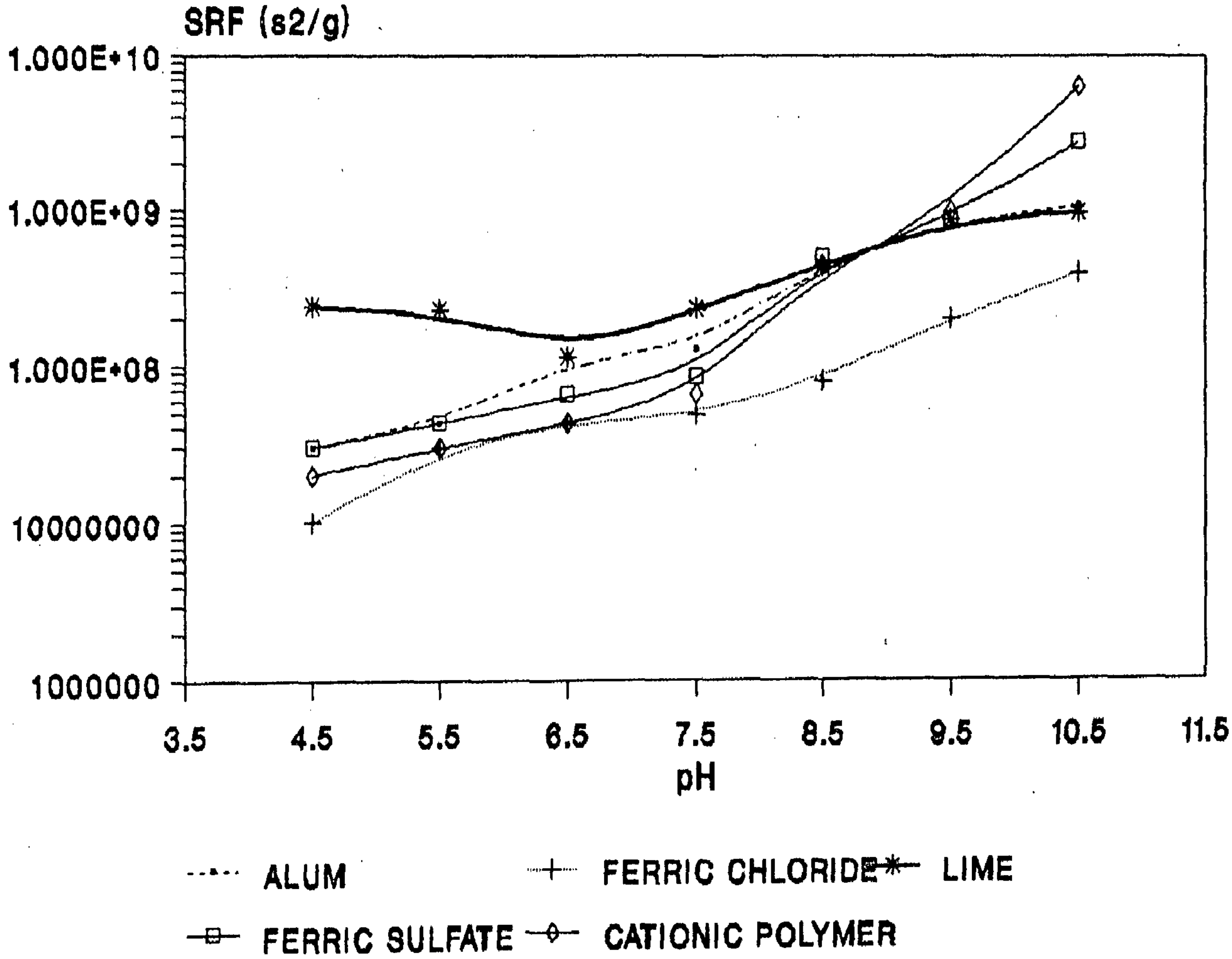
*OPTIMUM DOSE OF FLOCCULANTS WAS USED FOR CONDITIONING

Fig. 4.18c: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH FLOCCULANTS*
(Secondary Sludge Mill A, Trial No.3)



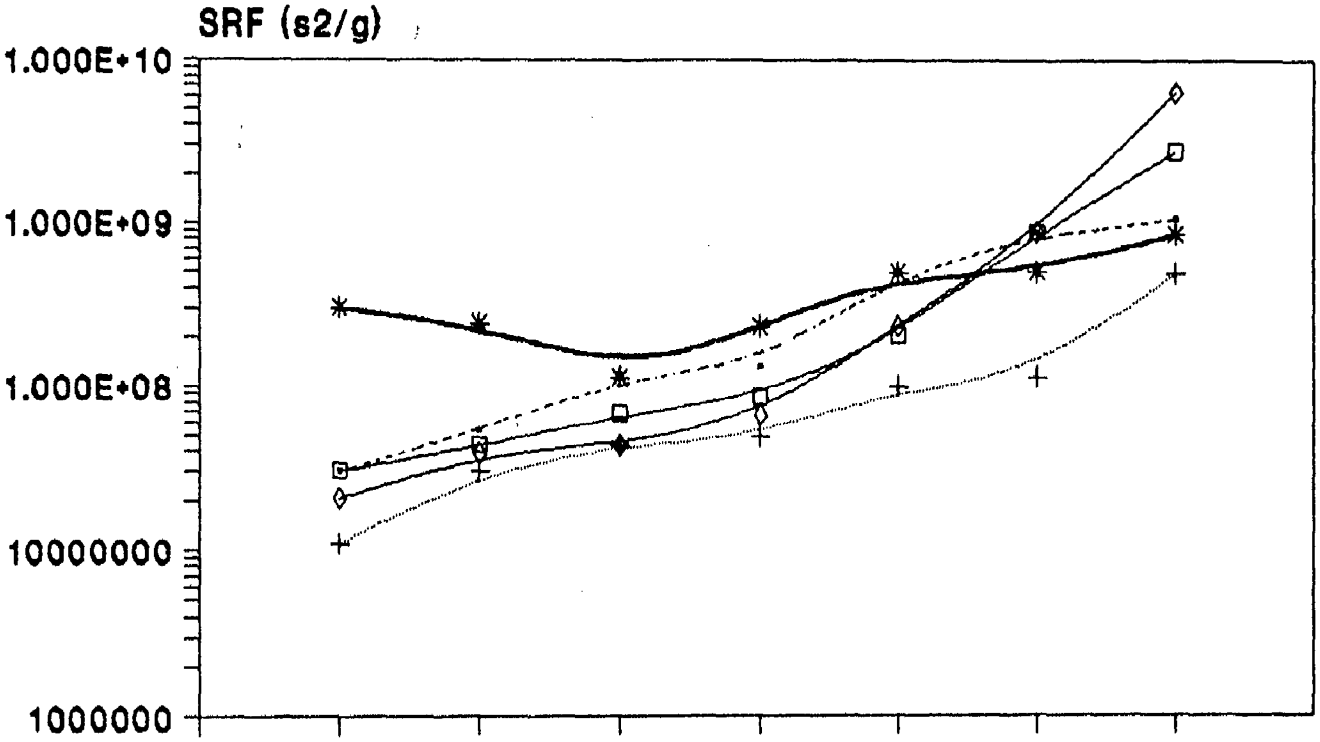
*OPTIMUM DOSE OF FLOCCULANTS WAS USED FOR CONDITIONING

Fig. 4.19a: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH FLOCCULANTS*
(Primary Sludge Mill A, Trial No.1)



*OPTIMUM DOSE OF FLOCCULANTS WAS USED FOR CONDITIONING

Fig. 4.19b: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH FLOCCULANTS*
(Primary Sludge Mill A, Trial No.2)



4.9 Effect of pH During Conditioning with Different Dose (Less Than The Optimum and Optimum) of Flocculants (Interaction of Dose and pH) :

Effect of pH on conditioning of sludge has been also determined at low dosage (lower, than optimum dose) for ferric chloride and cationic polymer. The results have been compared with that obtained at optimum dose and are shown in Tables 4.21a and 4.21b. The results are also depicted in Figures 4.20 a and b. It is evident that in case of underdose of flocculant, the SRF values increases at greater proportion compared to increase in SRF values of optimally conditioned sludge with the increase of pH. For example with primary sludge treated with 4% and 10% ferric chloride, the values of SRF at 6.5, 8.5, and 10.5 pH are respectively 11.5 and 4.3 times, 72 and 7.9 times, 414 and 39 times more that of value at 4.5 pH (Table No. 4.21a).

4.10 Effect of Storage on Dewatering and Conditioning:

The influence of secondary sludge storage on its dewatering performance has also been studied by performing test on the stored sludge. The results are plotted in Fig. 4.21a-b to 4.23a-b and the values are given in Table 4.22a, 4.22b and 4.22c.

Fig. 4.20a: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH DIFFERENT DOSE OF FLOCCULANTS (OPTIMUM* AND LESS THAN OPTIMUM**)

(Secondary Sludge Mill A, Trial No.1)

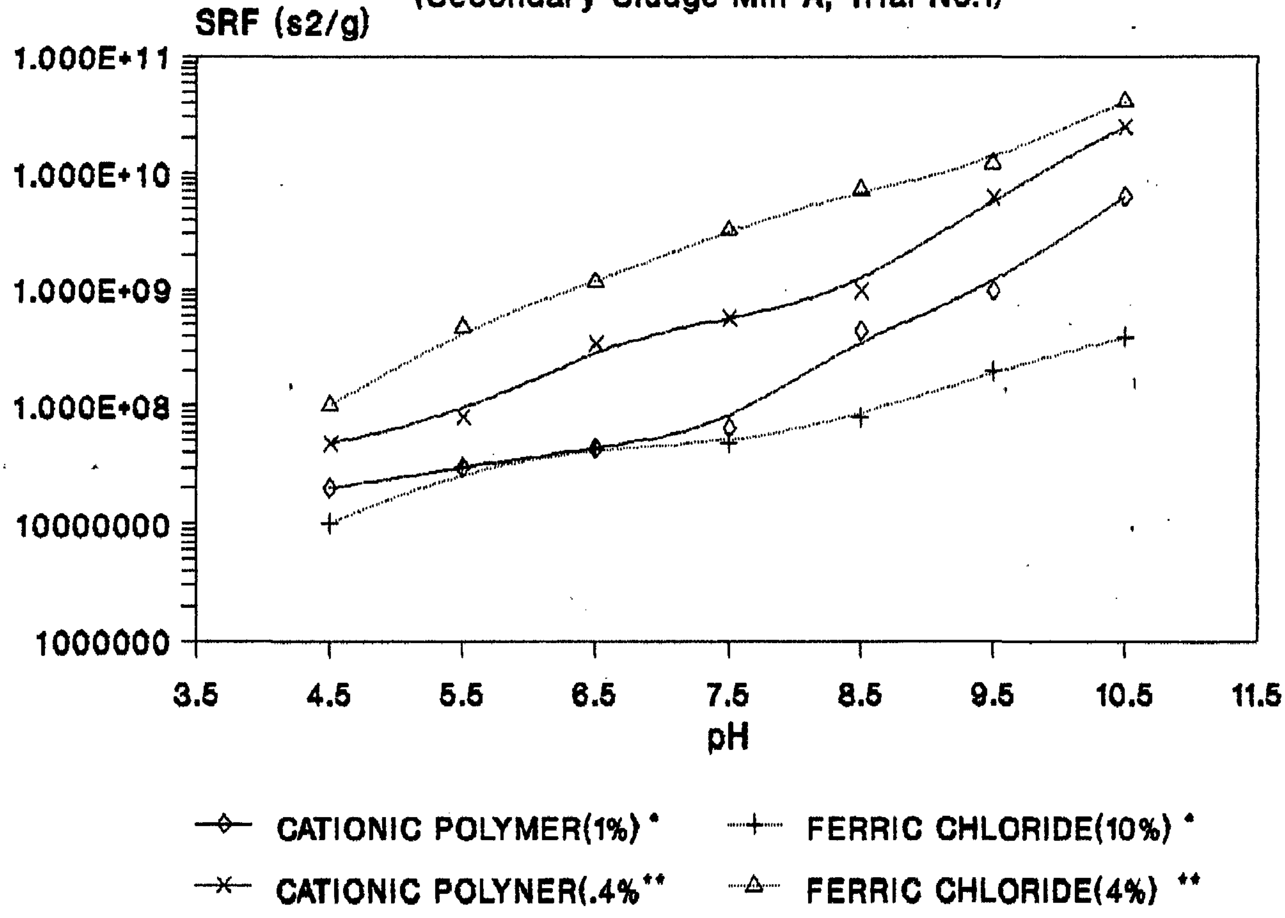
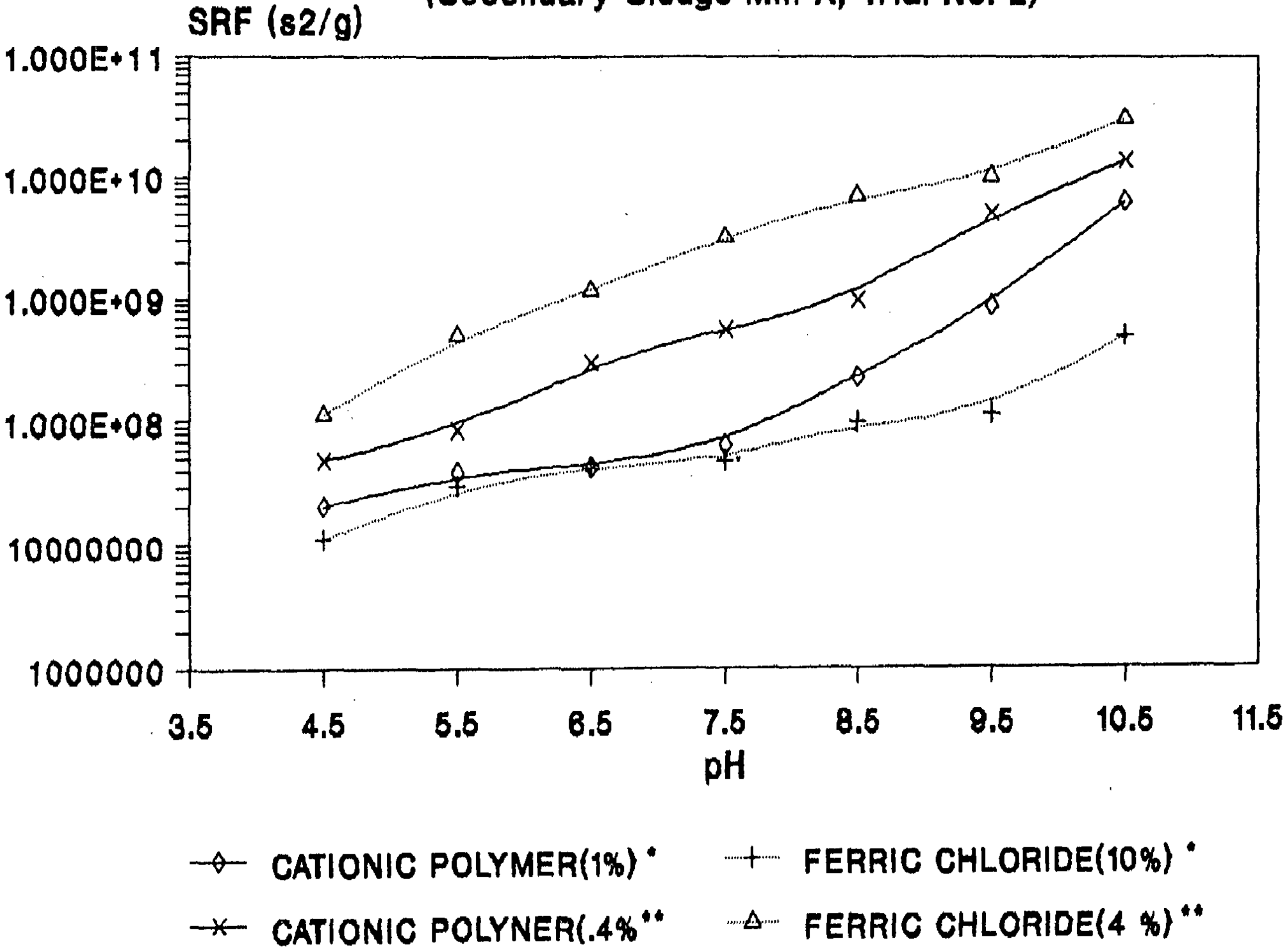


Fig. 4.20b: EFFECT OF VARYING pH ON *SRF* DURING CONDITIONING WITH DIFFERENT DOSE OF FLOCCULANTS (OPTIMUM* AND LESS THAN OPTIMUM**)

(Secondary Sludge Mill A, Trial No. 2)



It is evident that there was increase in SRF of stored sludge (SRF without flocculant) compared to fresh sludge samples. For examples SRF values of fresh sludge and stored sludge have been found to be 6.71×10^{10} and 1.00×10^{11} s^2/g respectively. It indicates that stored sludge is difficult to dewater compared to fresh sludge. An effect of storage on the sensitivity of conditioning with flocculants was nevertheless evident for sludge with all the flocculants used (FeCl3,Lime ,Cationic Polymer). With storage, underdosed sludges tends to be increasingly difficult to dewater having higher SRF values. SRF for the sludge conditioned optimally with flocculants is not affected by storage. Thus, it is possible to achieve the same filterability of the optimally conditioned sludge. For example, in case of ferric chloride treated fresh and stored sludge, the SRF values at 4%, 6% and 10% (optimum dose previously found) dose have been found to be 13.7 and 10.9 times, 139.8 and 100.5 times, 1455.5 and 1607 times lower respectively of initial SRF value without adding flocculant(Table No. 4.22a, Trial No.1). However, there was slight increase in optimum dose requirement in this case, and this increase is different for different flocculants. Minimum increase is found in case of ferric chloride and maximum in case of lime. For example, SRF values of 10% ferric chloride conditioned sludge are 4.61×10^7 and 6.21×10^7 for fresh and stored sludge respectively while in case of 16% lime treated, the SRF values for fresh and stored sludge have been found 7×10^7 and 1.58×10^8 respectively. The optimum dose of lime in case of stored sludge has been found to be 22% and 24% compared to 16% with fresh sludge (Table No. 4.22c).

Fig. 4.21a : EFFECT OF STORAGE ON DEWATERABILITY AND ON CONDITIONING WITH DIFFERENT DOSE OF FERRIC CHLORIDE
(Secondary Sludge Mill B , Trial No.1)

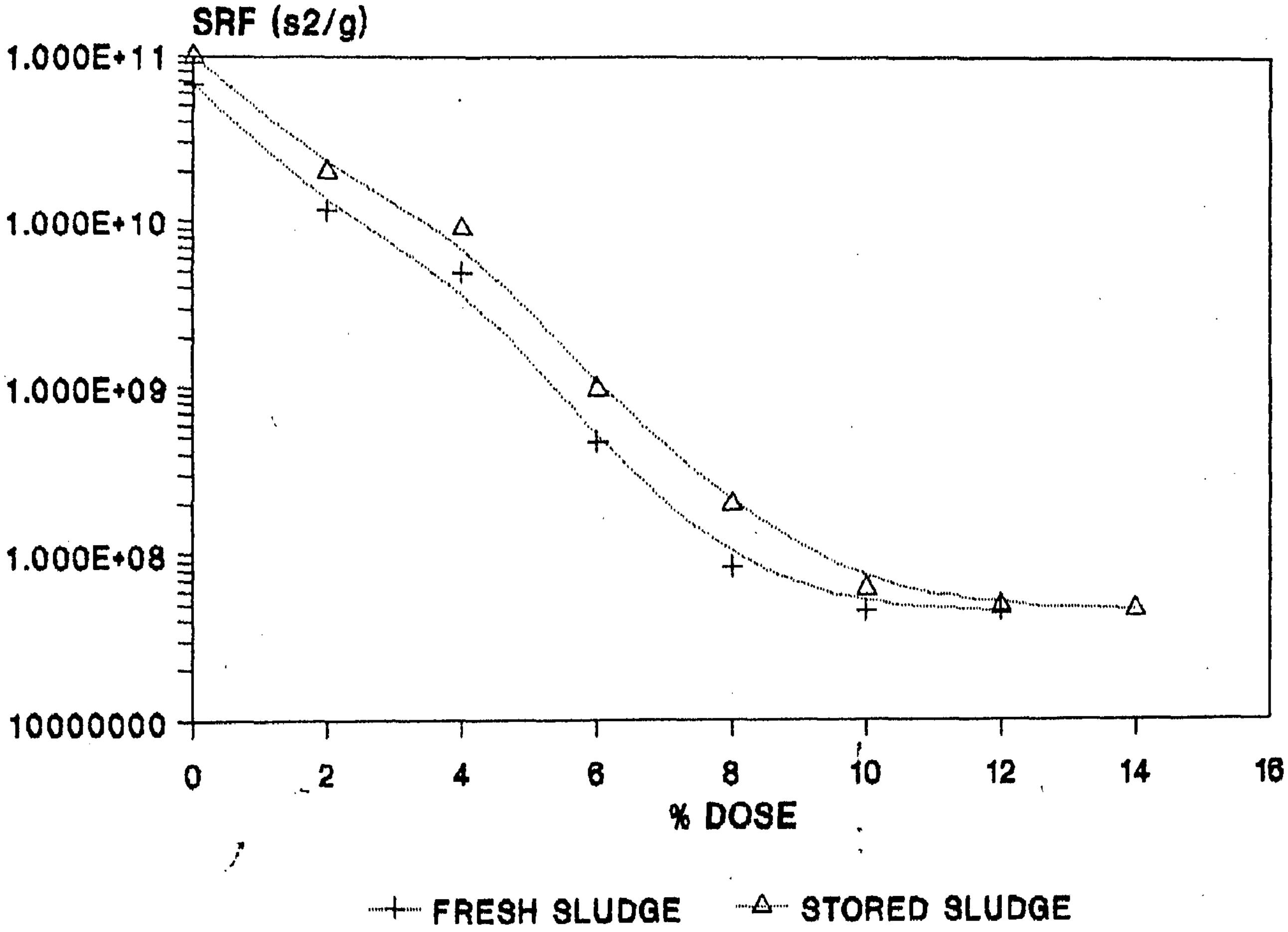


Fig. 4.21b : EFFECT OF STORAGE ON DEWATERABILITY AND ON CONDITIONING WITH DIFFERENT DOSE OF FERRIC CHLORIDE
(Secondary Sludge Mill B, Trial No.2)

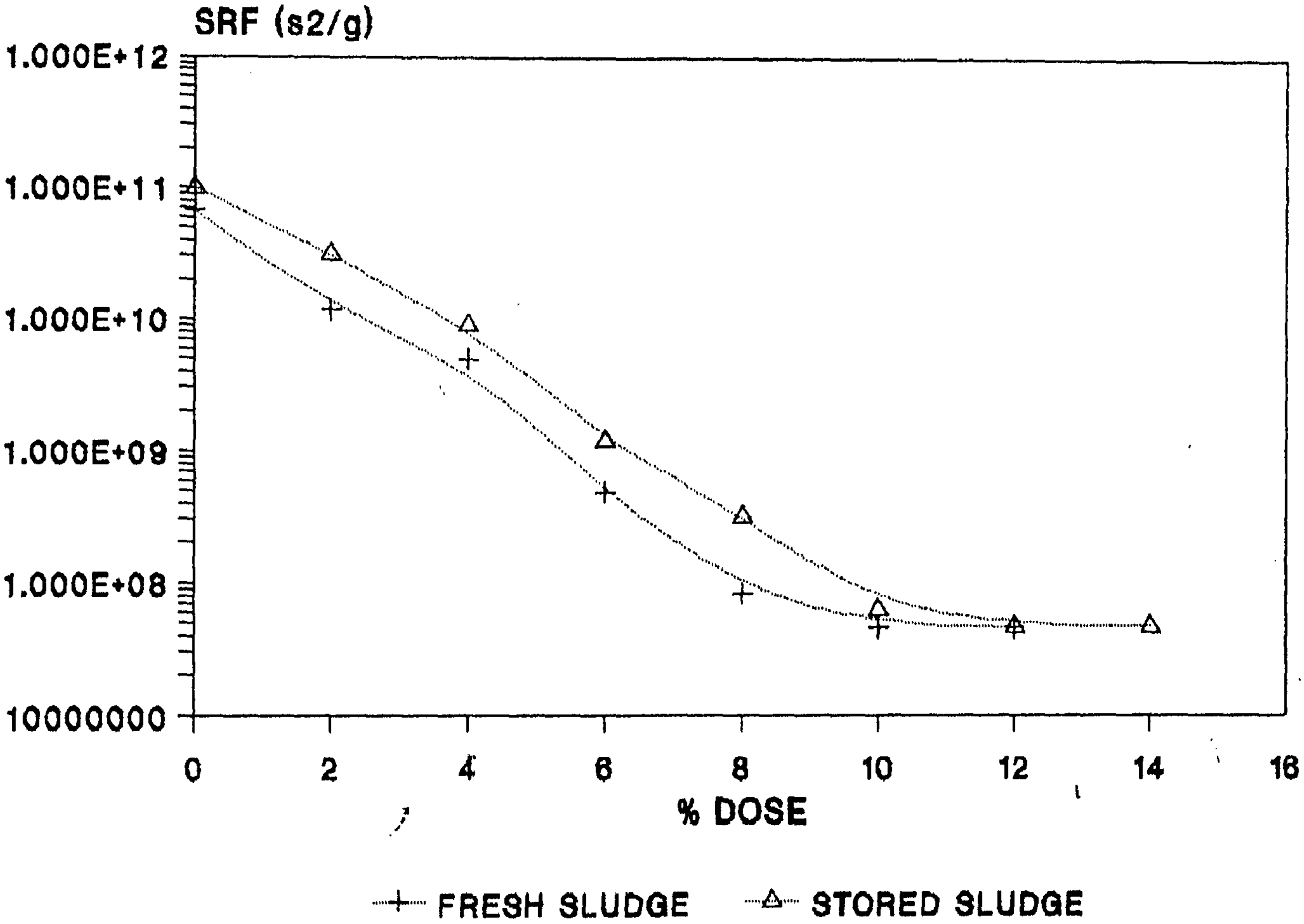


Fig. 4.22a : EFFECT OF STORAGE ON DEWATERABILITY AND ON CONDITIONING WITH DIFFERENT DOSE OF CATIONIC POLYMER

(Secondary Sludge Mill B, Trial No. 1)

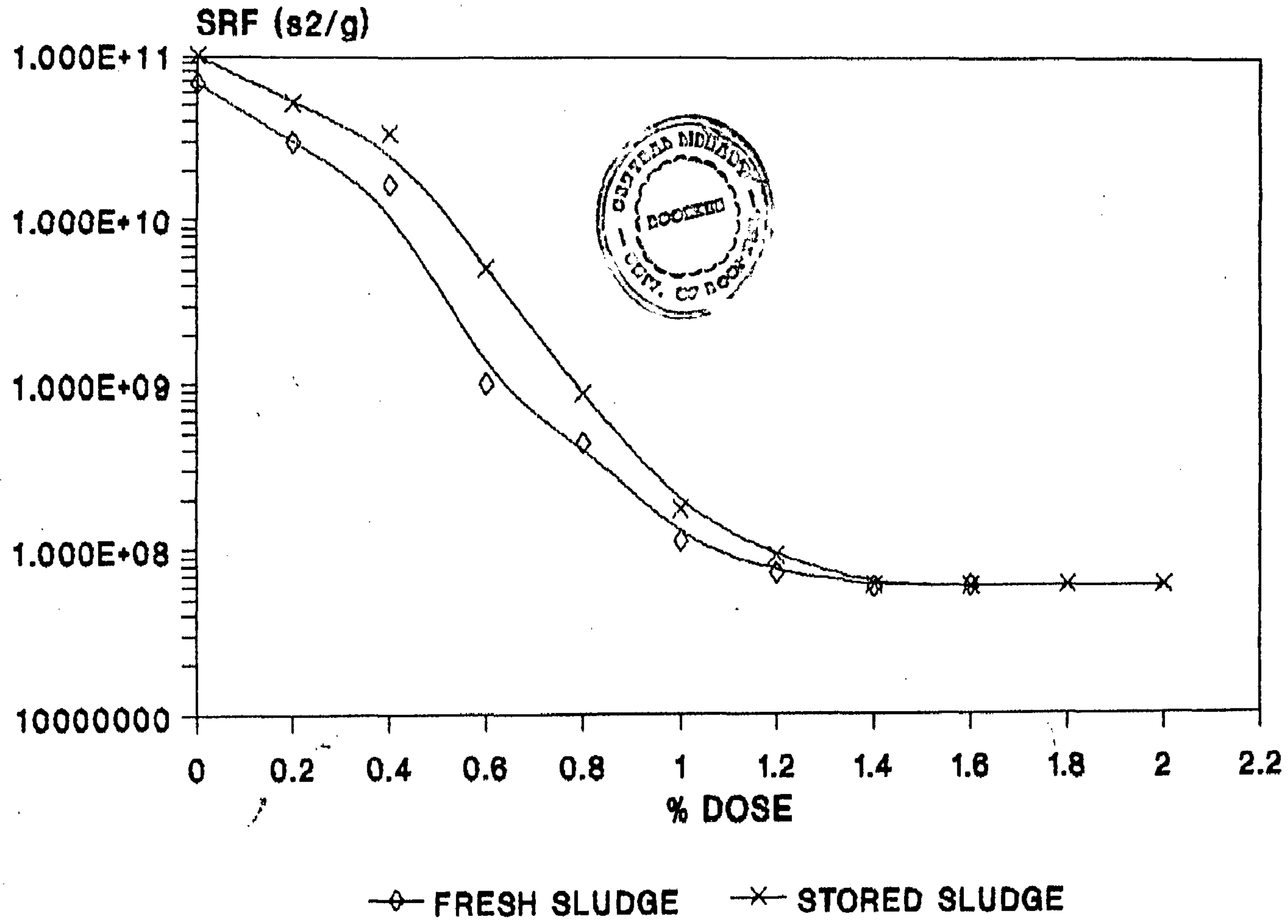


Fig. 4.22b : EFFECT OF STORAGE ON DEWATERABILITY AND ON CONDITIONING WITH DIFFERENT DOSE OF CATIONIC POLYMER
(Secondary Sludge Mill B, Trial No.2)

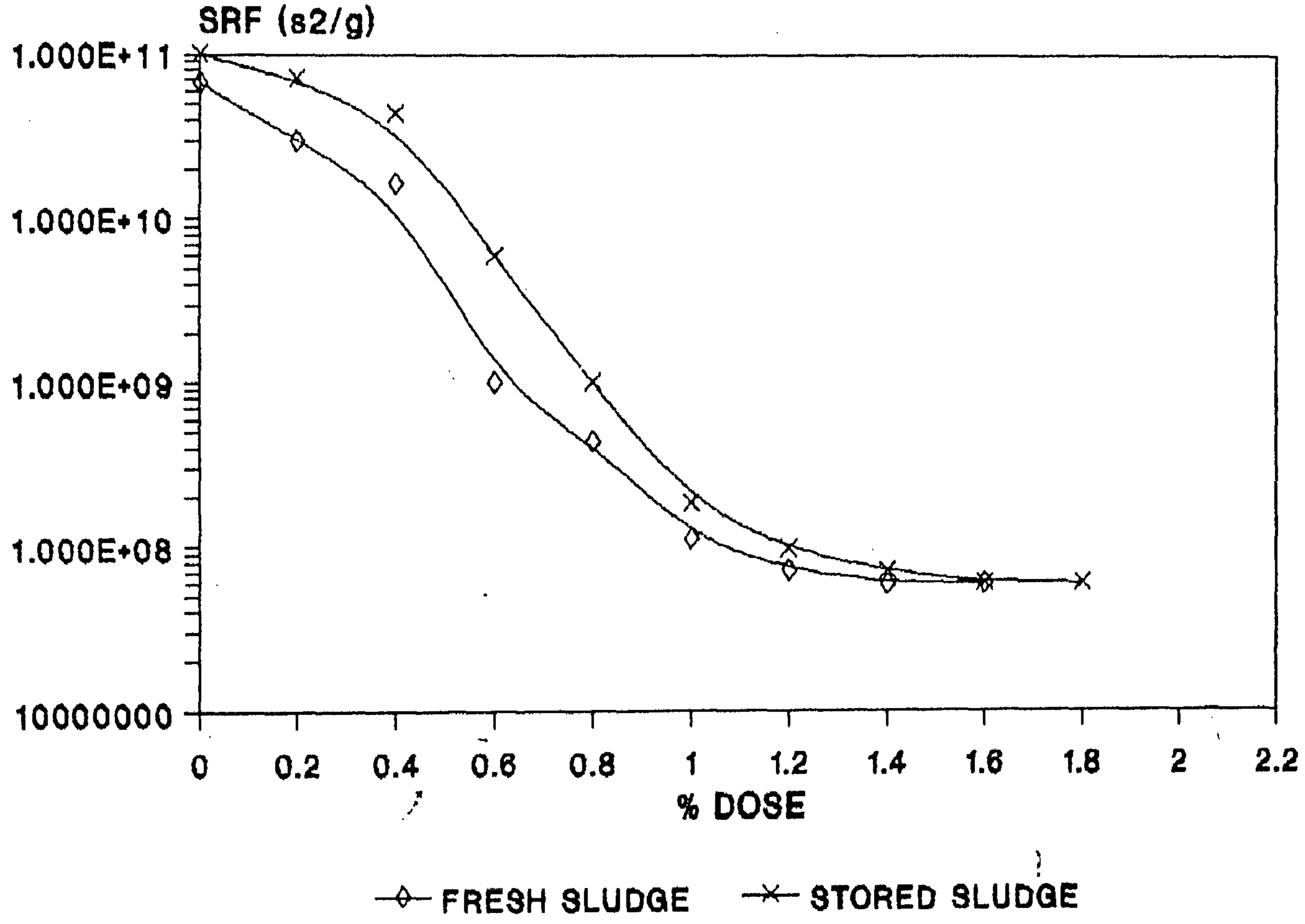


Fig. 4.23a : EFFECT OF STORAGE ON DEWATERABILITY AND ON CONDITIONING WITH DIFFERENT DOSE OF LIME
(Secondary Sludge Mill B, Trial No.1)

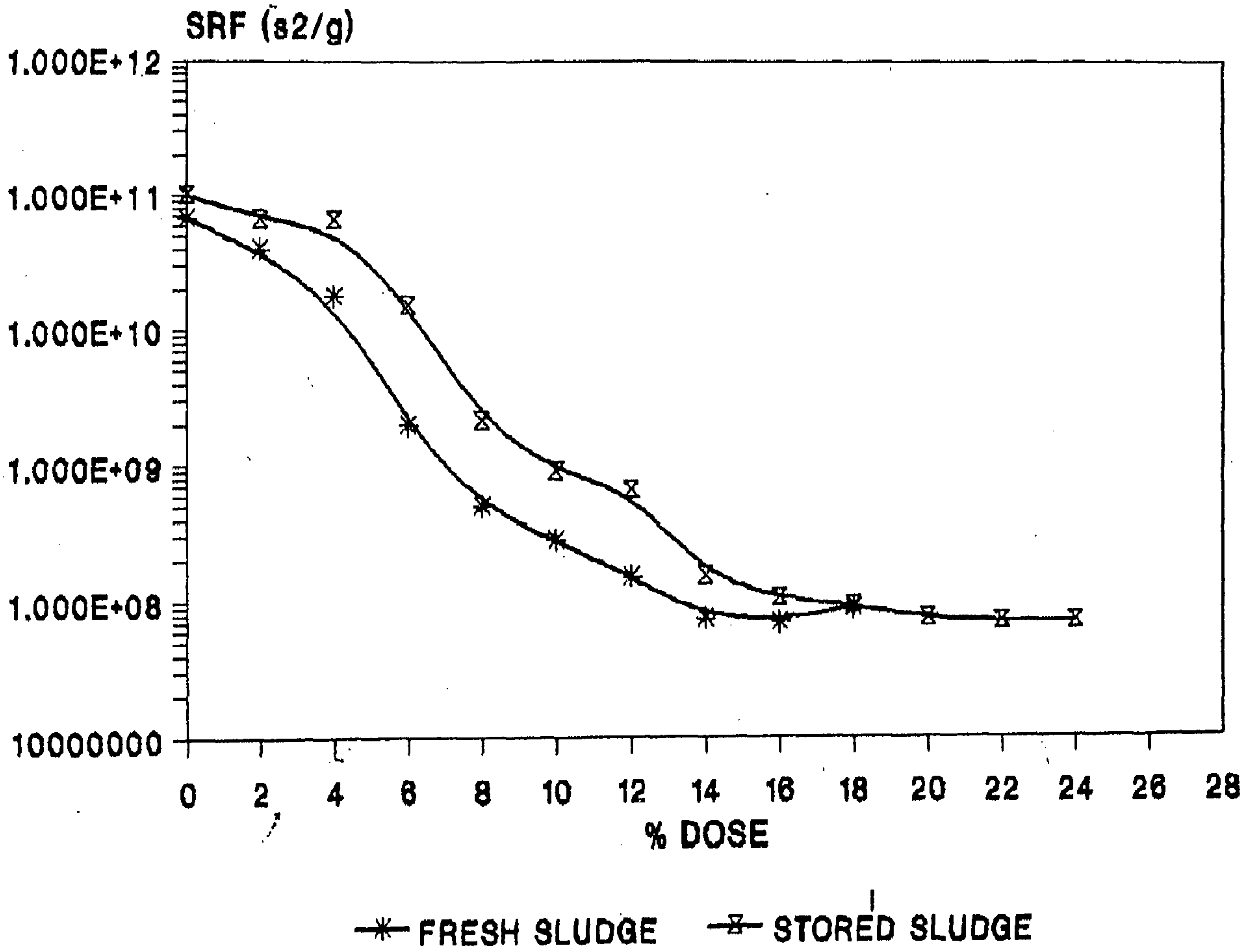
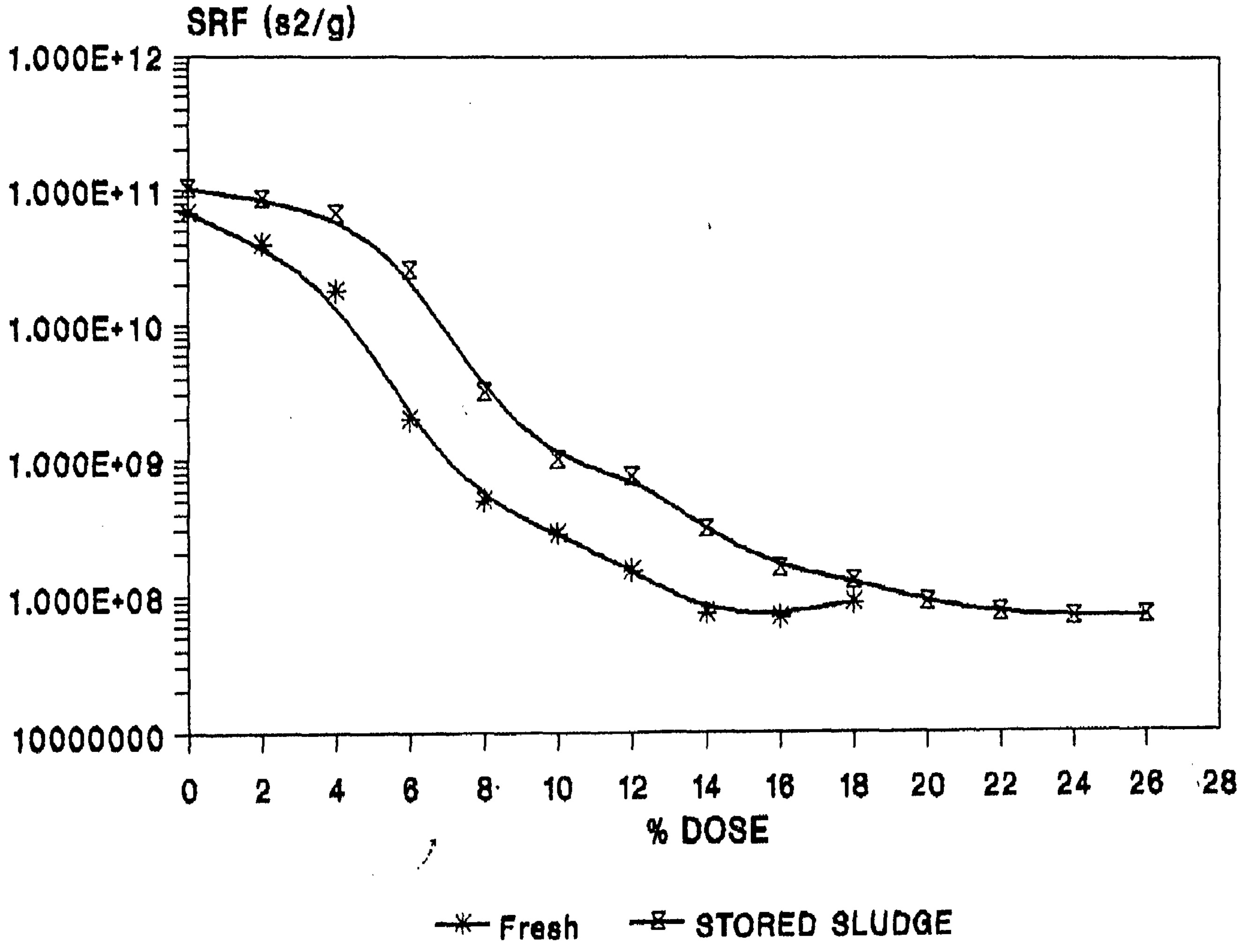


Fig. 4.23b : EFFECT OF STORAGE ON DEWATERABILITY AND ON CONDITIONING WITH DIFFERENT DOSE OF LIME
(Secondary Sludge Mill B,Trial No.2)



4.11 Preliminary Economic Evaluation of the Process

Preliminary economic calculations are given in Appendix-II. It has been found that in the present case utilisation of inorganic flocculants provide promising profit. The highest saving has been obtained with Alum followed by lime/ferric sulfate and ferric chloride. Thus although ferric chloride amongst inorganic flocculants has shown the best operational benefits by decreasing SRF values, its use is least profitable as its market cost is prohibitatively high and thus at present is not economically viable. Similarly, in the present case, at a cost of Rs. 2 lakhs per tonne and a optimum dose of 1.4% , utilisation of cationic polymer has not been found economical at par with inorganic flocculants.

It is also important to note that in case of conditioning of sludge, advantage of more dry sludge, less land requirement (due to less Vacuum filters required) has not been considered in the present economical evaluation. Moreover, at higher dryness of sludge, it can be better utilised to get suitable end products. Thus, overall it can be said that it is economical to have chemical conditioning of sludge.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

.1 CONCLUSIONS

sed on the results obtained experimentally and theoretically lculated, the following conclusions can be drawn:

From the results of SRF of different sludges obtained from two different Indian mill, it is found that primary sludges provide lower SRF than secondary activated sludges. Therefore they are easy to dewater. The dose of flocculant required for minimum SRF is also lower for primary sludge in comparison to secondary sludge from same treatment plant.

The high fines content in the sludge will result in high SRF value and poor dewaterability as indicated by high SRF values of sludges of Mill B. Also, the optimum dose requirement of the flocculant to achieve the minimum SRF value may be high in case of sludge of high fines content.

Flocculants have definite beneficial effect on sludge dewatering. However, the dose must be optimised in each case.

The performance of Ferric Chloride has been found to be the best among the inorganic flocculants used while lime gives the poorest values in terms of operational benefits by decreasing SRF. However, in case of Alum and ferric sulfate, the performance has been found to be sludge dependent. Similarly, amount of dose required for the best results (optimum conditioning) has been found to vary with the type of sludge (primary or secondary), and source, the nature or type of mill. Surprisingly, this can also be varying even with the same sludge collected at different times from the same mill.

Therefore, it can be concluded that the performance of a particular flocculant for conditioning and its dose required may vary with sludge to sludge and even with the same sludge with different characteristics, frequently varying with the mill conditions.

5. Between cationic and anionic polymers studied, the cationic polymers have shown better results. With anionic polymers, the effect on conditioning and hence on improvement in dewatering is found to be negligible in all the trials and with all the sludges used. Therefore, it can be concluded that if polymer is to be used for conditioning, it is better to choose cationic polymer than anionic polymer.

   However, the study is not made with non-ionic polymer which may give acceptable values than anionic.

6. With increase in pH, increase in SRF values noticed with all the flocculants used except in case of lime treated on primary sludge. However, increase was not very sharp between 5.5 to 7.5 pH. Therefore, with sludge of high pH values , the amount of dose required will be increased for a particular flocculant for the better dewatering capability. Otherwise,with the optimum dose the results will be poor.

7. From the results of effect of fast mixing time, it is found that it is very necessary that flocculant must be properly mixed with sludge (higher SRF at no fast mixing or fast mixing for 1/2 min.). However, too prolong fast mixing will deteriorate the conditioning (higher SRF at longer fast mixing time) because the fibres will not get the time to flocculate and some small flocs which are just developed will also break. Similarly, from the results of effect of slow mixing time on

conditioning, it is found that there is a particular time for which slow mixing (flocculation) is to be carried out. If the slow mixing time is much low than the optimum required, the SRF of sludge will be higher due to poor flocculation. Longer slow mixing time (upto 4-4.5 min), however, has not shown sever effect on SRF in the present study. But excessive variation may severely deteriorate the dewatering capability.

8. The stored sludge dewaters poorly. However, it can be dewatered to the same level at its optimum dose or at dose slightly higher than the optimum dose used for fresh sludge. The underdosage of flocculant will not improve the results and much overdosage will not also provide any extra benefits.
9. Preliminary economic evaluation has been made based on the optimized data on optimum flocculant dose and the relative benefits are shown. The study indicates a promise in future. Detailed study will throw more light on the economic indicators of the process.

Finally, it can be concluded that conditioning or flocculation of ETP sludge can result in excellent dewatering performance provided.

- the proper flocculant is employed,
- the flocculant dosage is adequate,
- the optimum pH is being maintained,
- correct mixing time is afforded,
- proper rpm for mixing is provided.

5.2 Recommendations for Future Study:

(a.) There are various factors like particle size distribution of sludge, zeta potential, turbidity, speed of mixing etc which also affect dewatering and conditioning of sludge with flocculants. A detailed analysis of these parameters is required. A simulation with these parameters particularly with particle size distribution may be helpful to make any generalisation of results for different types of sludge and for same sludge from the different mills or from the same mill under varying process conditions.

(b.) The effect on other environmental parameters like pH, BOD , TOC etc. has not been studied with amount and type of flocculant used for conditioning. This type of study is also necessary along with their effects on dewatering characteristics. This must be considered while selecting the best flocculant and its optimum dose.

Similarly, a more detailed economical comparison is also a must while selecting the best flocculent and its optimum dose..

(c.) Plant scale trials are also required before implementation in plant.

Table-4.1 : Specific Resistance to Filteration (SRF) Values of Unconditioned Primary Sludge (PS)and Secondary Sludge (SS) of Mill A and B.

Type of Sludge	SRF Values Trial 1	Trial 2	Trial 3	AVGERAGE VALUES
PS MILL A	3.43E+09	4.01E+09	7.45E+09	4.96E+09
SS MILL A	2.90E+10	2.98E+10	5.90E+09	2.16E+10
PS MILL B	1.90E+10	1.92E+10	1.71E+10	1.84E+10
SS MILL B	6.71E+10	6.61E+10	7.01E+10	6.78E+10

Table-4.2 : Fiber Classification and Ash Content of Primary Sludge of Mill A and B

Mesh Specification	% Fraction (Weight/Weight) Mill A	Mill B
+30	11.09	4.28
+50	16.81	3.95
+100	13.20	6.95
+200	2.80	3.80
-200	56.10	81.02
Ash %	21.25	20.56

*NOTE : All Values of Specific Resistance to Filteration (SRF) are in second^2/gram (s^2/g)

Table-4.3a : Specific Resistance to Filteration (SRF) Values at Different Vacuum (Pressure Drop).
(Primary Sludge Mill A)

Vacuum	SRF Values			
("Hg)	Trial No.1	Trial No.2	Trial No.3	Average Value
5	3.13E+09	3.58E+09	3.38E+09	3.36E+09
7	4.33E+09	5.16E+09	4.59E+09	4.69E+09
9	4.87E+09	5.85E+09	5.63E+09	5.45E+09
11	6.01E+09	6.80E+09	7.41E+09	6.74E+09
13	6.84E+09	6.01E+09	6.44E+09	6.43E+09

Table-4.3b : SRF Values at Different Vacuum (Pressure Drop).
(Secondary Sludge Mill A)

Vacuum	SRF Values			
("Hg)	Trial No.1	Trial No.2	Trial No.3	Average Value
5	3.09E+10	4.11E+10	3.90E+10	3.70E+10
7	5.31E+10	5.06E+10	5.24E+10	5.20E+10
9	5.08E+10	5.39E+10	5.65E+10	5.37E+10
11	5.99E+10	6.38E+10	6.21E+10	6.19E+10
13	8.01E+10	7.25E+10	7.66E+10	7.64E+10

Table-4.3c : Specific Resistance to Filteration (SRF) Values at Different Vacuum (Pressure Drop). (2.5% Ferric Chloride Conditioned Primary Sludge Mill A)

Vacuum ("Hg)	Trial No.1	Trial No.2	Trial No.3	Average Value
10	7.42E+08	8.01E+08	7.20E+08	7.54E+08
12	9.45E+08	1.03E+09	1.06E+09	1.01E+09
14	1.22E+09	1.09E+09	1.12E+09	1.14E+09
16	1.34E+09	1.39E+09	1.11E+09	1.28E+09
18	1.32E+09	1.58E+09	1.43E+09	1.44E+09

Table-4.4a : Specific Resistance to Filteration (SRF) Values at Different Consistency (Primary Sludge Mill A)

Trial No. 1		Trial No.2	
Consistecy (% Total Solids)	SRF Value	Consistecy (% Total Solids)	SRF Value
0.996	7.65E+09	0.990	7.69E+09
2.012	7.79E+09	2.110	7.89E+09
3.009	8.49E+09	3.011	8.39E+09
4.101	8.79E+09	4.103	8.98E+09
5.112	9.45E+09	5.102	9.25E+09

Table-4.4b : Specific Resistance to Filteration (SRF) Values at Different Consistency **(Secondary Sludge Mill A)**

Trial No. 1 Consistecy (% Total Solids)	SRF Value	Trial No.2 Consistecy (% Total Solids)	Value
0.565	1.32E+10	0.515	1.45E+10
1.032	1.29E+10	1.011	1.32E+10
2.049	1.31E+10	2.107	1.40E+10
3.111	1.86E+10	3.102	1.69E+10
4.109	1.97E+10	4.007	1.90E+10

Table-4.5a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. **(Primary Sludge Mill A ,Cy*% = 3.486,Trial No.1)**

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	3.43E+09	3.43E+09	3.43E+09	3.43E+09
2	1.95E+09	1.37E+09	2.48E+09	2.58E+09
4	6.01E+08	1.72E+08	1.05E+09	9.85E+08
6	1.82E+08	5.10E+07	6.09E+08	1.70E+08
08	6.45E+07	4.35E+07	2.21E+08	7.01E+07
10	5.22E+07	4.36E+07	8.53E+07	5.91E+07
12	6.01E+07		6.20E+07	5.01E+07
14			6.90E+07	7.00E+07

* Consistency (%Total Solids)

Table-4.5b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. (Primary Sludge Mill A ,Cy*% = 3.501,Trial No.2)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	4.01E+09	4.01E+09	4.01E+09	4.01E+09
2	2.48E+09	2.38E+09	2.58E+09	2.58E+09
4	7.15E+08	4.01E+08	9.85E+08	8.91E+08
6	1.62E+08	6.40E+07	2.21E+08	2.01E+08
08	7.05E+07	4.00E+07	9.83E+07	8.01E+08
10	5.92E+07	4.00E+07	7.02E+07	6.45E+07
12	4.60E+07		5.20E+07	5.01E+07
14	5.82E+07		7.01E+07	6.91E+07

* Consistency (%Total Solids)

Table-4.5c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. (Primary Sludge Mill A ,Cy*% = 3.410,Trial No.3)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	7.45E+09	7.45E+09	7.45E+09	7.45E+09
2	4.10E+09	2.83E+09	5.45E+09	5.45E+09
4	1.27E+09	6.73E+08	1.37E+09	2.09E+09
6	3.23E+08	8.50E+07	4.47E+08	3.73E+08
08	1.01E+08	6.02E+07	2.01E+08	1.51E+08
10	6.02E+07	4.05E+07	7.02E+07	6.23E+07
12	4.60E+07	4.36E+07	6.50E+07	5.10E+07
14	6.82E+07		5.80E+07	6.91E+07
16			6.82E+07	

* Consistency (%Total Solids)

Table-4.6a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. (Secondary Sludge Mill A ,Cy*% = 0.950,Trial No.1)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	2.90E+10	2.90E+10	2.90E+10	2.90E+10
2	1.15E+10	9.05E+09	1.55E+10	1.30E+10
4	5.30E+09	3.91E+09	7.75E+09	6.74E+09
6	2.90E+08	2.10E+08	3.61E+08	3.00E+08
08	1.10E+08	6.15E+07	1.49E+08	1.19E+08
10	8.20E+07	4.37E+07	7.60E+07	8.10E+07
12	5.10E+07	4.47E+07	6.99E+07	6.60E+07
14	4.61E+07		5.90E+07	4.99E+07
16	5.90E+07		4.80E+07	6.15E+07
18			7.00E+07	

* Consistency (%Total Solids)

Table-4.6b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. (Secondary Sludge Mill A ,Cy*% = 0.960,Trial No.2)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	2.98E+10	2.98E+10	2.98E+10	2.98E+10
2	1.10E+10	9.01E+09	1.50E+10	1.40E+10
4	6.31E+09	3.91E+09	7.75E+09	7.72E+09
6	5.86E+08	6.01E+08	8.91E+08	6.27E+08
08	1.24E+08	1.23E+08	1.88E+08	1.39E+08
10	8.20E+07	5.99E+07	1.40E+08	7.60E+07
12	6.10E+07	4.81E+07	8.01E+07	5.70E+07
14	4.95E+07	4.81E+07	6.85E+07	4.31E+07
16	4.96E+07		5.93E+07	4.31E+07
18			7.01E+07	

* Consistency (%Total Solids)

Table-4.6c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. (**Secondary Sludge Mill A ,Cy*% = 0.980,Trial No.3**)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	5.90E+09	5.90E+09	5.90E+09	5.90E+09
2	3.86E+09	1.95E+09	3.91E+09	2.95E+09
4	1.95E+09	6.51E+08	2.01E+09	1.05E+09
6	3.20E+08	1.37E+08	5.99E+08	3.21E+08
08	8.98E+07	7.60E+07	1.88E+08	1.36E+08
10	5.93E+07	4.31E+07	8.98E+07	8.98E+07
12	4.81E+07	4.36E+07	7.30E+07	5.60E+07
14	5.93E+07		6.40E+07	4.31E+07
16			4.82E+07	5.94E+07
18			7.03E+07	

* Consistency (%Total Solids)

Table-4.7a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants.

(Primary Sludge Mill B ,Cy* % = 3.256,Trial No.1)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	1.90E+10	1.90E+10	1.90E+10	1.90E+10
2	1.05E+10	8.70E+09	1.20E+10	1.20E+10
4	4.94E+09	4.02E+09	5.33E+09	3.01E+09
6	5.10E+08	2.36E+08	5.76E+08	5.41E+08
08	1.26E+08	4.46E+07	2.30E+08	1.04E+08
10	7.51E+07	4.46E+07	1.25E+08	6.05E+07
12	4.80E+07		7.25E+07	4.56E+07
14	5.04E+07		5.53E+07	5.50E+07
16			6.01E+07	

* Consistency (%Total Solids)

Table-4.7b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. (Primary Sludge Mill B ,Cy* % = 3.261,Trial No.2)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	1.92E+10	1.92E+10	1.92E+10	1.92E+10
2	1.19E+10	8.64E+09	1.33E+10	1.04E+10
4	4.94E+09	2.72E+09	5.33E+09	4.03E+09
6	6.42E+08	1.14E+08	7.78E+08	5.76E+08
08	1.44E+08	4.31E+07	2.37E+08	1.26E+08
10	7.93E+07	4.32E+07	1.00E+08	7.20E+07
12	4.86E+07		7.11E+07	5.01E+07
14	5.55E+07		5.51E+07	6.51E+07
16			6.01E+07	

* Consistency (%Total Solids)

Table-4.7c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants.

(Primary Sludge Mill B ,Cy* % = 3.350,Trial No.3)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	1.71E+10	1.71E+10	1.71E+10	1.71E+10
2	6.06E+09	6.00E+09	6.99E+09	5.01E+09
4	2.72E+09	3.01E+09	4.02E+09	2.50E+09
6	5.10E+08	4.14E+08	4.95E+08	4.34E+08
08	2.05E+08	6.51E+07	2.37E+08	1.51E+08
10	9.89E+07	4.10E+07	9.80E+07	7.93E+07
12	6.01E+07	4.46E+07	8.60E+07	4.31E+07
14	4.50E+07		7.93E+07	5.01E+07
16	5.01E+07		5.51E+07	
18			6.01E+07	

* Consistency (%Total Solids)

Table-4.8a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants (Secondary Sludge Mill B ,Cy*% = 0.901,Trial No.1)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	6.71E+10	6.71E+10	6.71E+10	6.71E+10
2	3.01E+10	1.18E+10	3.98E+10	1.68E+10
4	1.58E+10	4.91E+09	1.79E+10	5.01E+09
6	6.41E+08	4.80E+08	1.98E+09	6.30E+08
08	2.00E+08	8.31E+07	5.01E+08	1.50E+08
10	1.11E+08	4.61E+07	2.84E+08	8.00E+07
12	7.68E+07	4.61E+07	1.52E+08	6.02E+07
14	6.01E+07		9.87E+07	4.65E+07
16	4.65E+07		7.40E+07	4.71E+07
18	5.23E+07		7.00E+07	
20			8.91E+07	

* Consistency (%Total Solids)

Table-4.8b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants.

(Secondary Sludge Mill B ,Cy*% = 0.91 ,Trial No.2)

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	6.61E+10	6.61E+10	6.61E+10	6.61E+10
2	3.03E+10	1.16E+10	3.99E+10	1.78E+10
4	1.67E+10	4.90E+09	1.85E+10	5.09E+09
6	6.60E+08	4.86E+08	2.01E+09	6.36E+08
08	2.11E+08	8.29E+07	5.11E+08	1.61E+08
10	1.12E+08	4.60E+07	2.89E+08	8.06E+07
12	7.98E+07	4.71E+07	1.50E+08	6.09E+07
14	6.01E+07		9.87E+07	4.64E+07
16	4.61E+07		7.20E+07	4.69E+07
18	4.99E+07		6.89E+07	
20			7.21E+07	

* Consistency (%Total Solids)

Table-4.8c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Inorganic Flocculants. **(Secondary Sludge Mill B ,Cy*% = 0.86 ,Trial No.3)**

% Dose	Alum	Ferric Chloride	Lime	Ferric Sulfate
0	7.01E+10	7.01E+10	7.01E+10	7.01E+10
2	4.12E+10	3.81E+10	5.91E+10	3.01E+10
4	3.18E+10	5.12E+09	5.80E+10	3.02E+09
6	6.41E+08	6.40E+08	1.53E+10	8.10E+08
08	3.10E+08	1.00E+08	4.11E+09	2.33E+08
10	1.32E+08	5.31E+07	1.01E+09	9.87E+07
12	9.51E+07	4.39E+07	7.21E+08	7.29E+07
14	8.25E+07	4.41E+07	3.02E+08	6.21E+07
16	5.99E+07		9.99E+07	6.09E+07
18	4.55E+07		7.52E+07	6.66E+07
20	4.98E+07		6.85E+07	

* Consistency (%Total Solids)

Table-4.9a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) **(Primary Sludge Mill A ,Cy* % = 3.505,Trial No.1)**

% Dose	Anionic A	Cationic	Anionic B
0	4.61E+09	4.61E+09	4.61E+09
0.2	2.11E+09	1.59E+09	2.53E+09
0.4	4.20E+08	3.55E+08	3.98E+08
0.6	5.70E+08	1.01E+08	5.21E+08
0.8	7.01E+08	5.82E+07	6.45E+08
1.0		5.83E+07	

Table-4.9b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) **(Primary Sludge Mill A ,Cy* % = 3.511,Trial No.2)**

% Dose	Anionic A	Cationic	Anionic B
0	4.71E+09	4.71E+09	4.71E+09
0.2	2.01E+09	2.50E+09	2.01E+09
0.4	3.95E+08	3.65E+08	3.75E+08
0.6	2.20E+08	1.01E+08	1.75E+08
0.8	3.98E+08	5.80E+07	4.02E+08
1.0		5.80E+07	

* Consistency (%Total Solids)

Table-4.9C : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) (**Primary Sludge Mill A ,Cy* % = 3.460,Trial No.3**)

% Dose	Anionic A	Cationic	Anionic B
0	6.80E+09	6.80E+09	6.80E+09
0.2	2.94E+09	2.09E+09	3.45E+09
0.4	3.57E+08	3.67E+08	3.60E+08
0.6	2.56E+08	1.01E+08	4.21E+08
0.8	4.01E+08	7.85E+07	6.50E+08
1.0	5.50E+08	4.90E+07	
1.2		5.82E+07	

Table-4.10a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) (**Secondary Sludge Mill A ,Cy*% = 0.965,Trial No.1**)

% Dose	Anionic A	Cationic	Anionic B
0	1.98E+10	1.98E+10	1.98E+10
0.2	8.08E+09	8.96E+09	9.12E+09
0.4	4.38E+09	4.08E+09	4.17E+09
0.6	1.04E+09	1.09E+09	8.13E+08
0.8	1.01E+09	6.10E+08	1.01E+09
1.0	1.20E+09	3.25E+08	1.50E+09
1.2	2.01E+09	8.12E+07	3.01E+09
1.4		5.28E+07	
1.6		5.28E+07	

* Consistency (%Total Solids)

Table-4.10b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) (**Secondary Sludge Mill A ,Cy*% = 0.990,Trial No.2)**

% Dose	Anionic A	Cationic	Anionic B
0	8.25E+09	8.25E+09	8.25E+09
0.2	4.54E+09	4.78E+09	5.90E+09
0.4	1.04E+09	1.04E+09	1.04E+09
0.6	9.10E+08	7.25E+08	7.35E+08
0.8	1.04E+09	4.16E+08	1.01E+09
1.0	1.24E+09	2.21E+08	1.35E+09
1.2	1.89E+09	8.12E+07	1.51E+09
1.4		5.20E+07	
1.6		6.20E+07	

* Consistency (%Total Solids)

Table-4.10c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers)

(Secondary Sludge Mill A ,Cy*% =0.997 ,Trial No.3)

% Dose	Anionic A	Cationic	Anionic B
0	8.25E+09	8.25E+09	8.25E+09
0.2	3.97E+09	3.90E+09	3.91E+09
0.4	1.04E+09	1.24E+09	2.10E+09
0.6	8.10E+08	8.85E+08	8.25E+08
0.8	6.04E+08	4.16E+08	7.01E+08
1.0	8.04E+08	2.21E+08	1.55E+09
1.2	1.08E+09	8.11E+07	1.61E+09
1.4		6.20E+07	
1.6		6.21E+07	

* Consistency (%Total Solids)

Table-4.11a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) **(Primary Sludge Mill B ,Cy* % = 3.256,Trial No.1)**

% Dose	Anionic A	Cationic	Anionic B
0	1.90E+10	1.90E+10	1.90E+10
0.2	6.35E+09	6.99E+09	7.64E+09
0.4	5.90E+08	5.40E+08	6.02E+08
0.6	5.82E+08	9.80E+07	4.95E+08
0.8	6.25E+08	6.81E+07	7.01E+08
1.0	6.25E+08	5.89E+07	7.91E+08
1.2	7.40E+08	6.81E+07	

Table-4.11b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) **(Primary Sludge Mill B ,Cy* % = 3.261,Trial No.2)**

% Dose	Anionic A	Cationic	Anionic B
0	1.92E+10	1.92E+10	1.92E+10
0.2	6.65E+09	4.82E+09	7.95E+09
0.4	6.05E+08	3.41E+08	7.11E+08
0.6	5.96E+08	7.99E+07	4.50E+08
0.8	5.90E+08	6.82E+07	6.01E+08
1.0	7.02E+08	6.02E+07	8.06E+08
1.2		6.91E+07	

* Consistency (%Total Solids)

Table-4.11c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) **(Primary Sludge Mill B ,Cy* % = 3.350,Trial No.3)**

% Dose	Anionic A	Cationic	Anionic B
0	1.71E+10	1.71E+10	1.71E+10
0.2	7.01E+09	6.90E+09	7.92E+09
0.4	5.50E+08	5.50E+08	5.80E+08
0.6	5.15E+08	2.30E+08	5.78E+08
0.8	6.02E+08	9.80E+07	7.03E+08
1.0	7.20E+08	6.01E+07	8.01E+08
1.2		6.81E+07	

* Consistency (%Total Solids)

Table-4.12a : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) (Secondary Sludge Mill B ,Cy*% =0.901 ,Trial No.1)

% Dose	Anionic A	Cationic	Anionic B
0	6.71E+10	6.71E+10	6.71E+10
0.2	2.86E+10	3.01E+10	2.80E+10
0.4	1.48E+10	1.65E+10	1.20E+10
0.6	2.20E+09	1.01E+09	2.44E+09
0.8	2.18E+09	4.41E+08	2.21E+09
1.0	2.17E+09	1.12E+08	2.45E+09
1.2	2.40E+09	7.20E+07	3.25E+09
1.4	4.01E+09	5.90E+07	5.01E+09
1.6		6.01E+07	

* Consistency (%Total Solids)

Table-4.12b : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) **(Secondary Sludge Mill B ,Cy*% =0.910 ,Trial No.2)**

% Dose	Anionic A	Cationic	Anionic B
0	6.61E+10	6.61E+10	6.61E+10
0.2	3.02E+10	3.01E+10	4.00E+10
0.4	1.41E+10	1.40E+10	1.35E+10
0.6	4.10E+09	3.01E+09	5.35E+09
0.8	2.05E+09	3.27E+08	2.20E+09
1.0	3.50E+09	1.00E+08	2.01E+09
1.2	4.05E+09	6.00E+07	3.25E+09
1.4		4.99E+07	
1.6		5.90E+07	

* Consistency (%Total Solids)

Table-4.12c : Specific Resistance to Filteration (SRF) Values at Different Dosage of Polyelectrolytes (Polymers) (Secondary Sludge Mill B ,Cy*% = 0.860,Trial No.3)

% Dose	Anionic A	Cationic	Anionic B
0	7.01E+10	7.01E+10	7.01E+10
0.2	3.50E+10	3.98E+10	4.00E+10
0.4	1.35E+10	1.18E+10	1.20E+10
0.6	5.50E+09	1.02E+09	4.50E+09
0.8	2.20E+09	3.01E+08	2.41E+09
1.0	2.46E+09	1.12E+08	4.01E+09
1.2	3.30E+09	7.51E+07	4.05E+09
1.4		5.91E+07	
1.6		4.99E+07	
1.8		5.00E+07	

* Consistency (%Total Solids)

Table-4.13 : Optmum Dosage (%) of Various flocculants for Primary Sludge (P.S.) and Secondary Sludge (S.S.) of Mill A and Mill B.

Flocculant	% Optimum Dosage				
	Alum	Ferric Chloride	Lime	Ferric Sulfate	Cationic Polymer
Type of Sludge and Mill					
<u>P.S.</u> <u>Mill</u> <u>A</u>					
Trial No. 1	10	8	12	12	0.8
Trial No. 2	12	8	12	12	0.8
Trial No. 3	12	10	14	12	1.0
Avg. Value	11	9	13	12	0.9
<u>P.S.</u> <u>Mill</u> <u>B</u>					
Trial No. 1	12	8	14	12	1.0
Trial No. 2	12	8	14	12	1.0
Trial No. 3	14	10	16	12	1.0
Avg. Value	13	9	15	12	1.0
<u>S.S.</u> <u>Mill</u> <u>A</u>					
Trial No. 1	14	10	16	14	1.4
Trial No. 2	14	12	16	14	1.4
Trial No. 3	12	10	16	14	1.4
Avg. Value	13	11	16	14	1.4
<u>S.S.</u> <u>Mill</u> <u>B</u>					
Trial No. 1	16	10	18	14	1.4
Trial No. 2	16	10	18	14	1.4
Trial No. 3	18	12	18	16	1.6
Avg. Value	17	11	18	15	1.5

Table-4.14a : SRF Values at Different Rapid Mixing Time*
During Conditioning With Flocculants
(Secondary Sludge Mill A, Trial No. 1)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used Ferric Chloride(10%**)	 Cationic Polymer(1.4%**)
2 (0.0+2.0)	4.31E+09	5.01E+09
2.5 (0.5+2.0)	7.31E+08	8.90E+08
3 (1.0+2.0)	4.34E+07	6.00E+07
3.5 (1.5+2.0)	4.54E+07	6.10E+07
4 (2.0+2.0)	5.54E+07	7.01E+07
4.5 (2.5+2.0)	7.64E+07	1.11E+08
5 (3.0+2.0)	1.11E+08	1.29E+08

* Slow Mixing Time of Two Minute Kept Constant

** Optimum Dose Found

Table-4.14b : SRF Values at Different Rapid Mixing Time*
During Conditioning With Flocculants
(Secondary Sludge Mill A, Trial No. 2)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used: Ferric Chloride(10%)	Flocculants Used: Cationic Polymer(1.4%)
2 (0.0+2.0)	4.30E+09	4.95E+09
2.5 (0.5+2.0)	8.98E+08	9.01E+08
3 (1.0+2.0)	4.38E+07	6.09E+07
3.5 (1.5+2.0)	4.54E+07	6.11E+07
4 (2.0+2.0)	5.90E+07	7.11E+07
4.5 (2.5+2.0)	8.55E+07	1.21E+08
5 (3.0+2.0)	1.12E+08	1.31E+08

* Slow Mixing Time of Two Minute Kept Constant

** Optimum Dose Found

Table 4.15a : SRF Values at different Rapid Mixing Time*

During Conditioning With Flocculants

(Secondary Sludge Mill B, Trial No. 1)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used Alum (16%**)	 Cationic Polymer(1.4%**)
2 (0.0+2.0)	3.01E+10	3.02E+10
2.5 (0.5+2.0)	1.01E+09	1.80E+09
3 (1.0+2.0)	4.60E+07	4.90E+07
3.5 (1.5+2.0)	4.65E+07	5.01E+07
4 (2.0+2.0)	6.82E+07	5.92E+07
4.5 (2.5+2.0)	1.43E+08	1.01E+08
5 (3.0+2.0)	1.45E+08	1.21E+08

* Slow Mixing Time of Two Minute Kept Constant

** Optimum Dose Found

Table-4.15b : SRF Values at different Rapid Mixing Time*
During Conditioning With Flocculants
(Secondary Sludge Mill B, Trial No. 2)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used: Alum (16%**)	Flocculants Used: Cationic Polymer(1.4%**)
2 (0.0+2.0)	2.89E+10	3.25E+10
2.5 (0.5+2.0)	9.01E+08	1.50E+09
3 (1.0+2.0)	4.67E+07	4.85E+07
3.5 (1.5+2.0)	5.01E+07	4.94E+07
4 (2.0+2.0)	6.32E+07	5.65E+07
4.5 (2.5+2.0)	1.23E+08	1.11E+08
5 (3.0+2.0)	1.42E+08	1.21E+08

* Slow Mixing Time of Two Minute Kept Constant

** Optimum Dose Found

Table-4.16a : SRF Values at different Slow Mixing Time During Conditioning With Flocculants (Secondary Sludge Mill A, Trial No. 1)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used Ferric Chloride(10%**)	 Cationic Polymer(1.4%**)
1 (1.0+0.0)	4.51E+09	4.92E+09
1.5 (1.0+0.5)	9.81E+08	1.41E+09
2 (1.0+1.0)	1.01E+08	9.99E+07
2.5 (1.0+1.5)	7.26E+07	7.75E+07
3 (1.0+2.0)	4.30E+07	5.60E+07
3.5 (1.0+2.5)	4.39E+07	5.62E+07
4 (1.0+3.0)	4.31E+07	5.60E+07
4.5 (1.0+3.5)	4.35E+07	5.69E+07
5 (1.0+4.0)	5.31E+07	6.01E+07

* Rapid Mixing Time of One Minute Kept Constant

** Optimum Dose Found

Table-4.16b : SRF Values at different Slow Mixing Time During Conditioning With Flocculants (Secondary Sludge Mill A, Trial No. 2)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used Ferric Chloride(10%**)	Cationic Polymer(1.4%**)
1 (1.0+0.0)	4.91E+09	5.01E+09
1.5 (1.0+0.5)	1.31E+09	1.89E+09
2 (1.0+1.0)	2.11E+08	1.10E+08
2.5 (1.0+1.5)	9.08E+07	7.65E+07
3 (1.0+2.0)	4.28E+07	5.57E+07
3.5 (1.0+2.5)	4.28E+07	6.00E+07
4 (1.0+3.0)	4.38E+07	5.59E+07
4.5 (1.0+3.5)	4.46E+07	5.66E+07
5 (1.0+4.0)	4.99E+07	6.88E+07

* Rapid Mixing Time of One Minute Kept Constant

** Optimum Dose Found

Table-4.17a : SRF Values at different Slow Mixing Time
During Conditioning With Flocculants
(Secondary Sludge Mill B, Trial No. 1)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used	
	Alum $(16\%^{**})$	Cationic Polymer$(1.4\%^{**})$
1 (1.0+0.0)	2.99E+10	3.01E+10
1.5 (1.0+0.5)	7.25E+09	8.40E+09
2 (1.0+1.0)	9.99E+07	1.01E+08
2.5 (1.0+1.5)	6.70E+07	5.50E+07
3 (1.0+2.0)	4.66E+07	4.63E+07
3.5 (1.0+2.5)	6.66E+07	4.63E+07
4 (1.0+3.0)	5.05E+07	5.18E+07
4.5 (1.0+3.5)	5.32E+07	5.20E+07
5 (1.0+4.0)	6.11E+07	8.02E+07

* Rapid Mixing Time of One Minute Kept Constant

** Optimum Dose Found

Table-4.17b : SRF Values at different Slow Mixing Time During Conditioning With Flocculants (Secondary Sludge Mill B, Trial No. 2)

Total Time (Min) (Rapid + Slow Mixing)	Flocculants Used: Alum (16%**)	Flocculants Used: Cationic Polymer(1.4%**)
1 (1.0+0.0)	2.59E+10	3.01E+10
1.5 (1.0+0.5)	6.55E+09	7.10E+09
2 (1.0+1.0)	9.99E+07	2.09E+08
2.5 (1.0+1.5)	7.20E+07	6.48E+07
3 (1.0+2.0)	4.70E+07	4.63E+07
3.5 (1.0+2.5)	4.76E+07	4.65E+07
4 (1.0+3.0)	5.85E+07	4.63E+07
4.5 (1.0+3.5)	4.72E+07	6.30E+07
5 (1.0+4.0)	4.79E+07	7.02E+07

* Rapid Mixing Time of One Minute Kept Constant

** Optimum Dose Found

Table-4.18a : SRF Values at Different Rapid Mixing Time*
During Conditioning With Different Dose of
Flocculants (Optimum and Less Than Optimum)
(Secondary Sludge Mill A, Trial No. 1)

Total Time (Min) (Rapid + Slow Mixing)	Flocculant Used	
	Ferric Chloride(10%)	Ferric Chloride(6%)
2 (0.0+2.0)	4.31E+09	6.21E+09
2.5 (0.5+2.0)	7.31E+08	2.41E+09
3 (1.0+2.0)	4.34E+07	1.28E+08
3.5 (1.5+2.0)	4.54E+07	1.57E+08
4 (2.0+2.0)	5.54E+07	2.98E+08
4.5 (2.5+2.0)	7.64E+07	9.28E+08
5 (3.0+2.0)	1.11E+08	1.58E+09

*** Slow Mixing Time of Two Minute Kept Constant**

Table-4.18b : SRF Values at Different Rapid Mixing Time*
During Conditioning With Different Dose of
Flocculants (Optimum and Less Than Optimum)
(Secondary Sludge Mill A, Trial No. 2)

Total Time (Min) (Rapid + Slow Mixing)	Flocculant Used	
	Ferric Chloride(10%)	Ferric Chloride(6%)
2 (0.0+2.0)	4.30E+09	6.30E+09
2.5 (0.5+2.0)	8.98E+08	3.21E+09
3 (1.0+2.0)	4.38E+07	1.36E+08
3.5 (1.5+2.0)	4.54E+07	1.67E+08
4 (2.0+2.0)	5.90E+07	3.20E+08
4.5 (2.5+2.0)	8.55E+07	1.01E+09
5 (3.0+2.0)	1.12E+08	1.75E+09

* Slow Mixing Time of Two Minute Kept Constant

Table-4.19a : SRF Values at different pH During Conditioning
With Different Flocculants (At Optimum Dose)
(Secondary Sludge Mill A, Trial No. 1)

pH	Alum	Ferric Chloride	Lime	Ferric Sulfate	Cationic Polymer
4.5	2.28E+07	1.01E+07	8.56E+07	2.20E+07	1.94E+07
5.5	3.69E+07	2.61E+07	2.49E+08	3.59E+07	2.10E+07
6.5	1.24E+08	5.60E+07	4.01E+08	6.56E+07	5.68E+07
7.5	3.05E+08	8.32E+07	9.02E+08	1.52E+08	1.90E+08
8.5	4.08E+08	7.01E+08	3.33E+09	8.51E+08	3.23E+09
9.5	1.06E+10	1.89E+10	5.21E+09	1.01E+10	1.71E+10
10.5	3.70E+10	4.65E+10	8.45E+09	4.01E+10	7.23E+10

Table-4.19b : SRF Values at different pH During Conditioning
With Different Flocculants (At Optimum Dose)
(Secondary Sludge Mill A, Trial No. 2)

pH	Alum	Ferric Chloride	Lime	Ferric Sulfate	Cationic Polymer
4.5	2.20E+07	1.11E+07	8.98E+07	1.16E+07	1.91E+07
5.5	3.31E+07	2.60E+07	2.53E+08	2.50E+07	2.10E+07
6.5	9.98E+07	4.51E+07	3.98E+08	4.50E+07	5.60E+07
7.5	1.01E+08	8.00E+07	9.00E+08	1.00E+08	2.00E+08
8.5	3.04E+08	5.01E+08	2.58E+09	7.01E+08	3.32E+09
9.5	1.01E+10	8.89E+09	5.01E+09	1.05E+10	1.80E+10
10.5	3.80E+10	2.32E+10	8.30E+09	4.66E+10	7.00E+10

Table-4.19c : SRF Values at different pH During Conditioning With Different Flocculants (At Optimum Dose) (Secondary Sludge Mill A, Trial No. 3)

pH	Alum	Ferric Chloride	Lime	Ferric Sulfate	Cationic Polymer
4.5	5.20E+07	2.28E+07	9.01E+07	2.27E+07	1.94E+07
5.5	7.31E+07	3.67E+07	2.50E+08	3.67E+07	2.20E+07
6.5	1.98E+08	5.11E+07	4.21E+08	4.99E+07	5.60E+07
7.5	3.03E+08	8.32E+07	9.12E+08	1.24E+08	1.90E+08
8.5	4.21E+08	5.25E+08	3.00E+09	7.00E+08	3.00E+09
9.5	9.88E+09	1.05E+10	5.01E+09	9.89E+09	1.80E+10
10.5	3.00E+10	2.99E+10	8.33E+09	4.01E+10	6.01E+10

Table-4.20a : SRF Values at different pH During Conditioning With Different Flocculants (At Optimum Dose) (Primary Sludge Mill A, Trial No. 1)

pH	Alum	Ferric Chloride	Lime	Ferric Sulfate	Cationic Polymer
4.5	3.01E+07	1.01E+07	2.38E+08	3.00E+07	2.01E+07
5.5	4.31E+07	3.01E+07	2.28E+08	4.30E+07	3.00E+07
6.5	1.14E+08	4.31E+07	1.14E+08	6.51E+07	4.32E+07
7.5	1.26E+08	4.87E+07	2.30E+08	8.51E+07	6.51E+07
8.5	4.60E+08	7.99E+07	4.30E+08	4.91E+08	4.36E+08
9.5	8.64E+08	2.00E+08	8.71E+08	8.74E+08	9.84E+08
10.5	1.06E+09	3.94E+08	9.76E+08	2.72E+09	6.33E+09

Table-4.20b : SRF Values at different pH During Conditioning With Different Flocculants (At Optimum Dose)

(Primary Sludge Mill A, Trial No. 2)

pH	Alum	Ferric Chloride	Lime	Ferric Sulfate	Cationic Polymer
4.5	3.01E+07	1.10E+07	3.00E+08	3.01E+07	2.05E+07
5.5	5.31E+07	3.01E+07	2.39E+08	4.30E+07	3.90E+07
6.5	1.15E+08	4.32E+07	1.13E+08	6.61E+07	4.32E+07
7.5	1.30E+08	4.86E+07	2.28E+08	8.51E+07	6.51E+07
8.5	5.00E+08	9.86E+07	4.90E+08	1.99E+08	2.30E+08
9.5	8.71E+08	1.13E+08	5.00E+08	8.70E+08	8.71E+08
10.5	1.06E+09	4.91E+08	8.64E+08	2.76E+09	6.33E+09

Table-4.21a : SRF Values at Different pH During Conditioning With Different Dose of Flocculants (Optimum and Less Than Optimum)

(Primary Sludge Sludge Mill A, Trial No. 1)

pH	Ferric Chloride		Cationic Polymer	
	(4%)	(10%)	(0.4%)	(1.0%)
4.5	1.00E+08	1.01E+07	4.77E+07	2.01E+07
5.5	4.75E+08	3.01E+07	7.99E+07	3.00E+07
6.5	1.15E+09	4.31E+07	3.45E+08	4.32E+07
7.5	3.25E+09	4.87E+07	5.62E+08	6.51E+07
8.5	7.20E+09	7.99E+07	9.69E+08	4.36E+08
9.5	1.21E+10	2.00E+08	6.21E+09	9.84E+08
10.5	4.14E+10	3.94E+08	2.51E+10	6.33E+09

Table-4.21b : SRF Values at Different pH During Conditioning With Different Dose of Flocculants (Optimum and Less Than Optimum)

(Primary Sludge Sludge Mill A, Trial No. 2)

pH	Ferric Chloride (4%)	Ferric Chloride (10%)	Cationic Polymer (0.4%)	Cationic Polymer (1.0%)
4.5	1.13E+08	1.10E+07	4.86E+07	2.05E+07
5.5	5.01E+08	3.01E+07	8.51E+07	3.90E+07
6.5	1.15E+09	4.32E+07	3.01E+08	4.32E+07
7.5	3.20E+09	4.86E+07	5.61E+08	6.51E+07
8.5	6.99E+09	9.86E+07	9.71E+08	2.30E+08
9.5	1.01E+10	1.13E+08	5.06E+09	8.71E+08
10.5	3.03E+10	4.91E+08	1.35E+10	6.33E+09

Table-4.22a : SRF Values of Fresh and Stored Sludge at Different Dose of Ferric Chloride

(Secondary Sludge Mill B)

Dose (%)	Fresh Sludge	Stored Sludge Trial No. 1	Stored Sludge Trial No.2
0	6.71E+10	9.98E+10	1.01E+11
2	1.18E+10	2.02E+10	3.12E+10
4	4.91E+09	9.13E+09	9.13E+09
6	4.80E+08	9.93E+08	1.19E+09
08	8.31E+07	2.01E+08	3.20E+08
10	4.61E+07	6.21E+07	6.25E+07
12	4.61E+07	4.85E+07	4.69E+07
14		4.65E+07	4.67E+07

Table-4.22b : SRF Values of Fresh and Stored Sludge at Different Dose of Cationic Polymer

(Secondary Sludge Mill B)

Dose	Fresh	Stored Sludge	
(%)	Sludge	Trial No. 1	Trial No.2
0	6.71E+10	9.95E+10	9.98E+10
0.2	3.01E+10	5.09E+10	7.09E+10
0.4	1.65E+10	3.34E+10	4.36E+10
0.6	1.01E+09	5.07E+09	5.89E+09
0.8	4.41E+08	8.79E+08	9.99E+08
1.0	1.12E+08	1.74E+08	1.84E+08
1.2	7.20E+07	9.15E+07	9.62E+07
1.4	5.90E+07	6.02E+07	7.05E+07
1.6	6.01E+07	5.91E+07	6.01E+07
1.8		6.00E+07	6.01E+07
2.0		6.01E+07	

Table-4.22c : SRF Values of Fresh and Stored Sludge at Differen
Dose of Lime
(Secondary Sludge Mill B)

Dose	Fresh	Stored Sludge	
(%)	Sludge	Trial No. 1	Trial No.2
0	6.71E+10	1.01E+11	1.02E+11
2	3.98E+10	6.59E+10	8.62E+10
4	1.79E+10	6.46E+10	6.65E+10
6	1.98E+09	1.54E+10	2.54E+10
08	5.01E+08	2.12E+09	3.11E+09
10	2.84E+08	9.12E+08	9.99E+08
12	1.52E+08	6.48E+08	7.50E+08
14	7.40E+07	1.55E+08	3.05E+08
16	7.00E+07	1.05E+08	1.58E+08
18	8.91E+07	9.30E+07	1.29E+08
20		7.40E+07	8.91E+07
22		7.02E+07	7.45E+07
24		7.02E+07	6.98E+07
26			7.05E+07

Table -4.23b : Flocculant Added : ALUM

Dosage Applied (%) : 2.0

Feed Solids Concentration(%) : 3.528

VOLUME V(ml)	TIME t(sec)	t/V
5.0	31.25	6.25
10.0	68.80	6.88
15.0	105.15	7.01
20.0	164.80	8.24
25.0	225.00	9.00
30.0	295.20	9.84
35.0	362.95	10.37
40.0	444.00	11.10
45.0	519.75	11.55
50.0	631.50	12.63

DETAILED DERIVATION OF IMPORTANT FORMULAE USED IN CHAPTER 3 AND IN APPENDIX-III

1.0 Derivation of the Relationship for r (Specific Resistance to Filteration)(36,38,39) (Eq-1 Chapter 3)

The basic filteration equation derived from the Poiseuille and Darcy'law is written as -

$$dV/dt = \Delta PA/\mu(R_c + R_m) \qquad \text{--(I-1)}$$

where,

V = Volume of filtrate delivered in time t

dV/dt = Rate of filteration

ΔP = Driving force = pressure difference across filter (P is numerically equal to applied vacuum in gauge, because $P = P_{vacuum} - P_{atmospheric}$. Hence, it is indicated as P = applied vacuum)

R_c = Cake resistance to the flow of filtrate

R_m = Medium resistance to the flow of filtrate

A = Area of filtering surface

μ = Viscosity of filtrate

Cake resistance R_c varies directly with the thickness of the cake, and the proportionality can be expressed as,

$$R_c = Cl_f \qquad \text{--(I-2)}$$

similarly

$$R_m = Cl_f \qquad \text{--(I-3)}$$

where, C = Proportionality constant

l = Cake thickness at time t

l_f = Fictitious cake thickness with resistance equal to that of the filter medium

If, c is mass of dry cake solids deposited per unit volume of filtrate; p_c is cake density expressed as mass of dry cake solids per unit volume of wet filter cake ; V_f is fictitious volume of filtrate per unit of filtering area necessary to lay down a cake of thickness l_f.

The actual cake thickness plus the fictitious cake thickness is

$$l+l_f = c(V+AV_f)/p_cA \qquad \text{--(I-4)}$$

Equations (I-1) to (I-4) can be combined to give

$$dV/dt = A^2\_P/rc(V+AV_f)\mu \qquad \text{--(I-5)}$$

where, r equals C/p_c and is known as specific cake resistance.

The physical significance of parameter r can be appreciated if in Eq (I-5) medium resistance R_m is neglected. Solving for r,

VALUES OF VARIOUS DATA (VOLUME V,ml COLLECTED IN TIME t,sec etc.) COLLECTED DURING PERFORMING EXPERIMENTS OF SPECIFIC RESISTANCE TO FILTERATION (FOR SAMPLES ONLY VALUES FOR SOME EXPERIMENTS HAVE BEEN GIVEN)

CASE A: Primary sludge Mill A, Trial No.1

Table -4.23a : Flocculant Added : No
Dosage Applied (%) : Nil
Feed Solids Concentration(%) : 3.486

VOLUME V(ml)	TIME t(sec)	t/V
2.0	13.68	6.84
4.0	26.40	6.60
6.0	42.36	7.06
8.0	64.80	8.10
10.0	88.80	8.88
12.0	107.16	8.93
14.0	132.02	9.43
16.0	158.40	9.90
18.0	184.86	10.27
20.0	220.60	11.03
22.0	252.12	11.46
24.0	285.60	11.90
26.0	323.96	12.46
28.0	367.36	13.12
30.0	415.20	13.84

Table -4.23b : Flocculant Added : ALUM

Dosage Applied (%) : 2.0

Feed Solids Concentration(%) : 3.528.

VOLUME V(ml)	TIME t(sec)	t/V
5.0	31.25	6.25
10.0	68.80	6.88
15.0	105.15	7.01
20.0	164.80	8.24
25.0	225.00	9.00
30.0	295.20	9.84
35.0	362.95	10.37
40.0	444.00	11.10
45.0	519.75	11.55
50.0	631.50	12.63

DETAILED DERIVATION OF IMPORTANT FORMULAE USED IN CHAPTER 3 AND IN APPENDIX-III

1.0 Derivation of the Relationship for r (Specific Resistance to Filteration)(36,38,39) (Eq-1 Chapter 3)

The basic filteration equation derived from the Poiseuille and Darcy'law is written as -

$$dV/dt = \Delta PA/\mu(R_c + R_m) \qquad \text{--(I-1)}$$

where,

V = Volume of filtrate delivered in time t

dV/dt = Rate of filteration

ΔP = Driving force = pressure difference across filter (P is numerically equal to applied vacuum in gauge, because $P = P_{vacuum} - P_{atmospheric}$. Hence, it is indicated as P = applied vacuum)

R_c = Cake resistance to the flow of filtrate

R_m = Medium resistance to the flow of filtrate

A = Area of filtering surface

μ = Viscosity of filtrate

Cake resistance R_c varies directly with the thickness of the cake, and the proportionality can be expressed as,

$$R_c = Cl_f \qquad \text{--(I-2)}$$

similarly

$$R_m = Cl_f \qquad \text{--(I-3)}$$

where, C = Proportionality constant

l = Cake thickness at time t

l_f = Fictitious cake thickness with resistance equal to that of the filter medium

If, c is mass of dry cake solids deposited per unit volume of filtrate; p_c is cake density expressed as mass of dry cake solids per unit volume of wet filter cake ; V_f is fictitious volume of filtrate per unit of filtering area necessary to lay down a cake of thickness l_f.

The actual cake thickness plus the fictitious cake thickness is

$$l+l_f = c(V+AV_f)/p_cA \qquad \text{--(I-4)}$$

Equations (I-1) to (I-4) can be combined to give

$$dV/dt = A^2\_P/rc(V+AV_f)\mu \qquad \text{--(I-5)}$$

where, r equals C/p_c and is known as specific cake resistance.

The physical significance of parameter r can be appreciated if in Eq (I-5) medium resistance R_m is neglected. Solving for r, values for G vary from 30 to 85 sec^{-1}

μ = Dynamic viscosity of slurry ($N.\ s/m^2$)

V_t = Volume of the tank, m^2

A = Area of paddle, m^2

v = Relative velocity of paddle in fluid, (m/s) usually 0.7 -0.8 of paddle tip speed, v_p

C_D = Coefficient of Drag of flocculator paddles moving perpendicular to the fluid. For rectangular paddles this is about 1.8.

p_d = Mass fluid density (kg/m^3)

6.1. Power Required

Volume of conditioning tank V_t = $0.55\ m^3$

Assuming G = 85 /s

Assuming μ as 2 times the viscosity of water at 20^0 C

$= 2 \times 8.953 \times 10^{-4}\ Ns/m^2$

Therefore,

Power required P $= (85)^2 \times 2 \times 8.953 \times 10^{-4} \times 0.55$

$= 7.12$ Watt

Hence, Power for motor at 60% efficiency

$= 11.858$ Watts $\simeq 12.0$ Watts

However, the value is very low and hence unconsiderable for practical purpose.

6.2. Area required

It has been reported (37) that a paddle tip speed (v_p) of approximately 0.6-0.9 m/s achieves sufficient turbulence without breaking up the floc. Assuming a value of 0.9 m/s

v $= 0.75 \times v_p = 0.675$ m/s

C_d = 1.8

P_d = 1000 kg/m^3

P (power) = 12.0 Watts (kg/m^2-s^2)

Hence, Area of paddle A = $(2x12.0)/(1.8x1000x0.675^3)$

= 0.04 m^2

7.0: Estimation of Air Suction Rate and Power Requirement of Vacuum Pump:

Assumptions:

1. Resistance of filter medium is negligible.
2. Value of r/r_a is same in both cases viz. with and without flocculants
3. Any effects caused by air leakage are taken in the value given for r/r_a
4. The vacuum pump and motor have an overall efficiency of 50% based on an isotropic compression.
5. The temperature of the surroundings and of slurry is 25°C and the pressure of surrounding is 1 atm.
6. The filter removes all of the solid from the slurry.
7. Dryness of cake is assumed same in both the cases i.e. with and without flocculant

Volume of air per unit time can be calculated using Eq (I-25)

Here, k_f = 0.3 (fraction submergence of drum)

let k_a = 0.1 (fraction of drum area available for air suction)

μ = 8.953×10^{-4} Ns/m^2(Viscosity of filtrate(equal to water) at 25^{o}c)

μ_a = 1.9×10^{-5}Ns/m^2(Viscosity of air at 25^{o}C)

let $r/r_o = 0.6$ (specific resistance to cake/ specific air suction cake resistance)

Case I: Without Flocculant

Vacuum applied is 15"Hg (5.08x10^{4}N/m^2)

p_2 = 10.1×10^4 N/m^2(surrounding pressure)

p_1 = 05.1×10^4 N/m^2(suction pressure)

[10.1x10^4-5.08x10^4(Applied Vacuum 15"Hg)]

Air flow rate at p_2 and at 25^o C $= \dfrac{140 \times 0.1 \times 8.95 \times 10^{-4} \times 0.6}{0.3 \times 1.9 \times 10^{-5} \times 2 \times 40}$

$= 16.49$m^3/hr.

Air flow rate at p^1 and at 25^o C $= \dfrac{16.49 \times 10.1 \times 10^4}{5.02 \times 10^4}$

$= 33.18$ m^3/hr.

Thus, Power required can be calculated using equation (I-26) and (I-27)

$= [1.4/(1.4-1)) \times 5.02 \times 10^4 \times 33.18 \times (1/(3600 \times 1000 \times 0.5)]$

$\times[(10.1 \times 10^4/5.02 \times 10^4)^{\{(1.4-1)/1.4)\}} - 1]$

= 0.73 KW

Case II : With Flocculant

Vacuum applied 8"Hg (2.71x10^{4}N/m^2)

p_2 = 10.1×10^4 N/m^2(surrounding pressure)

p_1 = 7.4×10^4 N/m^2(suction pressure)

$[10.1\times10^4-2.70\times10^4$(Applied Vacuum 8"Hg)]

Therefore,

$$\text{Air flow rate at } p_2 \text{ and } 25^\circ\text{ C} = \frac{140 \times 0.1 \times 8.95 \times 10^{-4} \times 0.6}{0.3 \times 1.9 \times 10^{-5} \times 2 \times 40}$$

$$= 16.49\,m^3/hr.$$

$$\text{Hence, air flow rate at } p_1 \text{ and } 25^\circ\text{ C} = \frac{16.49 \times 10.1 \times 10^4}{7.40 \times 10^4}$$

$$= 22.57\ m^3/hr.$$

Thus,

Power required can be calculated using Eqs. (I-26)and (I-27)

$$= [1.4/(1.4-1)] \times 7.40 \times 10^4 \times 22.57 \times [1/(3600 \times 1000 \times 0.5)]$$

$$\times [(10.1 \times 10^4/7.40 \times 10^4)^{\{(1.4-1)/1.4\}} - 1]$$

$$= 0.31\ KW$$

B. ECONOMIC ANALYSIS CONSIDERING MAJOR ITEMS OF COST AND SAVINGS AND USING A NON DETAIL ESTIMATE FOR CAPITAL INVESTMENT

A preliminary economic comparison can be based on the following assumptions for the cases i.e. with or without flocculants.

Land requirement is equal,(however in case of dewatering without conditioning, the land required will be much more due to five number of vacuum filters in place of one vacuum filter and provision for conditioning tank etc. in case of conditioning of sludge).Considering only cost of vacuum filters, chemical consumption and additional equipment requirement for conditioning are considered. Power consumption is almost the same in both the cases except power consumption in vacuum filter operation. Plant life is 10 years.Rate of interest 18% per annum.Maintenance cost is 5% of capital cost (low cost figure is assumed as maintenance requirement in case of filters is generally low) Working days in a year 330. The minimum SRF obtained in case of each flocculant is almost same and the optimum dose of alum, ferric chloride, lime, ferric sulfate and cationic polymer is approximately 15%, 10%, 18%, 14% and 1.4% (based on experiments)

CASE I : No arrangement for flocculation facility :

a) Fixed cost :

Cost of one filter of 50 m^2 (15' x12') = Rs. 18 Lakhs and hence five filters cost Rs. 90 Lakhs

Yearly interest and insurance on capital(.90x0.18)
= Rs. 16.2 Lakhs

Yearly depreciation(10% of equipment cost)
= Rs. 9.0 Lakhs

Yearly depreciation , interest etc.
= Rs. 25.2 Lakhs

Total Depreciation plus interest etc. per day
= Rs. 7636

b) Operating cost (per day):

Let motor of 5 kW is required for each vacuum filter and total 3 number of persons per shift are required for operation of 5 filters.

i) Total electricity cost (Rs.2 per KWH) = Rs. (5x5x20x2)

= Rs. 1000

ii) Total manpower cost (Rs.100 per person)

= Rs. 3x3x100

= Rs. 900

iii) Maintenance cost = Rs. 0.05x(90/330)

= Rs. 1363

Total operating cost = Rs. 3263

Total fixed + operating cost = Rs. 10,899

CASE II With arrangement for flocculation facilities

a) Fixed cost :

Cost of one filter of $20\ m^2$ (10' x 7') = Rs. 12 Lakhs

Cost of accessories for conditioning arrangement (conditioning tank, one additional pump and flocculator) = Rs. 50,000

Total cost of equipments and accessories = Rs. 12.5 lakhs

Yearly interest plus insurance on capital

(12.5x0.18) = Rs. 2.25 Lakhs

Yearly depreciation(10%) = Rs. 1.25 Lakhs

Yearly depreciation, interest etc. = Rs. 3.50 Lakhs

Total depreciation plus interest etc. per day

= Rs. 1060

b) Operating cost(per day) :

Let motor of same 5 kW is required for filter and 1 person per shift is required for operation.

i) Total electricity cost (Rs.2 per KWH) = Rs. (5x1x20x2)

= Rs. 200

ii) Total manpower cost (Rs.100 per person)

= Rs. 1x3x100

= Rs. 300

iii) Maintenance cost = Rs. 0.05x (12.5/330)

= Rs. 189

Total operating cost excluding chemical cost

= Rs. 689

iv) Chemical cost

CASE I Using alum as flocculant

Alum required per day (15% on TS basis) = 2.8x0.15

= 0.42Tonne

Cost of alum (Rs.2000 per Tonne) = Rs. 840

Total fixed + operating cost(per day) = Rs. 2589

Savings per day(10,899-2589) = Rs. 8310

Savings per annum = Rs. 27.42 lakhs

CASE II Using Ferric chloride as flocculant

Ferric chloride required per day (10% on TS basis) = 2.8x0.10

= 0.28 Tonne

Cost of ferric chloride (Rs.20,000 per Tonne)

= Rs. 5600

Total fixed + operating cost(per day) = Rs. 7349

Savings per day(10,899-7349) = Rs. 3550

Savings per annum = Rs 11.72 lakhs

CASE III Using Lime as flocculant

Lime required per day (18% on TS basis) = 2.8x0.18

= 0.504Tonne

Cost of lime (Rs.2000 per Tonne) = Rs. 1008

Total fixed + operating cost(per day) = Rs. 2757

Savings per day(10,899-2757) = Rs. 8142

Savings per annum = Rs 26.87 lakhs

CASE IV Using Ferric sulfate as flocculant

Ferric sulfate required per day

(14% on TS basis) = 2.8x0.14

= 0.392Tonne

Cost of ferric sulfate(Rs.3000 per Tonne) = Rs. 1176

Total fixed + operating cost(per day) = Rs. 2925 .

Savings per day(10,899-2925) = Rs. 7974

Savings per annum = Rs 26.31 lakhs

CASE V Using cationic polymer

Cationic polymer required per day

(1.4% on TS basis) = 2.8x0.014

= 0.0392 Tonne

Cost of cationic polymer

(Rs.2.0lakhs per Tonne) = Rs. 7840

Total fixed + operating cost(per day) = Rs. 9589

Savings per day (10,899-9589) = Rs. 1310

Savings per annum = Rs. 4.32 lakhs

APPENDIX III

APPENDIX-III

```
      PROGRAM SPRESCALCULATION
      INTEGER IANS,KK
      DIMENSION X(25),Y(25)
C     THIS PROGRAMME CALCULATES SRF (SPECIFIC RESISTANCE TO
      FILTERATION)
      WRITE(*,*)'CALCULATION FOR SPECIFIC RESISTANCE'
      WRITE(*,*)
      DO 150 J=1,100
C     A: CALCULATION OF SLOPE OF BEST FIT LINE OF V vs t/V
      WRITE(*,*)'A: CALCULATION OF SLOPE OF BESTFT LINE OF V vs t/V'
      WRITE(*,*)
      WRITE(*,*)'     VALID MAXIMALITY FOR 20 POINTS'
      WRITE(*,*)
      WRITE(*,*)'      ENTER NUMBER OF POINTS     '
      WRITE(*,*)
      READ(*,*)N
      WRITE(*,*)'GIVE THE VALUES OF POINTS ON X Axis (VOLUME,V)'
      READ(*,*)(X(I),I=1,N)
      WRITE(*,*)'GIVE THE VALUES OF POINTS ON Y Axis (t/V)'
      READ(*,*)(Y(I),I=1,N)
      S1=N
      S2=0.0
      S3=0.0
      S5=0.0
      S6=0.0
      DO 200 I=1,N
      S2=S2+X(I)
```

```
       S3=S3+Y(I)
       S5=S5+(X(I)*X(I))
       S6=S6+(X(I)*Y(I))
 200   CONTINUE
       S4=S2
       ASLOP=(S3*S4-S1*S6)/(S2*S4-S1*S5)
       WRITE(6,490)N
 490   FORMAT(1X,'NUMBER OF POINTS =',I3/)
       WRITE(6,400)(X(I),I=1,N)
       WRITE(6,410)(Y(I),I=1,N)
 400   FORMAT(1X,'VALUES OF X =',20F6.2/)
 410   FORMAT(1X,'VALUES OF Y =',20F6.2/)

       WRITE(*,90)ASLOP
 90    FORMAT(5X,' SLOPE  =',F10.5/)
       WRITE(6,90)ASLOP
C      WHETHER YOU WANT TO STOP PROGRAMME OR WANT RECHECKING OR WANT
C      TO PROCEED FOR NEXT CALCULATION: ENTER VALUE ACCORDINGLY
       WRITE(*,*)'SHOULD I PROCEED FOR NEXT CALCULATION OR RECALCU
     1 LATE IT OR STOP (ENTER 1 FOR NEXT CAL AND 2 FOR STOP)'
       READ(*,*)IANS
       IF(IANS.EQ.2) THEN
       STOP
       ELSE IF(IANS.EQ.1)THEN
       GO TO 160
       ENDIF
       WRITE(*,520)
       WRITE(6,520)
```

```
520    FORMAT(11X,5('-'),'RECHECKING OF COORELATION COEFF FOR ',
      1'OTHER VALUE OF N (NUMBER OF POINTS)',5('-')//)
150    CONTINUE
160    WRITE(*,*)
C      B:"CALCULATION OF c (MASS OF DRY CAKE DEPOSITED PER UNIT
C         VOLUME OF FILTRATE) AND r (SRF)
       WRITE(*,*)'B: CALCULATION OF C AND SP RESISTANCE'
       WRITE(*,*)
       WRITE(*,*)'PLEASE GIVE THE FOLLOWING INFORMATION'
       WRITE(*,*)
       WRITE(*,1)
1      FORMAT(1X,'  RUN NO','  FLOCCULENT ADDED', '    %'/)

       READ(*,80)RUNNO
80     FORMAT(A4)
       READ(*,210)FLOC1,FLOC2,FLOC3,FLOC4
210    FORMAT(4A4)
       READ(*,95)PER
95     FORMAT(A4)

       WRITE(*,*)'GIVE VALUES OF Cc,Ci IN % F6.3 & F5.3/'
       READ(*,10)CC
10     FORMAT(F6.3)
       READ(*,5)CI
5      FORMAT(F5.3)

       C=(CC*CI)/(100.0*(CC-CI))
```

```
       D  = 09.50
       WRITE(*,*)'GIVE P(VAC) IN "Hg (F5.2)'

       READ(*,30)P
30     FORMAT(F5.2)


       P1 = P*34.5
        A = (3.14*(D**2))/4.0

         VIS = 0.008953
       S=ASLOP
                       R = (2.0*P1*(A**2)*S)/(VIS*C)
       WRITE(6,450)CC,CI,VIS
450    FORMAT(3X,'Cake Dryness CC',36X,' =',1X,F6.3/3X,
    1'Initial slurry (feed) consistency CI',15X,' =',1X,F5.3/3X,
    1'VISCOSITY OF FILTERATE',30X,'=',1X,F8.6// 21X,30('*')/)
        WRITE(*,60)
60     FORMAT(24X,'CALCULATION OF SPECIFIC RESISTANCE')
       WRITE(*,70)
70     FORMAT(21X,40('_')//)

       WRITE(6,60)
       WRITE(6,70)
       WRITE(*,*)
        WRITE(*,1)
       WRITE(*,*)
       WRITE(6,1)
```

```
      WRITE(*,3)RUNNO,FLOC1,FLOC2,FLOC3,FLOC4,PER
3     FORMAT(5X,A4,3X,4A4,2X,A4/)
      WRITE(6,3)RUNNO,FLOC1,FLOC2,FLOC3,FLOC4,PER


      WRITE(*,20)C
20    FORMAT(1X,'Mass of cake deposited per unit volume',
     1' of filterate c='F7.5/)
      WRITE(*,*)
      WRITE(6,20)C
      WRITE(*,45)P1,A
45    FORMAT(1X,'VAC IN g/cm2  =',F6.2,3X,'AREA cm2 =',F5.2/)
      WRITE(*,*)
      WRITE(6,45)P1,A
      WRITE(*,55)R
55    FORMAT(1X,'SPRES (sec2/g)=',E12.5//40('*'),'END',38('*'))
      WRITE(6,55)R
      WRITE(6,900)
900   FORMAT('1',28X,'NEXT CALCULATION'/28X,19('-'))
500   STOP
      END
```

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REFERENCES

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Table -4.23c : Flocculant Added : ALUM

Dosage Applied (%) : 4.0

Feed Solids Concentration(%) : 3.541

VOLUME V(ml)	TIME t(sec)	t/V
5.0	13.70	2.74
10.0	27.90	2.79
15.0	47.85	3.19
20.0	71.40	3.57
25.0	90.00	3.60
30.0	114.60	3.82
35.0	140.00	4.00
40.0	168.00	4.20
45.0	198.00	4.40
50.0	237.50	4.75

Table -4.23d : Flocculant Added : ALUM

Dosage Applied (%) : 6.0

Feed Solids Concentration(%) : 3.542

VOLUME V(ml)	TIME t(sec)	t/V
5.0	6.15	1.23
10.0	12.20	1.22
15.0	20.85	1.39
20.0	30.00	1.50
25.0	37.00	1.48
30.0	46.50	1.55
35.0	56.00	1.60
40.0	67.20	1.68
45.0	73.35	1.63
50.0	95.50	1.91

Table -4.23e : Flocculant Added : ALUM

Dosage Applied (%) : 8.0

Feed Solids Concentration(%) : 3.550

VOLUME V(ml)	TIME t(sec)	t/V
10.0	6.00	.60
20.0	12.20	.61
30.0	20.70	.69
40.0	31.60	.79
50.0	40.50	.81
60.0	49.80	.83
70.0	61.60	.88
80.0	72.00	.90
90.0	84.60	.94
100.0	104.00	1.04

Table -4.23f : Flocculant Added : ALUM

Dosage Applied (%) : 10.0

Feed Solids Concentration(%) : 3.563

VOLUME V(ml)	TIME t(sec)	t/V
10.0	5.80	.58
20.0	12.00	.60
30.0	19.50	.65
40.0	28.80	.72
50.0	37.00	.74
60.0	45.00	.75
70.0	54.60	.78
80.0	64.80	.81
90.0	80.10	.89
100.0	93.00	.93

Table -4.23g : Flocculant Added : ALUM

Dosage Applied (%) : 12.0

Feed Solids Concentration(%) : 3.556

VOLUME V(ml)	TIME t(sec)	t/V
10.0	6.10	.61
20.0	12.40	.62
30.0	20.70	.69
40.0	28.80	.72
50.0	38.00	.76
60.0	48.60	.81
70.0	58.80	.84
80.0	68.00	.85
90.0	87.30	.97
100.0	99.00	.99

CASE B: Secondary sludge Mill B, Trial No.1

Table -4.24a : Flocculant Added : No

Dosage Applied (%) : Nil

Feed Solids Concentration(%) : 0.901

VOLUME V(ml)	TIME t(sec)	t/V
2.0	18.78	9.39
4.0	44.24	11.06
6.0	88.14	14.69
8.0	140.48	17.56
10.0	184.80	18.48
12.0	248.52	20.71
14.0	320.74	22.91
16.0	401.28	25.08
18.0	486.00	27.00
20.0	594.00	29.70
22.0	701.14	31.87
24.0	820.32	34.18
26.0	936.00	36.00
28.0	1083.32	38.69
30.0	1259.10	41.97

Table -4.24b : Flocculant Added : FERRIC CHLORIDE

Dosage Applied (%) : 2.0

Feed Solids Concentration(%) : 0.909

VOLUME V(ml)	TIME t(sec)	t/V
5.0	32.10	6.42
10.0	72.00	7.20
15.0	130.05	8.67
20.0	199.20	9.96
25.0	262.25	10.49
30.0	340.20	11.34
35.0	423.50	12.10
40.0	520.40	13.01
45.0	648.90	14.42
50.0	784.50	15.69

Table -4.24c : Flocculant Added : FERRIC CHLORIDE

Dosage Applied (%) : 4.0

Feed Solids Concentration(%) : 0.917

VOLUME V(ml)	TIME t(sec)	t/V
5.0	22.25	4.45
10.0	49.00	4.90
15.0	76.35	5.09
20.0	115.00	5.75
25.0	153.75	6.15
30.0	195.90	6.53
35.0	235.90	6.74
40.0	280.80	7.02
45.0	350.10	7.78
50.0	415.50	8.31

Table -4.24d : Flocculant Added : FERRIC CHLORIDE

Dosage Applied (%) : 6.0

Feed Solids Concentration(%) : 0.926

VOLUME V(ml)	TIME t(sec)	t/V
10.0	8.60	.86
20.0	18.80	.94
30.0	33.00	1.10
40.0	47.20	1.18
50.0	60.50	1.21
60.0	76.80	1.28
70.0	91.00	1.30
80.0	115.20	1.44
90.0	138.60	1.54
100.0	164.00	1.64

Table -4.24e : Flocculant Added : FERRIC CHLORIDE

Dosage Applied (%) : 8.0

Feed Solids Concentration(%) : 0.958

VOLUME V(ml)	TIME t(sec)	t/V
10.0	2.70	.27
20.0	5.60	.28
30.0	9.00	.30
40.0	12.00	.30
50.0	16.00	.32
60.0	20.40	.34
70.0	24.50	.35
80.0	29.60	.37
90.0	34.20	.38
100.0	40.00	.40

Table -4.24f : Flocculant Added : FERRIC CHLORIDE

Dosage Applied (%) : 10.0

Feed Solids Concentration(%) : 1.030

VOLUME V(ml)	TIME t(sec)	t/V
20.0	2.40	.12
30.0	3.90	.13
40.0	5.60	.14
50.0	7.50	.15
60.0	10.20	.17
70.0	11.90	.17
80.0	14.40	.18
90.0	16.20	.18
100.0	19.00	.19
110.0	22.00	.20

Table -4.24g : Flocculant Added : FERRIC CHLORIDE

Dosage Applied (%) : 12.0

Feed Solids Concentration(%) : 1.043

VOLUME V(ml)	TIME t(sec)	t/V
20.0	2.60	.13
30.0	4.20	.14
40.0	5.60	.14
50.0	7.50	.15
60.0	9.60	.16
70.0	11.20	.16
80.0	13.60	.17
90.0	17.10	.19
100.0	20.00	.20
110.0	23.10	.21

CASE C: Secondary sludge Mill A, Trial No.1

Table -4.25a : Flocculant Added : No

Dosage Applied (%) : Nil

Feed Solids Concentration(%) : 0.965

VOLUME V(ml)	TIME t(sec)	t/V
2.0	13.42	6.71
4.0	32.20	8.05
6.0	48.42	8.07
8.0	68.72	8.59
10.0	105.00	10.50
12.0	127.44	10.62
14.0	164.22	11.73
16.0	192.80	12.05
18.0	217.08	12.06
20.0	261.40	13.07
22.0	296.78	13.49
24.0	340.80	14.20
26.0	406.12	15.62
28.0	474.04	16.93
30.0	511.20	17.04

Table -4.25b : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 0.2

Feed Solids Concentration(%) : 0.974

VOLUME V(ml)	TIME t(sec)	t/V
5.0	31.30	6.26
10.0	72.80	7.28
15.0	112.20	7.48
20.0	173.80	8.69
25.0	237.50	9.50
30.0	309.30	10.31
35.0	385.70	11.02
40.0	461.20	11.53
45.0	582.30	12.94
50.0	679.50	13.59

Table -4.25c : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 0.4

Feed Solids Concentration(%) : 0.979

VOLUME V(ml)	TIME t(sec)	t/V
5.0	20.85	4.17
10.0	48.00	4.80
15.0	79.80	5.32
20.0	113.80	5.69
25.0	146.00	5.84
30.0	180.30	6.01
35.0	223.30	6.38
40.0	274.00	6.85
45.0	333.90	7.42
50.0	389.50	7.79

Table -4.25d : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 0.6

Feed Solids Concentration(%) : 0.985

VOLUME V(ml)	TIME t(sec)	t/V
5.0	7.70	1.54
10.0	15.90	1.59
15.0	26.85	1.79
20.0	37.80	1.89
25.0	48.25	1.93
30.0	60.90	2.03
35.0	73.15	2.09
40.0	92.00	2.30
45.0	104.40	2.32
50.0	121.00	2.42

Table -4.25e : Flocculant Added. : CATIONIC POLY.

Dosage Applied (%) : 0.8

Feed Solids Concentration(%) : 0.990

VOLUME V(ml)	TIME t(sec)	t/V
5.0	5.30	1.06
10.0	10.90	1.09
15.0	18.00	1.20
20.0	24.80	1.24
25.0	32.00	1.28
30.0	40.20	1.34
35.0	49.00	1.40
40.0	57.20	1.43
45.0	67.95	1.51
50.0	78.00	1.56

Table -4.25f : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 1.0

Feed Solids Concentration(%) : 0.999

VOLUME V(ml)	TIME t(sec)	t/V
10.0	7.90	.79
20.0	16.40	.82
30.0	25.20	.84
40.0	38.40	.96
50.0	50.00	1.00
60.0	63.60	1.06
70.0	75.60	1.08
80.0	93.60	1.17
90.0	114.30	1.27
100.0	130.00	1.30

Table -4.25g : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 1.2

Feed Solids Concentration(%) : 1.014

VOLUME V(ml)	TIME t(sec)	t/V
10.0	2.70	.27
20.0	5.60	.28
30.0	9.00	.30
40.0	12.40	.31
50.0	17.00	.34
60.0	21.00	.35
70.0	24.50	.35
80.0	30.40	.38
90.0	34.20	.38
100.0	41.00	.41

Table -4.25h : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 1.4

Feed Solids Concentration(%) : 1.025

VOLUME V(ml)	TIME t(sec)	t/V
20.0	2.60	.13
30.0	4.20	.14
40.0	6.40	.16
50.0	8.50	.17
60.0	10.20	.17
70.0	12.60	.18
80.0	14.40	.18
90.0	18.00	.20
100.0	21.00	.21
110.0	25.30	.23

Table -4.25i : Flocculant Added : CATIONIC POLY.

Dosage Applied (%) : 1.6

Feed Solids Concentration(%) : 1.037

VOLUME V(ml)	TIME t(sec)	t/V
20.0	2.80	.14
30.0	4.50	.15
40.0	6.40	.16
50.0	8.00	.16
60.0	10.20	.17
70.0	12.60	.18
80.0	16.00	.20
90.0	18.90	.21
100.0	22.00	.22

APPENDIX I