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INFLUENCE OF SALINITY ON THE PERFORMANCE OF A SLUDGE BLANKET CLARIFIER

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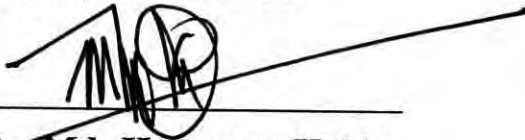
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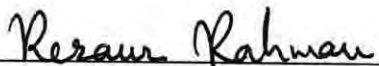
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DECLARATION

I hereby declare that the research work reported in this thesis has been performed by me and this work has not been submitted elsewhere for any other purpose. To the best of my knowledge and belief, the thesis contains no material previously published or written by any other person except when due reference is made in the text of the thesis.

April, 2000

Misbah Uddin Khan

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List of Abbreviation

AWWA	American Water Works Association
CWASA	Chittagong Water Supply and Sewerage authority
hr	Hour
mg/l	Milligram per Litre
NTU	Nephelometric Turbidity Unit
ppm	Parts Per Million
TCU	True Colour Unit
TDS	Total Dissolved Solid
TS	Total Solid
TSS	Total Suspended Solid
WHO	World Health Organisation

ABSTRACT

Coagulation is an important technique in water treatment to remove colloidal and non-settlable fine particles successfully. These particles are forced to settle as floc with the help of chemicals and particle transport mechanism. Common coagulant dose is alum $[\text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{H}_2\text{O}]$, readily dissolves in water, is used in the pH range of 5.5 to 7.8. One of the limitations of coagulation is influence of salinity. Addition of salts interferes in the coagulation and, alum floc breaks in presence of salinity in water. CWASA faced the salinity problem in 1991 for cyclone tide and in 1995 for backwater effect of sea. To review CWASA's problem during saline intrusion and improve the situation, a physical model of sludge blanket clarifier which angle is same to Mohara Treatment Plant's clarifier has been set-up for this study. Both the clarifiers work in the same method, hence, clarifier used in the laboratory can be considered similar to Mohara's clarifier. It was found that saline intrusion problem could be minimised by controlling flow.

Performance Study for different units of the plant for selected parameters, i.e., pH, turbidity, colour, Total Dissolved Solid (TDS), Total Solid (TS), alkalinity and chloride have been done for each unit of the plant and for the whole plant taking samples at inlet and outlet of each unit. The study reveals that sedimentation unit of the plant is good in removing turbidity and Total Suspended Solid (TSS). Coagulation unit's (Flash mixer and Clarifier unit) performance in removing colour and turbidity is about 75-95%. Mohara Treatment Plant is performing well in removing turbidity, colour and TS. Alkalinity, pH and chloride of finished water were always in the range comparing World Health Organisation (WHO) guideline. This study has been done at low flow (winter season) condition of river Halda. Further study of the plant is required at high flow condition and during saline intrusion. The study shows that performance of clarifier depends on discharge, angle of clarifier with horizontal and depth of sludge. Critical discharge for the clarifier used in the study when sludge blanket disintegrates initially due to concentrated

force was about $936 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge. Clarifier's performance decreases when salt is added at any flow. Increased salt increases density of water, hence concentrated force increases at the inlet of clarifier. Increased concentrated force increases initial dispersion of floc in the clarifier. But $134\text{-}535 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge is the optimum discharge range for the clarifier used when performance is good at optimum salt value. Limiting chloride was found 1000 mg/l from limiting concentrated force of $24764 \text{ c.g.s. unit}$ at 17.5 cm sludge depth for the clarifier used in the laboratory. Maximum tolerable discharge for the clarifier used during salinity was about $893 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge at minimum 500 mg/l of chloride, while maximum tolerable chloride was about 3400 mg/l at minimum discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge. Again, maximum tolerable discharge for clarifier of Mohara during salinity was about $2219 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge at minimum 500 mg/l of chloride, while maximum tolerable chloride was about 6800 mg/l at minimum discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge. Upto 3400 mg/l of chloride and at minimum discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge, clarifier's performance can be considered similar to slow mixing coagulation. CWASA could control both discharge and chloride at the flash mixer during salinity intrusion.

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CHAPTER ONE

INTRODUCTION



1.1 Introduction

Coagulation is an important technique in water treatment to remove colloid, 10^{-5} to 10^{-2} mm in size, and fine non-settleable particles successfully. Organic colour and turbidity are removed by Coagulation. It is a two step process involving particle destabilisation followed by particle transport to promote collisions between the destabilised particles to form flocs to settle due to gravity. Destabilisation is induced by the addition of a suitable coagulant. Coagulant may be aluminium or iron salts and dose of coagulant depends on water pH, turbidity, alkalinity etc. Particle contact, after applying coagulant, is ensured through appropriate mixing. Common coagulant dose is alum $[Al_2(SO_4)_3 \cdot 14H_2O]$, readily dissolves in water, is used in the pH range of 5.5 to 7.8 (MacDonald, 1987). Cationic Al^{3+} creates double layer ionic compression of charged colloids, adsorbs on the surface of colloid and neutralises the charge of colloid, and particles become destable. Particle collision through flocculation enhances Brownian motion of particles and alum floc $[Al(OH)_3$ flocs], gelatinous precipitate of colloidal flocs, are formed.

One of the limitations of coagulation is influence of salinity. Addition of salts interferes in the coagulation, and alum floc breaks in presence of salinity in water. It increases residual turbidity. Salinity intrusion is a common problem in Bangladesh, especially in the coastal areas. Chittagong Water Supply and Sewerage Authority (CWASA) faced salinity intrusion problem at the intake of river Halda of Mohara Water Treatment Plant in 1991 for cyclone tide and in

1995 for backwater effect of sea. It was observed that the highest tides occur at the times of the new and full moons and from storm surges following cyclone depressions in the Bay of Bengal. The risk of saline intrusion at the intake is substantially high when the two events occur at the same time. These are the critical periods of the year for saline intrusion (MotMacDonald, 1995). During those periods, alum flocs were broken and sludge blanket disintegrated in the sludge blanket clarifier, which is used by CWASA at the plant. Turbidity of water increased in the filtered and distributed water. It was reported that people faced laxative problem at that time. Clarifier's performance is decreased during salinity. This severity emphasises to go for a model study on influence of salinity on the performance of a sludge blanket clarifier.

Sludge blanket clarifier is used to remove floc through coagulation, flocculation, filtration and sedimentation. A physical model of sludge blanket clarifier which angle (60°) is same to Mohara Treatment Plant's clarifier has been set-up for this study. Both the clarifiers work in the same method, hence, clarifier used in the laboratory can be considered similar to Mohara's clarifier. Performance of the plant has also been studied.

1.2 Objective of the Study

Objectives of the study are given below :

- ◆ To identify controlling parameters on the performance of a sludge blanket clarifier.

- ◆ To measure a critical chloride value upto which sludge blanket clarifier could perform well, and to get a allowable discharge-chloride relationship during salinity.
- ◆ To study the recent performance of CWASA's Mohara Treatment Plant.

1.3 Rationale of the Study

Performance of sludge blanket clarifier has been studied by varying discharge, sludge depth and angle of clarifier. It would provide controlling parameters of a sludge blanket clarifier. Influence of salinity would be studied by using NaCl at different chloride and discharge doses. It would provide limiting values of chloride and discharge from discharge-chloride relationship during salinity. As CWASA is using sludge blanket clarifier at the plant, these results would be useful to them and they would be able to overcome the salt intrusion problem. The authority will be able to control discharge at the flash mixer and salt in the rapid mixing zone by using AgNO_3 . Performance of the Mohara Treatment Plant would give an idea on maintenance and on future expansion of the plant.

1.4 Limitation of the Study

The study has some limitations. Only NaCl has been used in the study to measure influence of salt on clarifier's performance. Influence of salinity means influence of mixture of salts, i.e., NaCl, CaCl_2 , NaNO_3 , MgCl_2 etc. Selected dose of kaolin and alum are not truly representative for all through the season at the inlet of sedimentation basin of the plant. It could be overcome by using different selected kaolin dose at different flow conditions of river

Halda. Size and volume of the clarifier used is much lower than Mohara's clarifier. So, dimensional analysis for the clarifier used and clarifier of Mohara was not possible. Maximum tolerable discharge at minimum chloride has been measured per unit volume of sludge. The study could not provide actual tolerable discharge for Mohara's clarifier. Performance study of filtration unit of Mohara, which was not possible due to inaccessibility. TDS and TSS were measured only once, as measuring instruments of TDS and TSS were out of order. Hence, it was not possible to get range of TDS and TSS data for each unit of the plant. Sampling data obtained at the plant should have been tested at high and low tide in a day. Sampling method, use of sampler and sampling locations could effect on results.

1.5 Organisation of the Thesis

The thesis report consists of seven chapters. Objective of the study has been stated in chapter one. Chapter two is the review of previous studies. Detail methodology of the study and instrumental set-up is given in chapter three. Mohara Treatment Plant's performance study was one of the objectives and has been stated in chapter four. Influence of salt on slow and rapid mixing coagulation has been shown in chapter five. Chapter six describes sludge blanket clarifier's performance, its main controlling parameters and influence of salinity on its performance. Finally conclusions and recommendations have been given in chapter seven.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Previous studies have been discussed in this chapter. Clarifier is used to remove floc, like coagulation. To study the performance of clarifier, it is necessary to understand coagulation's physical and chemical characteristics. Sludge blanket clarifier, its performance, sludge blanket flocculation, controlling parameters of a clarifier are discussed in this chapter. Case study of sludge blanket clarifier at Mohara, Monno Textiles and Saidabad Water Treatment Plant are discussed here.

2.2 Characteristics of Coagulation

Surface waters generally contain a wide variety of colloidal impurities that may cause the water to appear turbid or may impart colour. The presence of charge, which causes the particles to repel one another, is the major stabilising factor. Colloidal particles are difficult to separate from water because the particles will not settle by gravity and are so small that they pass through the pores of most common filtration media. To be removed, the individual colloids must aggregate grow in size with the help of chemicals at optimum pH and turbidity. The process of destroying the stabilising forces and causing aggregation of clay colloids is referred to as chemical coagulation (Benfield, 1982).

Conceptually, an electric double layer can be formed at the interface between an aqueous and a non-aqueous medium through the assumption of the interface and through the creation of a diffuse layer in the aqueous phase by an equivalent number of counter-ions of opposite charge. The surface charge accumulates in three principal ways (Fair, et. al, 1967):

1. On chemically inert materials a small surface charge may be established by preferential adsorption of a single type of ion, i.e., OH^- ion.
2. At the phase boundary of solid surfaces, the charge may result from isomorphic replacements within the lattice and by lattice imperfections.
3. The primary charge of colloidal particles may come from the ionisation of complex inorganic groups on the surface of dispersed particles.

Physical measurements of the electric properties of colloids is electrophoretic mobility or zeta potential which is the potential difference between the bulk liquid and the shearing plane at the envelope of water moving with the particle is shown in Figure 2.1 (Fair, et. al, 1967). The ordinary range of zeta potential is 10 to 200 mV. Occasionally coagulation is slow at zero zeta potential or sometimes effective coagulation takes place when the zeta potential is far away from zero. Use of chemicals is responsible to reduce zeta potential value.

The electric properties of colloid particles maintain them in the colloidal state. Entering into their behaviour are two opposing forces: (1) an attractive, Vanderwal's force (curve *A* in Figure 2.2) tending to draw the particles together, and (2) an electrostatically repulsive force (curve *R* in Figure 2.2) tending to keep apart. Curves *A* and *R* are combined in curve *S* as the resultant

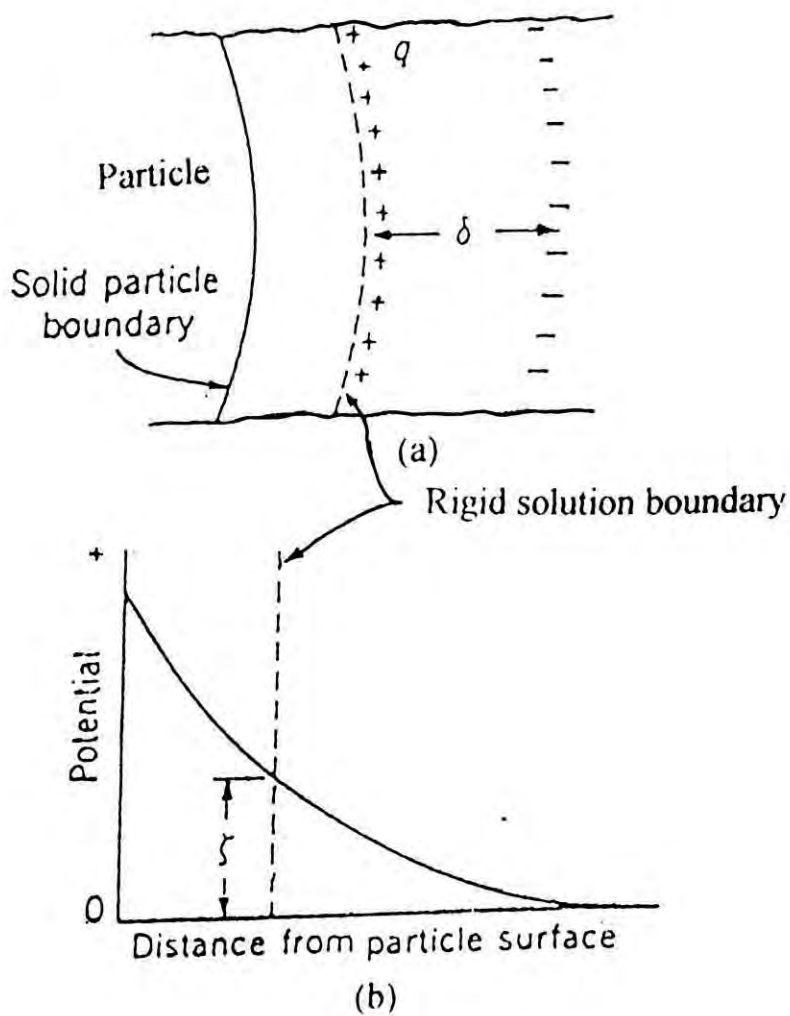


Figure 2.1: Electrical relations at surfaces of colloids (a) Simple Helmholtz picture of particle surface, showing net charge q and double-layer distance δ (b) potential relations corresponding to charge distribution (Source: Fair, et al, 1967)

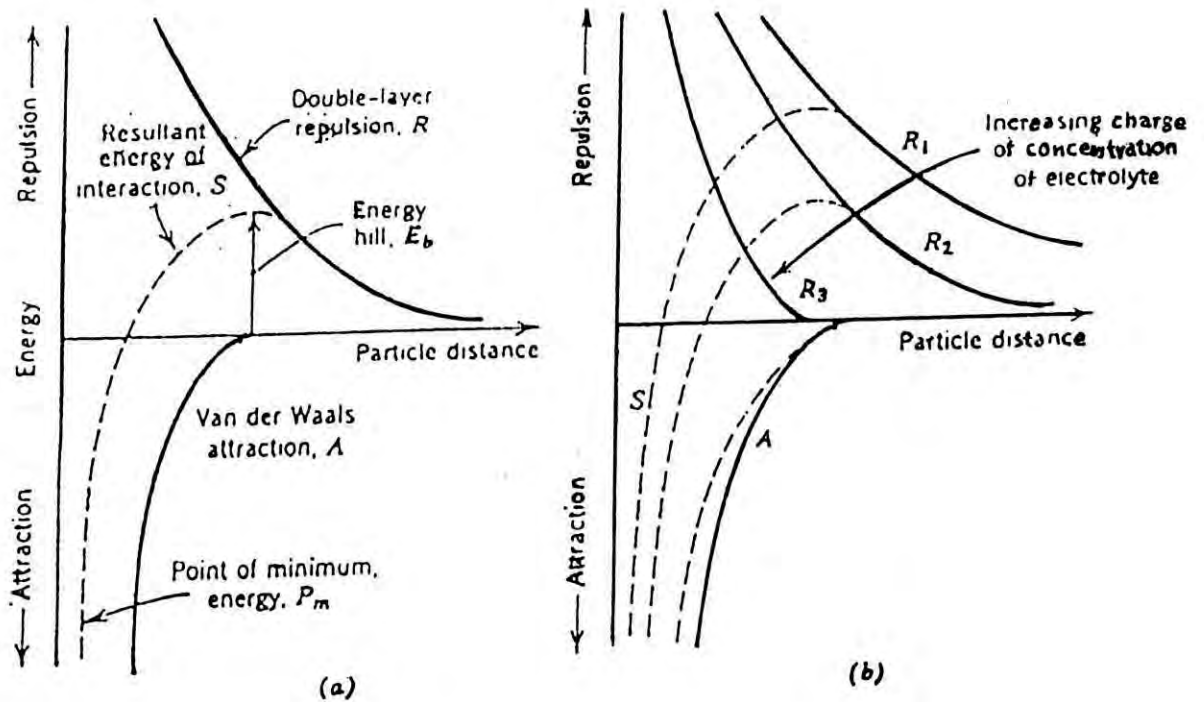
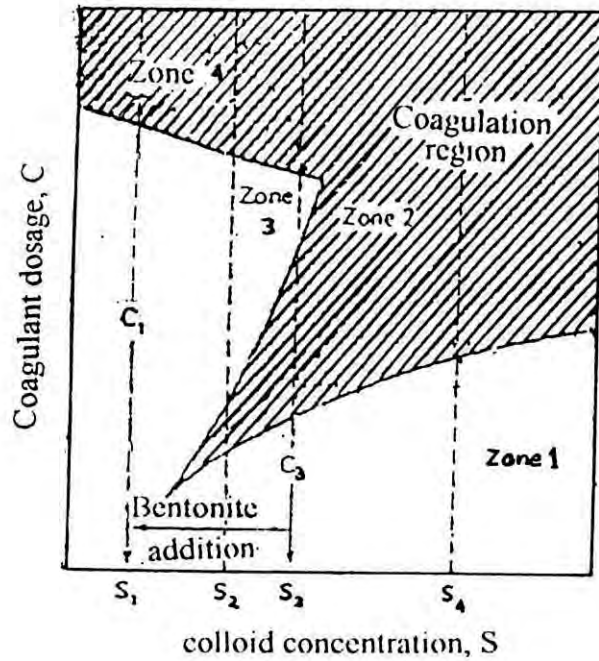


Figure 2.2: Energy of interaction between two colloidal particles
 (Source: Fair, et al, 1967)

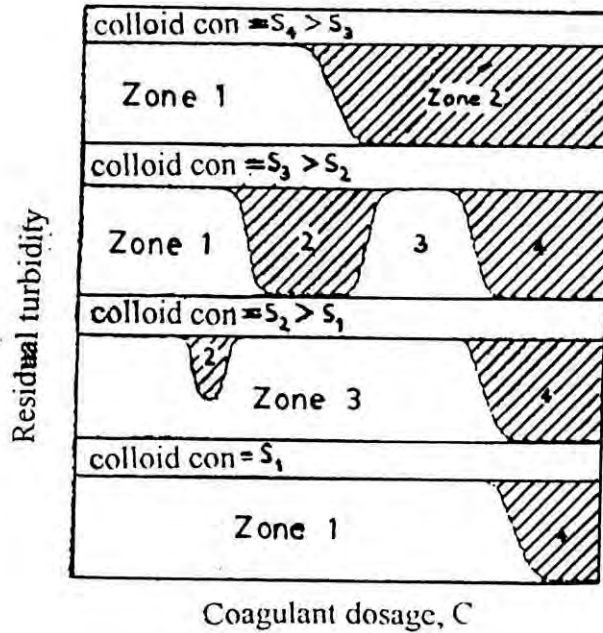
energy of interaction. To approach each other, the particles must surmount the energy hill E_b (Fair, et. al, 1967). To induce colloidal particle to aggregate, two distinct steps must occur: (1) the repulsion forces must be reduced (i.e., the particle must be destabilised), and (2) particle transport must be achieved to provide contacts between the destabilised particles. Particle destabilisation can be achieved by four mechanisms: (1) double-layer compression, (2) adsorption and charge neutralisation, (3) enmeshment in a precipitate, and (4) adsorption and inter particle bridging.

Coagulation may be done by iron (iii) salts or alum depending on pH, turbidity and alkalinity of water. Optimum chemical dose is fixed by batch method, i.e., Jar test method. Effect of turbidity on coagulation is shown in Figure 2.3. For alum, pH range must be kept in between 5.5 to 7.8 (MacDonald, 1987). Alkalinity i.e., NaOH is added to limit the pH of water during coagulation. Chemical factors, such as the complex of ferric and aluminium ions, are of importance in coagulation with alum or ferric salts. Charge on a colloid may be H^+ or OH^- hydroxyl ions (or other acid or basic ions), neutralisation of charge can often be brought about by changes in pH (Fair, et. al, 1967). It is believed that the aluminium sulphate reacts with the alkalinity in the water to produce a colloidal suspension of aluminium hydroxide that is positively charged by the presence of surplus trivalent alumina ion. This positive charged colloid is then attracted to any negatively charged colloid to form flocs.

Rapid mixing is provided to enhance mixing of the coagulant and raw water perfectly. Destabilisation and the early stages of floc formation occur during rapid mixing, resulting in reducing coagulant demands and improved aggregation in subsequent flocculation units (Letterman, et. al, 1973). Rapid mixing, non-uniform mixing, will be quite undesirable if destabilisation by



(a)



(b)

Figure 2.3: Schematic coagulation curves at constant pH. Shaded areas represent regions in which coagulation occurs (Stumm and O'Melia, 1968)

adsorption is desired. Destabilisation will be poor in areas of low chemical concentration, may also be poor in areas of high chemical concentration because of over adsorption and charge reversal (AWWA, 1990). Contacts between destabilised particles are essential for agglomeration to occur. These contacts can be achieved by three separate mechanisms: (1) thermal motion (Brownian motion), (2) bulk liquid motion (stirring), and (3) differential settling. When Brownian motion produces contacts, for small particles, the process is termed perikinetic flocculation, and when produced by stirring or settling for particles more than 1^{μ} m it is termed as orthokinetic flocculation.

The rate change of particle concentration by perikinetic flocculation can be expressed as follows (Swift, et. al, 1964):

$$j_{pk} = dN^0/dt = -4hkT (N^0)^2/3\mu$$

Where N^0 = total concentration of particles in suspension at time t , h = a collision efficiency factor, fraction of collisions that produce aggregates, k =Boltzmanns constant (1.38×10^{-16} erg/degree), T = absolute temperature ($^{\circ}K$), μ = fluid viscosity (gram/cm-sec).

And Weber (1972) indicates the rate of change of particle concentration as a result of orthokinetic flocculation:

$$j_{ok} = dN^0/dt = -2\eta(G)d^3 (N^0)^2/3\mu$$

where G = velocity gradient, d = particle diameter (cm)

Velocity gradients vary considerably throughout a flocculation basin, and the value at any given point G , is difficult to determine. Camp and Stein (1943) defined a mean velocity gradient, G , that can be used to describe the average conditions within the basin. Velocity gradients for flocculation basins must be high enough to achieve the particles aggregation, however, they must not be so high that they shear the flocs apart (Benefield, 1982). Velocity gradient can be expressed as,

$$G = \sqrt{P/\mu V}$$

where, P = power input, V = volume of basin and μ = absolute viscosity.

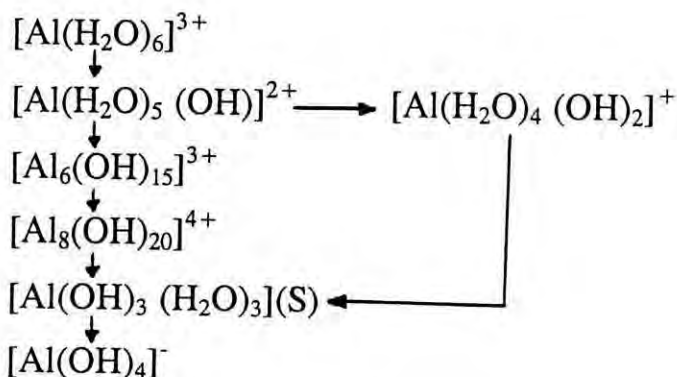
Design values for the velocity gradient depend on the coagulant used. Gradients between 25/sec and 100/sec have been found to acceptable for iron(III) and aluminium(III)flocs, but lower values, 15/sec to 20/sec, are better when polymers are used. Current design favours the use of basins with more compartments having G value decreasing form compartment to compartment (e.g., 90/sec, 70/sec, 40/sec). This plan provides maximum mixing to enhance aggregation at the influent end but promotes larger flocs by reducing mixing and shear at the effluent end. The detention time in a flocculation basin is also an important parameter because it determines the amount of time that particles are exposed to the velocity gradient and thus it is a measure of contact opportunity in the basin. A detention time (t) of 30 minutes is commonly used for design. However, camp number or Gt values, in the range of 10^4 to 10^5 , are frequently recommended for design (Benefield, 1982).

2.3 Chemistry of Aluminium

Aluminium (III) salts are the most widely used coagulants in water treatment. The different aluminium exhibited in water are directly associated with coagulation. Thus it is necessary to consider the aqueous chemistry of these coagulants (Hossain, 1996).

There is a little doubt that the aqueous chemistry of aluminium is complex and diverse because of numerous hydrolysis intermediates formed prior to precipitation of aluminium hydroxide, $\text{Al(OH)}_3(\text{S})$ provided a fairly clear description of the hydrolysis species of Al^{3+} and interactions with the colloids in the context of coagulation and restabilization. When aluminium salts are added to water, the metal ion Al^{3+} hydrates, co-ordinating six molecules of water and forming an aquometal ion, $\text{Al(H}_2\text{O)}_6^{3+}$. The aquometal ion can then react and form several hydrolysis species. It follows from the charge reversal concentration that the hydrolysed species cause charge reversal. Some of the simplest is monomeric and dimeric hydroxocomplexes where co-ordination occurs with OH^- legends that replace the six co-ordinated water molecules.

Stumm and Morgan (1962), Packham and Sheiham (1977) and others have given the stepwise conversion of the tripositive aluminium ion to the negative aluminium ion as pH increases are as follows:



Amirtharajah and Mills (1982) have reported a number of aluminium polymers that may possibly be involved in coagulation and flocculation processes. These are: $\text{Al}_{13}(\text{OH})_{34}^{5+}$, $\text{Al}_7(\text{OH})_{17}^{4+}$, $\text{Al}_8(\text{OH})_{20}^{4+}$, $\text{Al}_6(\text{OH})_{15}^{3+}$, $\text{Al}_2(\text{OH})_2^{4+}$, $\text{Al}_2(\text{OH})^{5+}$, $\text{Al}_4(\text{OH})_8^{4+}$, $\text{Al}_{13}\text{O}_4(\text{OH})_{24}^{7+}$, $\text{Al}_3(\text{OH})_4^{5+}$, $\text{Al}_{13}(\text{OH})_{32}^{7+}$ and $\text{Al}_{14}(\text{OH})_{34}^{8+}$, to name but a few.

The degree of alkalinity in the solution is an important determinant in aluminium speciation. Other dominant factors include the concentration of reactants, contamination by other substances, pH, temperature and reaction time. Matijevic et. al (1964) have found that the hydroxometal complexes readily adsorb on surfaces and the charges that they carry may cause charge reversals of the surfaces that they adsorb on, second, the sequential hydrolysis reactions release H^+ ions, which lowers the pH of the solution in which they are formed; and the concentration of the various hydrolysis species will be controlled by the final concentration of H^+ ions, that is, by the pH.

Hundt and O'Melia (1988) reported the work of Baes and Mesmer (1976). In this, they described the aqueous chemistry of Al using five monomers Al^{3+} , $\text{Al}(\text{OH})^{2+}$, $\text{Al}(\text{OH})_2^+$, $\text{Al}(\text{OH})_3$ and $\text{Al}(\text{OH})_4^-$; three polymers $\text{Al}_2(\text{OH})_4^{2+}$, $\text{Al}_3(\text{OH})_4^{5+}$ and $\text{Al}_{13}\text{O}_4(\text{OH})_{24}^{7+}$ and a solid precipitate $\text{Al}(\text{OH})_3(\text{s})$. They also have discussed the influence of the chemical behaviour of anions of Al in solution. The presence of anions with a strong affinity for Al, such as sulphate, greatly affects the Al species in solution. Sulphate, a tetrahedral polyvalent anion, tends to link OH-Al polymers together, but in a distorted arrangement. Therefore, most basic salts containing sulphate are amorphous. In the presence of sulphate less alkali is necessary to produce a visible precipitate than when solutions containing chloride or nitrate salts are titrated. They also presumed a

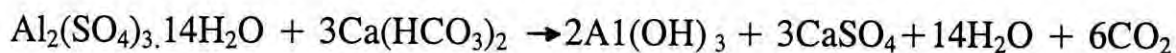
screening effect, which accelerates the formation of polymers and assists in the linking of planer complexes to form the solid lattice.

Sullivan and Singley (1968) have estimated the quantity of mononuclear aluminium species (monomers) at different pH. The estimates are given in Figure 2.4. The dominant species upto pH 4.5 is Al^{3+} , from 4.5 to 8.0 it is $Al(OH)_3$ and above pH 8 it is $Al(OH)_4^-$.

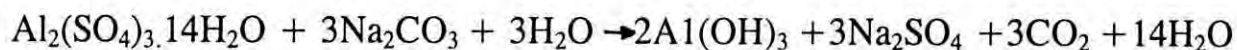
Obviously, pH must be controlled to establish optimum conditions for coagulation. Control is complicated by the fact that the aquametal ions of Al(iii) and Fe(iii) are acidic in nature. Waber's (1972) equations show:



Hydrogen ions liberated by the addition of alum will react with natural alkalinity in the water as follow (Benefield, 1982):



Theoretically, each mg/l of alum will consume approximately 0.50 mg/l (as $CaCO_3$) of alkalinity and produce 0.44 mg/l of carbon dioxide. If the natural alkalinity is not sufficient to react with the alum and buffer the pH, it may be necessary to add alkalinity to the water in the form of lime or soda ash (Benefield, 1982).



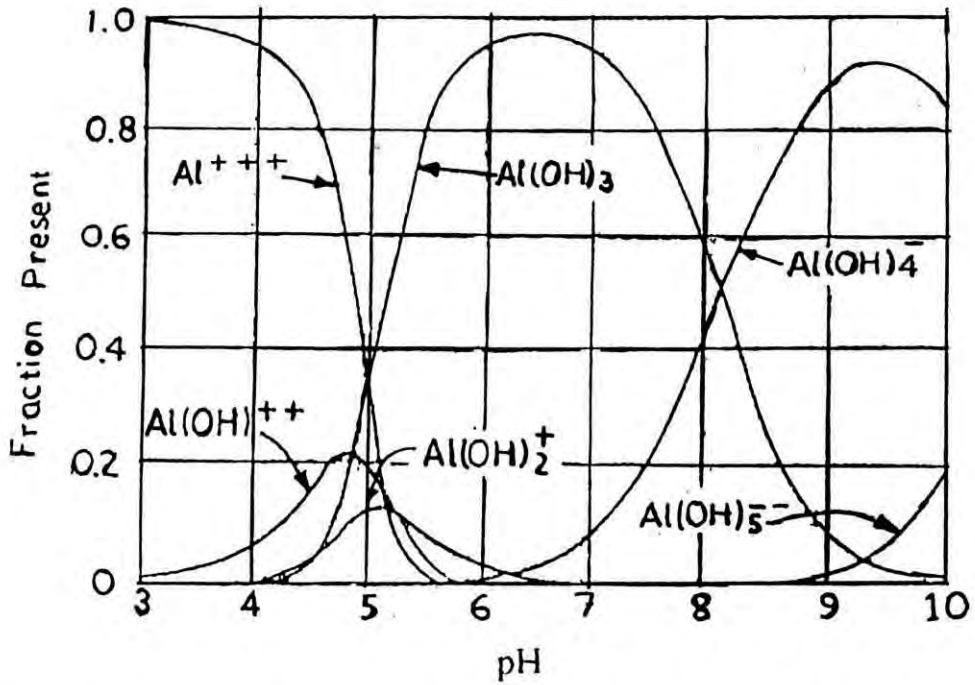


Figure 2.4: Species present as function of pH for $1 \cdot 10^{-4}$ M aluminium perchlorate (Source: Sullivan and Singly, 1968)

2.4 Breakage of Alum Flocculation

Studies were made of the breakdown of alum floc after reaching an ultimate size when the velocity gradient was suddenly increased to a higher value. Breakage of floc is directly affected by velocity gradient when it crosses limiting value. It can be seen from Figure 2.5. Boadway (1978) had an study on growth and breakage of alum floc due to fluid shear. The study shows, the ultimate diameter of floc when it breaks is,

$$D_u \propto (W/G)^{0.38}$$

The ultimate number of particles is given by the relationship,

$$N_u \propto G^{1.14} W^{0.25}$$

where, D_u is the ultimate dia of floc, N_u is the ultimate number of floc, W is the total suspended solid and G is the velocity gradient.

Larger flocs are weaker because of the poor fitting inherent with their formation and they break due to velocity gradient. A floc breaks when a weak portion of its structure exposes into such an orientation that it comes under stress from the force due to viscosity and shear. For floc particles, if length $\cong 2$ times width and viscosity $\cong \mu$, then the shear stress in the equivalent solid is given by the relationship,

$$S = 6 G \mu_0 \quad (19/16)$$

where, S is shear force of floc, μ_0 is the viscosity of fluid.

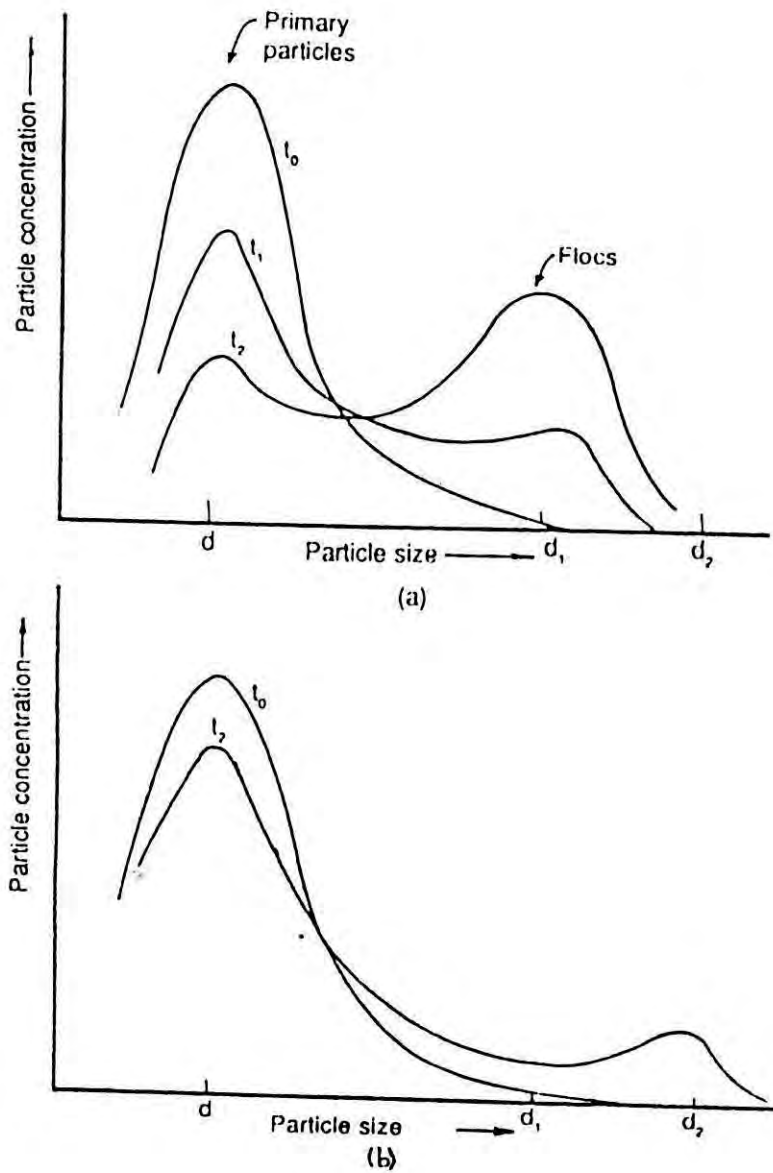


Figure 2.5: Effect of velocity gradient on floc growth (a) High G value (b) Low G Value (Source: AWWA, 1990)

This stress is not a function of size. In practice, equilibrium floc size is dependent on shear, which must imply that mean failure strength of particles is less for larger flocs. It is possible to approximate the probabilities within about 0.1 by a straight line from the origin through the median value by the following equation,

$$P_{(S)} = S/S_u$$

where, $P_{(S)}$ = probability that a particle will break if subjected to a load S , and S_u = the minimum load that is almost certain to cause failure.

2.5 Influence of Salinity on Rapid and Slow Mixing Coagulation

Rapid and slow mixing coagulation are provided by using paddles during jar tests. Energy dissipation is occurred through paddles. Controlled velocity gradient provides formation of floc during coagulation. Influence of salt changes velocity gradient.

Fayer, et. al (1967) stated that;

$$P = 5.74 \times 10^{-4} C_D [(1-k)n]^3 .r^3 A \text{ for a single blade in paddle mixing.}$$

here, n is rpm, C_D is drag coefficient, k is constant and r is paddle radius. $C_D = 1.8$ and $k = 0.25$, Energy dissipation can be expressed,

$P = 0.00044 . n^3 .r^3 A$, and velocity gradient (G) is $= \sqrt{(P /MV)}$, using the above value of P , G can be written as;

$$G = \sqrt{(0.00044 \cdot n^3 \cdot r^3 A / \mu V)}$$

Hence, it is clear that at without salt condition,

$$P = f(\text{rpm}) \text{ and } G = f(\text{rpm})$$

And for varying salt,

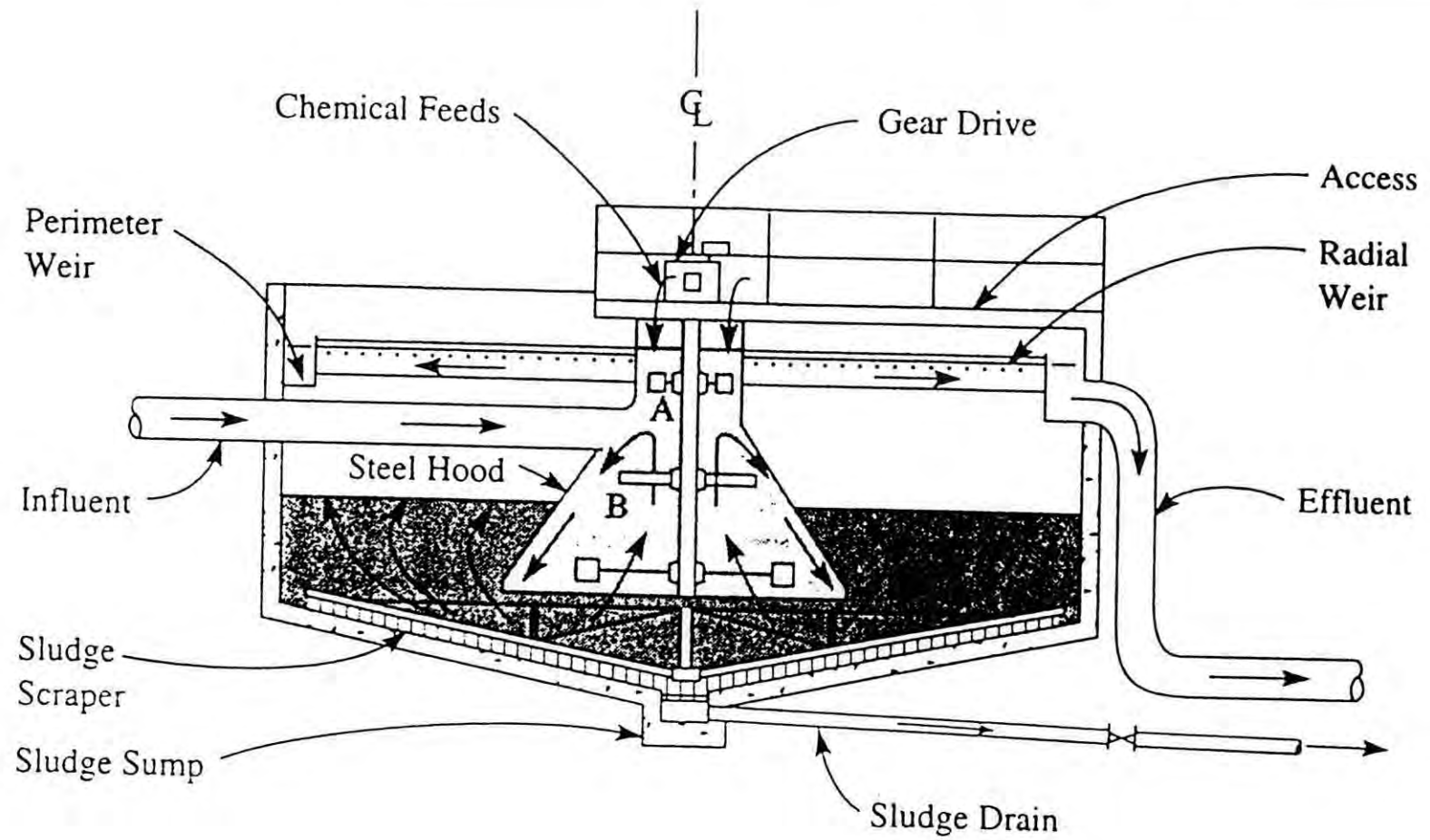
$$P = f(\text{rpm, density}) \text{ and } G = f(\text{rpm, density})$$

Hence, it is clear that, salt effects on velocity gradient or coagulation. Salt's cations and anions dissociate in water and enhance conductivity, i.e., ionic loading in water. Distil water has the minimum ionic loading (Fair, et al, 1967). Salts dissolve in water as cations and anions, and they neutralise each other. Hence, pH remains almost same during salt addition.

2.6 Introduction to Sludge Blanket Clarifier:

Clarifier unit is fundamentally similar in design in that it combines solids contact mixing, flocculation, solids-water separation, and continuous removal of sludge in a single package-type basin. Such unit is often referred to as upward-flow sludge blanket type settling units (ASCE, AWWA and CSCE, 1969).

Mixing, flocculation, and clarification may be conducted in a single tank such as that in Figure 2.6. The influent raw water and chemicals are mixed in the center cone-like structure. The solids flow down under the cone (sometimes called a "skirt"). As the water flows upward, the solids settle to form a sludge blanket. This design is called an up-flow solids-contact basin. The units are best suited to treat feed water that has a relatively constant quality. It is often favored for softening because the water quality from wells is relatively



- Zone A — rapid mix
- Zone B — flocculation and solids contact
- Zone C — upflow and sludge-blanket zone

Figure 2.6: Typical up-flow solids-contact unit (Source: AWWA, 1990)

constant and the sludge blanket provides a further opportunity to drive the precipitation reactions to completion (Davis and Cornwell, 1998).

Up-flow solids contact type clarifiers are selected because they are simple to operate, can be operated manually, and don't incorporate a lot of imported equipment requiring extensive maintenance. Further, the in-built flocculation mode of operation deletes the necessity for separate flocculation units. Particles carried by the water are carried upward until they reach the point at which their settling velocity is equal to the up-flow velocity of the fluid. These suspended particles rise through the flocculation zone, then come together forming a sludge blanket which acts as a filter, straining the agglomerated particles (Akers, 1975).

The sludge blanket unit is more sensitive to changes in flow rate and temperature. In addition, the source water solids and coagulant doses must be adequate to build a stable blanket on startup. Activated silica and other coagulant aids are often necessary for these clarifiers.

If differential sedimentation or solids classification is the primary purpose, the small or light, discrete particles are purposefully carried over the effluent weir of the basin while the large or heavy particles settle to the tank bottom. If floc build-up and removal is the primary function, entering particles are not intended to remain discrete, but to conjoin into aggregates that are eventually withdrawn from the up-flowing water. For floc build-up vertical flow tanks (Figure 2.7) are differentiated zonally. Inlet and sludge zone are in close contact, and the flocculation zone is occupied in part or as a whole by a cloud or blanket of flocs, not unlike a fluidized filter bed in its general nature. Rising flocs or particles come into contact with settling flocs or particles and with a

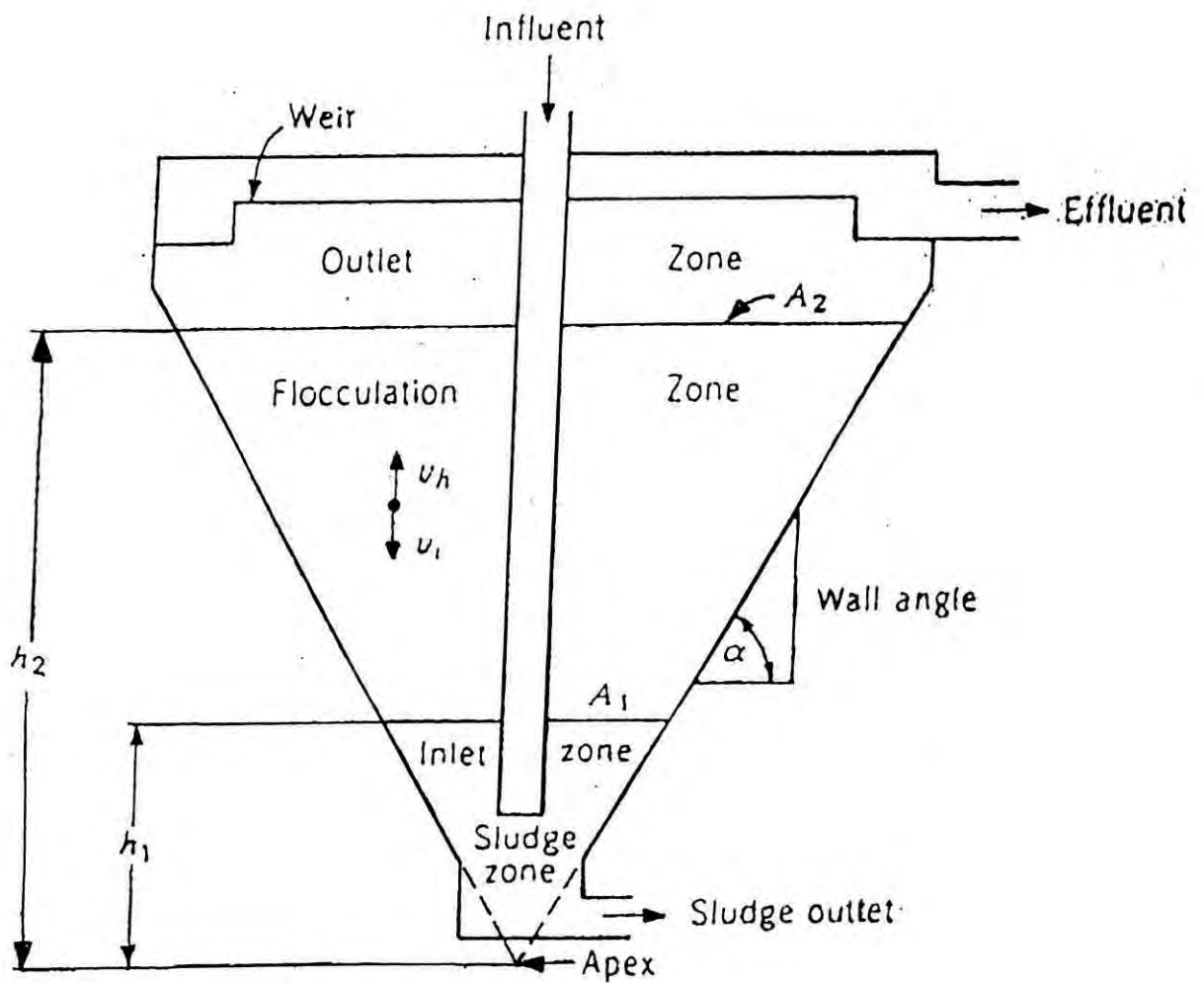


Figure 2.7: Vertical section through conical or pyramidal upflow tank (Fair, et al, 1967)

stationary cloud of flocs or particles in equilibrium with their hydraulic environment. An outlet zone at the top of the tank allows for some upward and downward displacement of the flocculation zone (Fair, et al, 1967).

In this type of settling tank (also known as a clarifier), the sludge formed through flocculation is retained as an expanded blanket. Water flows regularly and evenly up through the sludge blanket. The raw water is introduced at the base of the sludge blanket via a distribution system that promotes continuous mixing. The water flocculates as it passes through the “sludge filter” and emerges clarified in the upper portion of the unit (Degremont, 1991).

If water is fed continuously into the bottom of the sludge blanket, the sludge eventually ceases to remain suspended in the liquid. Instead, it settles gradually in some zones, ultimately forming a compact mass of settled sludge in which the water has created preferential channels, thus destroying the efficient contact between the water passing through the sludge blanket and the sludge that forms it. On the other hand, if water is allowed to enter intermittently, quickly and at a high flow, and then is stilled for an extended period, the sludge mass is seen to remain in a regular suspension. All the sludge is entrained toward the top as the water flows in, but then settles regularly during the subsequent stilling period, as it would do in a jar at absolute rest. The resulting sludge mass is uniform in every respect (Degremont, 1991).

Jar tests may be conducted in laboratory to measure the maximum rising velocity to which a sludge blanket can be subjected; this is the sludge cohesion

coefficient. This maximum rising velocity depends on a number of factors: raw water consumption, coagulant dosages and flocculation, temperature, etc (Degremont, 1991).

2.7 Sludge Blanket Flocculation

The flocculation zone of up-flow sludge blanket or solids contact clarifiers (Figure 2.8) function as fluidized beds with hydro-dynamical similarities and dissimilarities to a horizontal flow flocculator (AWWA, 1990). Hudson (1965), Ives (1968), and Tambo and Hozumi (1979) have analyzed flocculation in sludge blanket zones by starting from Smooluchowski's equation for orthokinetic flocculation and using simplifying assumptions.

$$(N_{ij})_o = (1/6) (d_i + d_j)^3 G n_i n_j$$

In a sludge blanket, let the n_j particles be flocs ($d_j = 1000$ to $2000 \mu\text{m}$) and the incoming primary particles be $n_1 (= n_i)$ particles ($d_i = d_1 = 1$ to $2 \mu\text{m}$). Because $d_1 \ll d_j$, then $(d_1 + d_j) = d_j$. Therefore the collisions between the primary particles and the flocs in the blanket are given by

$$(N_{ij})_o = (1/6) d_j^3 G n_i n_j$$

The number of collisions per unit time is equal to the rate of disappearance of n_1 particles multiplied by a collision efficiency factor α , and therefore

$$-(dn_1/dt) = (\alpha/6) d_j^3 G n_i n_j$$

$$\text{Again, } \phi = (\pi d^3 n/6) \quad (\text{AWWA, 1990})$$

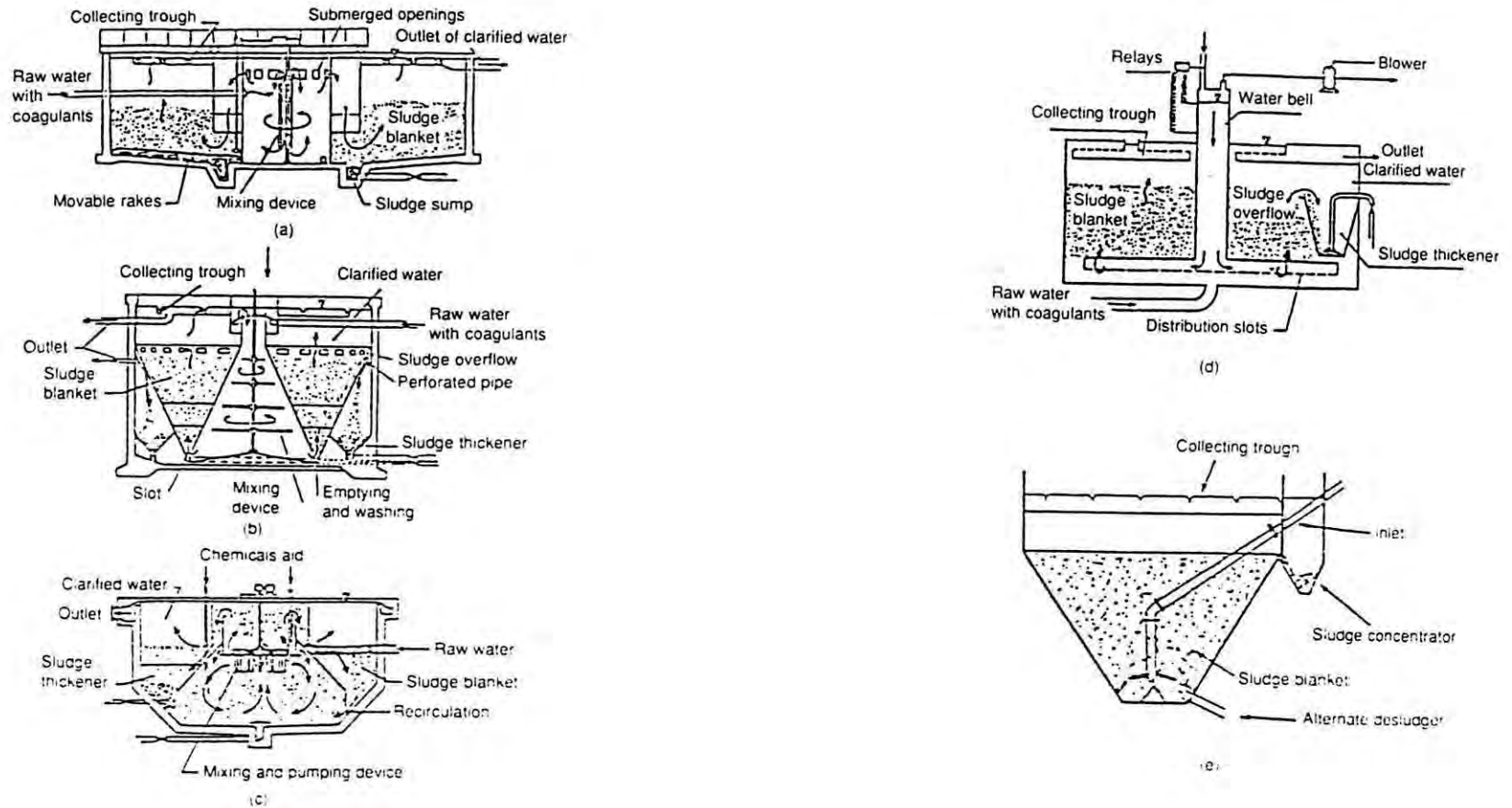


Figure 2.8: Up-flow solids contact clarifiers (a) Mechanically agitated bed clarifier (b) Hydraulically fluidized bed clarifier (c) Sludge circulation clarifier (d) Unsteady discharge clarifier (Pulsator) (e) Hopper bottom, hydraulically fluidized clarifiers (Source: Amirtharajah, 1978)

$$n_j d_j^3 / 6 = \phi / \pi$$

where, ϕ (floc volume fraction) is volume of floc per volume of suspension for spherical flocs. $-(dn_1/dt)$ can be simplified,

$$-(dn_1/dt) = (\alpha G \phi n_1 / \pi)$$

The above equation is a first order kinetic equation that can be integrated for a batch reactor by separating the variables, giving the effluent concentration of primary particles n_1^1 as

$$(n_1^1 / n_1^0) = \exp (-\alpha G \phi t_L / \pi)$$

where t_L is the liquid detention time. The variables affecting flocculation in a sludge blanket may be represented by $G \phi t_L$. The magnitude of $G \phi t_L$ has been suggested to be approximately 100 for design of sludge blanket clarifiers.

An alternate approach for analysis of these units, developed by Bond (1960, 1961) and Tesarik (1967), considers the sludge blanket as a fluidized bed and uses its hydrodynamic characteristics. Using hindered settling theory and the continuity equation, Bond showed that

$$v_s = v_p (1 - f \phi^{2/3})$$

where, v_s is settling velocity of whole suspension, v_p is settling velocity of individual particles and f is shape factor = 2.78 for ferric and alum floc.

Bond (1961) used the above the equation for analysis and design of sludge blanket units by establishing an applicable value for v_p based on typical values

of temperature, coagulants used, and, if possible, pilot scale tests. For design, the nominal up-flow velocity v_u at the slurry separation line (which is the same as v_s) was equated to $0.50v_p$. For flocculation without the use of polymers, typical values for v_p at 15°C were (1) floc for color removal with alum = 0.18 ft/min, (2) floc for turbidity removal with alum = 0.30 ft/min, and (3) softening floc = 0.30 ft/min.

Tesarik (1967) used the following Richardson and Zaki equation for analyzing these clarifiers.

$$(v_u / v_p) = \epsilon_o^n = (1 - \phi)^n$$

where, v_u is nominal up-flow velocity, ϵ_o = porosity and n is coefficient = 4 for inorganic hydrous oxide flocs.

2.8 Hydraulics of Sludge Blanket Clarifier

Sludge blanket clarifier is a widely used technique in removing alum floc. This is also known as differential settlement. In sludge blanket filtration, operations are aimed at the control of (1) floc growth, (2) positioning of the flocculation zone or sludge blanket surface, and (3) regulation of the intensity of floc shear. Hydraulic control is exerted by proper dissipation of hydraulic power and for adjustment of residence time in the flocculation or contact zone (Fair, et. al, 1967).

The power dissipated, P , which can be expressed,

$$P = Q\rho gh_f$$

where ρ is the mass density of the fluid, g is the gravity constant, h_f is the head loss in passage through a zone of depth (h_2-h_1) and Q the rate of flow (Fair, et. al, 1967).

$$h_f = [(\rho_s - \rho) / \rho] (1 - f_e) (h_2 - h_1) = (S_s - 1) (1 - f_e) (h_2 - h_1)$$

where ρ_s and S_s are respectively the mass density and specific gravity of the flocs, and f_e is the relative pore space of the flocculation zone. For a capacity of clarifier (C), cross-sectional area A and wall angle α ,

$$C = \int A dh = 4 \cot^2 \alpha \int h^2 dh = 4/3 [\cot^2 \alpha (h_2^3 - h_1^3)] \text{ for a square pyramidal tank, and}$$

$$C = \pi \cot^2 \alpha \int h^2 dh = \pi/3 [\cot^2 \alpha (h_2^3 - h_1^3)] \text{ for a conical tank.}$$

The detention time t_d is $f_e C / Q$, and $f_e = (v/v_s)^{1/5} = (v_h/v_s)^{1/5}$

where v_s , v_h , and v being the settling, interstitial (hindered setting), and face velocities of the particles and fluid respectively. If these values are introduced into the relevant expressions for wanted and limiting velocity gradients which is $G = \sqrt{(P/MV)}$ and the product of gradients and exposure time t_d is formed to identify contact opportunity is,

$$G = [(g/v) (S_s - 1) (1 - f_e) (h_2 - h_1) / (C/Q)]^{1/2}$$

and, because $t_d = f_e C / Q$,

$$G t_d = f_e [(g/v) (S_s - 1) (1 - f_e) (h_2 - h_1) (C/Q)]^{1/2}$$

here, $\mu/f = \nu$ and if G and Gt_d are to be controlled, f_e , h , and C are the manageable variables and must be selected to suit wanted floc growth and clarification. To assure zonal stability by preventing floc rise and escape, the cross-sectional area (or width) of the tank must, as a practical matter, be enlarged in the direction of flow. At the same time useful initial G value should be imposed to promote floc building, while a destructive terminal G value is avoided to keep the floc formed from being broken up and swept over the effluent weir. For adequate contact opportunity, the period of residence should be long enough to accomplish wanted results. Cross-sectional area is increased in the direction of flow by providing a wall angle of 45° to 65° with the horizontal ($2 \cot \alpha = 2.00$ to 0.93) to create a diameter of circular tanks or width of square tanks as large as 2.00 to 0.93 times the distance from the apex. At a wall angle of $63^\circ 26'$ incidentally, diameter D and width B equal the apical distance, i.e., $D = B = H$ (Fair, et al, 1967).

2.9 Design Features of Clarifier

The solids contact unit was first used primarily for softening in the treatment of potable waters; however, its use as a clarification unit for turbidity, color, iron and manganese removal has become more prominent. To operate efficiently as a clarification basin, proper design of the effluent collection system is important. Substantially vertical velocity should be maintained in the clear water zone. This is accomplished by the use of circumferential, radial, concentric, or transverse launder systems. The clarification area should be sized on the basis of the settling velocities of the particles kept in suspension and circulation (ASCE, AWWA and CSCE, 1969).

The most important design features of one class of these units include (ASCE, AWWA and CSCE, 1969):

1. Rapid and complete mechanical mixing of chemicals, raw water, and a suspension of solids should be provided for
2. Mechanical means should be provided for constantly circulating, a controlled velocities, large volumes of liquid containing the solids being used for contacting. A relatively low speed impeller can accomplish this circulation. Several speed variation may be advisable for any circulator. The maximum peripheral speed should not exceed 5 fps.
3. Means should be provided for determining and varying the suspended-solids concentration in the contacting zone.
4. Automatic collection and discharge of excess solids should maintain the optimum solids concentration, after proper thickening in concentrators or hoppers. The sludge discharge can be controlled by easily adjustable inter-controlled hydraulic or pneumatic actuators, or by proportionate sludge blow off.
5. The clarification area should be so sized that the up-flow velocity should be at least 50 percent below the particle settling velocity at a point at least 5 ft below the point of effluent takeoff.
6. An effluent launder takeoff system should be provided so that substantially vertical velocity will be maintained in the clear water zone. In general, it is wise to limit the maximum horizontal movement of clarified water to about 3 times the clear-water depth, or, according to the limitation in above, or about 15 ft.

2.10 Performance of Clarifier

Sludge blanket clarifier works as a filter media, flocculation chamber and sedimentation basin. f_e , C , h_2 , h_1 , Q and t_d effect on floc formation (Fair, et al, 1967). Fair, et al (1967) stated velocity gradient (G) for a sludge blanket clarifier in the following way,

$$G = [(g/\nu) (S_s-1) (1-f_e) (h_2-h_1)/(C/Q)]^{1/2}$$

where, g is acceleration due to gravity, ν is kinematic viscosity, S_s is specific gravity of floc, f_e is relative pore space, (h_2-h_1) is flocculation zone, h_1 is sludge depth, C is capacity of clarifier and Q is discharge. C can be written as (Fair, et al, 1967);

$$C = \frac{\pi}{3} \cot^2 \alpha (h_2^3 - h_1^3)$$

α is angle of clarifier with horizontal. Using the values of C , G can be simplified as,

$$G = [(g/\nu) (S_s-1) (1-f_e) (h_2-h_1) / ((\pi/3)\cot^2 \alpha (h_2^3 - h_1^3) / Q)]^{1/2}$$

Here, g , S_s and f_e are constant. Hence, velocity gradient can be written as;

$$G = f(Q, \alpha, h_1, h_2)$$

From the above expressions, it is clear that: angle of clarifier with horizontal, discharge, sludge depth and flocculation zone (h_2-h_1) are the major controlling

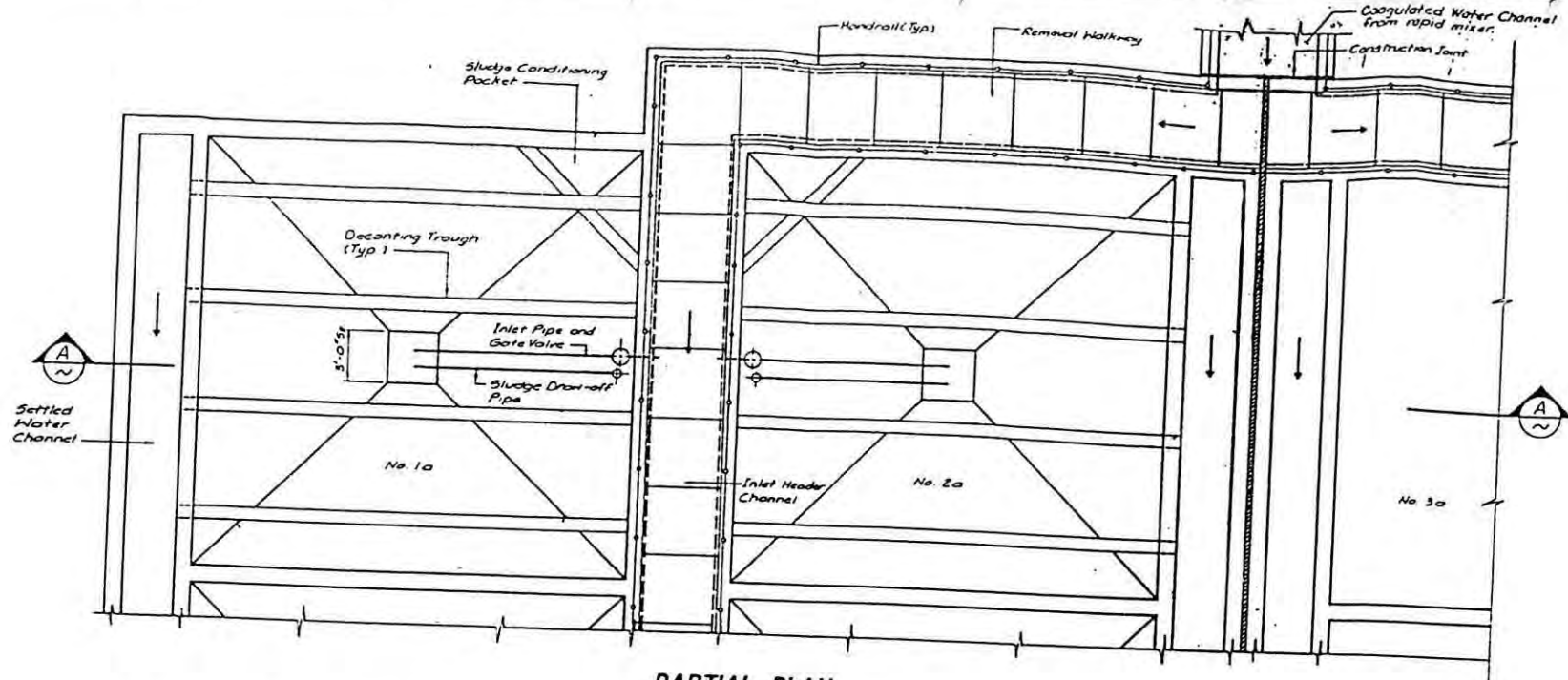
parameters on the performance of a sludge blanket clarifier at normal condition.

2.11 Case Study: Sludge Blanket Clarifier used in Bangladesh

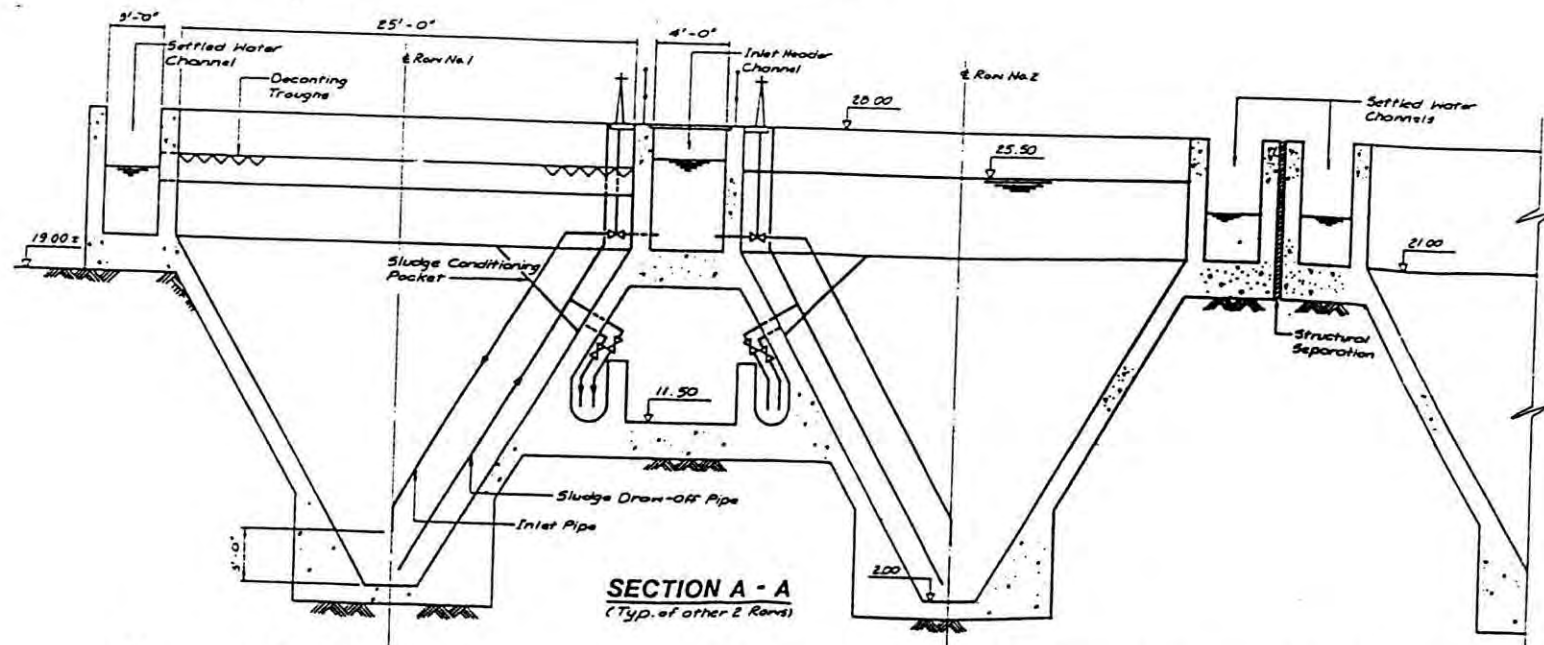
Sludge blanket clarifier has been used in Bangladesh for water treatment purpose. It was first introduced at Mohara Water Treatment Plant during 1987. It has now been used at Saidabad Water Treatment Plant and at Monno Fabrics. Monno Fabrics is using clarifiers at water treatment plant and also at effluent treatment plant. These are discussed bellow:

2.11.1 Mohara Water Treatment Plant clarifier:

Chemically dosed water flows from the mixing chambers to a series of 24 up-flow hopper, solids contact type clarification tanks. Up-flow clarifiers combine flocculation and sedimentation into a single unit. As shown in the partial plan and section of Figure 2.9. Each clarifier consists of an inverted, truncated pyramid, which is topped by a 25-foot square tank section having vertical walls. The sides of the pyramid portion slope at about 60° to the horizontal. An inlet pipe discharges vertically downward near the bottom of the hopper portion of each tank. The discharge velocity and the change in direction from downward to upward flow create a condition of agitation good for initial flocculation. The 24 solids-contact chambers act as a combination of flocculation-sedimentation process. The chemically treated water is piped from the raw water channels into the bottom of each clarifier. As the water rises through the expanding portion of the tank, the upward velocity (and mixing action) decreases to a minimum of 0.75 mm/s (8.9 fph) along the vertical wall,



PARTIAL PLAN



SECTION A - A
(Typ. of other 2 Rows)

Figure 2.9: Partial plan and section of clarifier used at Mohara (MacDonald, 1981)

4E

where the suspended matter comes together with the sludge blanket and other particles forming a floc (MacDonald, 1981).

Two means of manual sludge drawoff are provided: one continuously via a fixed sludge conditioning corner pocket in each unit, and secondly, a sludge drawoff pipe for the heavier sludge which settles to the bottom after the unit has been taken out of service specifically for this purpose (MacDonald, 1981).

Figure 2.9 shows configuration of the clarifiers, the raw coagulated water flowing in channels from the rapid mixing chamber and down between each of the two rows of four rows of clarifiers. The water is piped from these channels into the bottom of each clarifier. The energy input to the water for tapered flocculation is provided by the head difference in the channel and the clarifier water surface, and the expanding cross sectional area of the clarifier. Channels down the extreme outside of the outer rows of clarifiers and between the two centre rows of clarifiers will collect the clarified water for conveyance to the filters.

With 24 clarifiers, one or two can be taken out of service for maintenance and/or for drawing off sludge, without appreciably affecting the up-flow velocity of the other units or their performance. Taking one or two units out of service will raise up-flow velocities in the units remaining in service by only 4.4 or 9.1%, respectively (MacDonald, 1981). Detail of Mohara's clarifier has been shown in Table 2.1.

Table 2.1: Detail of Mohara's clarifier (MacDonald, 1987)

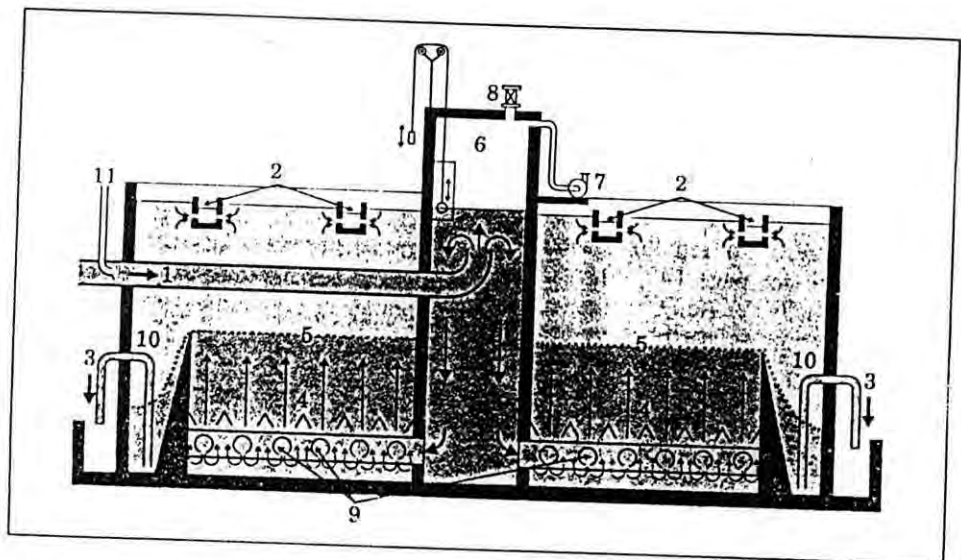
Number of clarifier	24 Nos.
Type of clarifier	Upflow solids contact Type
Volume of each clarifier	207 m ³
Detention time	1.2 hours
Overflow rate	0.75 mm/s (1333 imp gpd/sq ft)
Minimum upflow velocity of water	0.75 mm/s (8.9 fph)

2.11.2 Saidabad Water Treatment Plant Clarifier:

Pulsator clarifier has been used at Saidabad Water Treatment Plant. This is the most widely used clarifier in the world; more than one million cubic meters of water are treated every hour in Pulsator clarifiers (Degremont, 1991).

This simple sludge blanket-type clarifier is highly reliable, flexible and can be easily adapted to existing tanks to increase their treatment capacity. Generally used for water clarification, it allows rising velocities between 2 and 4 m/hr, or even higher in special cases, depending on the sludge cohesion coefficient (Degremont, 1991).

Pulsator clarifier is used at Saidabad can be seen from Figure 2.10. The clarifier comprises a flat-bottom tank, with a series of perforated pipes at its base, through which the raw water is injected to ensure even distribution over



- | | |
|------------------------------------|------------------------------------|
| 1 - Raw water inlet. | 7 - Vacuum pump. |
| 2 - Clarified water outlet. | 8 - Air release valve. |
| 3 - Sludge removal. | 9 - Raw water distribution system. |
| 4 - Stilling baffles. | 10 - Sludge concentrators. |
| 5 - Upper level of sludge blanket. | 11 - Reagent feed. |
| 6 - Vacuum chamber. | |

Figure 2.10: Pulsator clarifier used at Saidabad (Degremont, 1992)

the entire floor of the clarifier. A series of perforated pipes or troughs at the top of the tank allow uniform collection of the settled water, avoiding flow variation from one unit component to another. Details of Saidabad clarifier have been shown in Table 2.2.

Table 2.2: Details of Saidabad Water Treatment Plant Clarifier (Degremont, 1995)

Name	Pulsator Clarifier
No. of clarifier	4 No.
Size of each clarifier	30 m * 28.70 m = 861 m ²
Capacity of each unit	2525 m ³ /hr
Total capacity	10100 m ³ /hr
Retention time	1 hr 42 min.
Sludge blanket thickness	3.0 m
Sludge blanket surface area	714.60 m ²
Rise rate over the sludge blanket	3.53 m/hr
Contact time in the sludge blanket	50 min.
No. of distribution holes	2688 No.
Depth of water	5.0 m

2.11.3 Monno Fabrics Clarifier:

Monno Fabrics is using clarifiers in their factory. One clarifier is used for water treatment and two clarifiers are used for effluent treatment in the factory. Primary and secondary clarifiers are used for effluent treatment. Conical inverted pyramid type clarifier is used for water treatment. The water treatment clarifier has cylinder at top above cone. Diameter of cylinder is 9 m and height is about 2.7 m, while diameter of the cone used is 1.68 m and depth is about 1.025 m. Detail of Monno Fabric's water treatment clarifier has been shown in Table 2.3.

Table 2.3: Detail of Monno Fabric's water treatment clarifier (Ion Exchange Ltd, 1996)

Type of clarifier	Upflow solids contact clarifier
Inflow in the clarifier	168 m ³ /hour
Desludging	1 m ³ /hour
Detention time	60 minutes
Angle of clarifier	51°
Volume of the clarifier	182.45 m ³
Nominal upflow velocity	2.32 mm/s

2.12 Influence of Salinity in the Clarifier

Due to salinity intrusion at the intake of river Halda, breakage of alum flocs and sludge blanket disintegration were observed in the clarifier at the Mohara Water Treatment Plant. Supplied water quality and quantity were also hampered due to influence of salinity. CWASA then had to control flow to stable sludge blanket (MacDonald, 1995). From Mohara's experience, it can be

said that salinity has a direct influence on performance of a sludge blanket clarifier. Salinity decreases clarifier's performance.

CHAPTER THREE

METHODOLOGY OF THE STUDY AND INSTRUMENTAL SETUP

3.1 Introduction

Mohara Treatment Plant's performance has been analysed for selected parameters as a part of the current study. Representative samples of the plant need to be created for the study to use in the paddle mixing and also in the clarifier. Sequential steps of the study methods have been discussed in this chapter. A physical model of sludge blanket clarifier, which is similar to Mohara's clarifier has been set-up to measure performance of a sludge blanket clarifier and influence of salinity on its performance.

3.2 Methodology of the Study

The study has seven sequential steps. They are:

1. Performance study of Mohara Treatment Plant
2. Fixing of kaolin dose
3. Fixing of optimum alum dose
4. Addition of salt in rapid mixing coagulation
5. Addition of salt in slow mixing coagulation
6. Performance study of a sludge blanket clarifier, and
7. Addition of salt on clarifier's performance.

3.2.1 Performance study of Mohara Treatment Plant:

It could be done by collecting samples at intake of Halda, inlet of sedimentation basin, inlet of flash mixer, outlet of clarifier and at distribution

point. Parameters selected to be tested were colour, turbidity, TSS, TDS, alkalinity, pH and chloride. Efficiency of different units and of the whole plant would then be measured. Seasonal variation of raw water quality was also observed.

Two samples were taken at a time at every point of sampling. Samples have been taken twice a day at two hours interval. Detention time in sedimentation basin and clarifier are 2 and 1.2 hours respectively. So, sampling has been done at two hours interval, which would give proper data.

3.2.2 Fixing of kaolin dose:

It would be fixed for laboratory analysis to get synthetic sample of river Halda at Mohara to use in rapid and slow mixing coagulation, and in sludge blanket clarifier. Kaolin dose would be fixed-up at 200 NTU turbidity, and at optimum pH and alkalinity of water.

3.2.3 Fixing of optimum alum dose:

It would be fixed from representative Mohara sample considering turbidity, pH and alkalinity of water by jar test method. Samples having fixed kaolin and optimum alum dose would be used for analysis of the study.

3.2.4 Addition of salt in rapid mixing coagulation:

Rapid mixing coagulation would be done at high rpm (300 rpm) for 30 seconds by jar tests. NaCl would be added here to check the influence of salt during coagulation. Residual turbidity, pH, conductivity etc. of the top water would be measured after allowing sedimentation of the water for 30 minutes.

3.2.5 Addition of salt in slow mixing coagulation:

Slow mixing coagulation would be done at 40 rpm for 5 minutes, and then at 20 rpm for 10 minutes. NaCl would be used to check influence of salt during coagulation. Residual turbidity, pH and conductivity of the water would be measured after 30 minutes of sedimentation.

3.2.6 Performance study of a sludge blanket clarifier:

A physical model of sludge blanket clarifier similar to Mohara Treatment Plant's clarifier would be made of plastic cone with steel stand. Angle of clarifier would be 60° with horizontal. Performance of clarifier is controlled by velocity gradient, which depends on discharge, angle of clarifier, sludge depth and flocculation zone. Performance of clarifier would be measured by varying discharge, angle of clarifier and sludge depth. Residual turbidity, pH and conductivity would be measured at different points of clarifier. Initial and final turbidity would be used to measure performance of the clarifier. Relative pore space of flocculation zone and specific gravity of floc would also be measured during laboratory analysis.

3.2.7 Addition of salt on clarifier's performance:

Different doses of NaCl would be used at different flow condition to observe the effect of chloride on clarifier's performance. Performance of clarifier would be measured by varying discharge and chloride. Residual turbidity, pH and conductivity would be measured at different points of clarifier. Clarifier's performance in presence of chloride would be measured from initial and final turbidity of water.

3.3 Instrumental Set-up

Influence of salinity on the performance of a sludge blanket clarifier has been studied by a physical model of clarifier. The model posses 60° angle with horizontal and works in the same method used at Mohara's clarifier. Hence, it can be considered similar to Mohara's clarifier.

3.3.1 Physical model of clarifier used in the study:

A conical shape, up-flow solid-contact, inverted pyramid type clarifier has been used in the current study. The clarifier has been made of transparent plastic sheet with steel stand and support. The physical model of clarifier has been shown in Figure 3.1. Floc dispersion due to concentrated force while flow in the clarifier could be seen through transparent cone. The clarifier has 15 inches height and 18 inches width. It's dimension has been shown in Figure 3.2. Angle of clarifier with horizontal is 60°. Volume of the clarifier is 0.02085 m³, on the other hand, volume of Mohara's clarifier is about 207 m³. Artificial sludge has been used initially, which was created by jar tests.

3.3.2 Collection of data through the clarifier:

An arrangement of continuous flow has been made for data collection. Detention time was fixed at 72 minutes, which is same to Mohara's clarifier. Sludge depth and discharge have been varied at without salt condition to measure optimum sludge depth and discharge on clarifier's performance. Residual turbidity, pH and conductivity were measured at different points of clarifier, i. e., at point 2, 3, 4 and top. Arrangement of continuous flow has been shown in Figure 3.3. Samples with optimum alum and kaolin dose have been mixed initially, then the water was allowed to flow into the clarifier

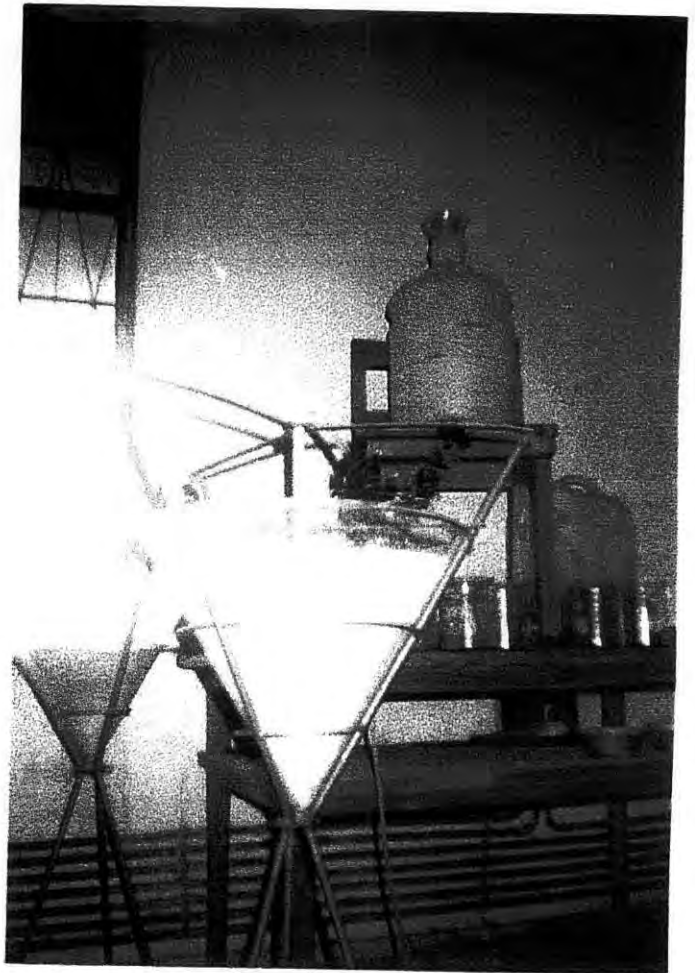
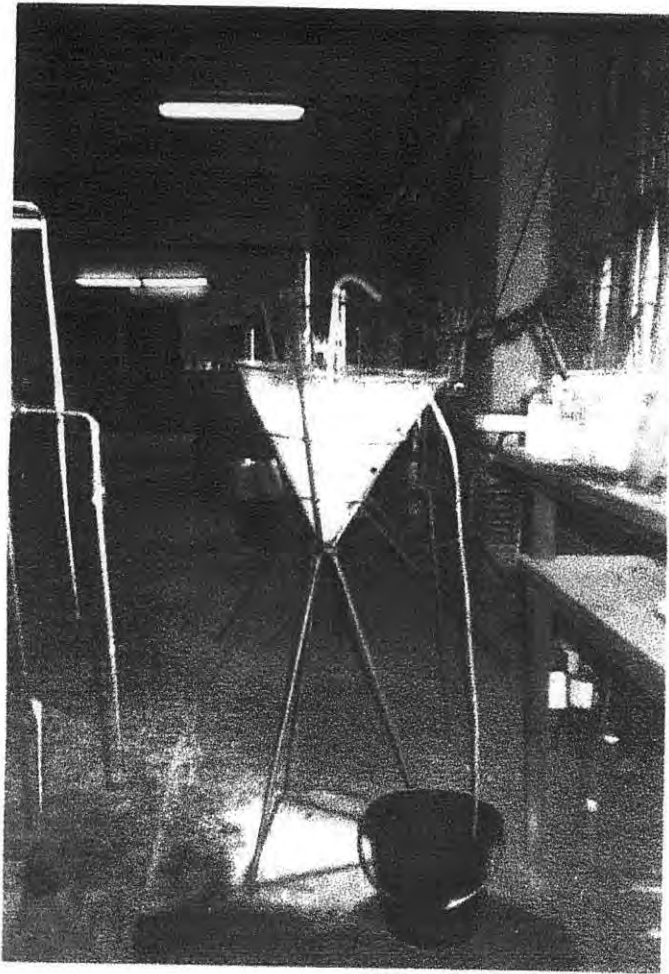


Figure 3.1: Physical model of sludge blanket clarifier and arrangement of continuous flow

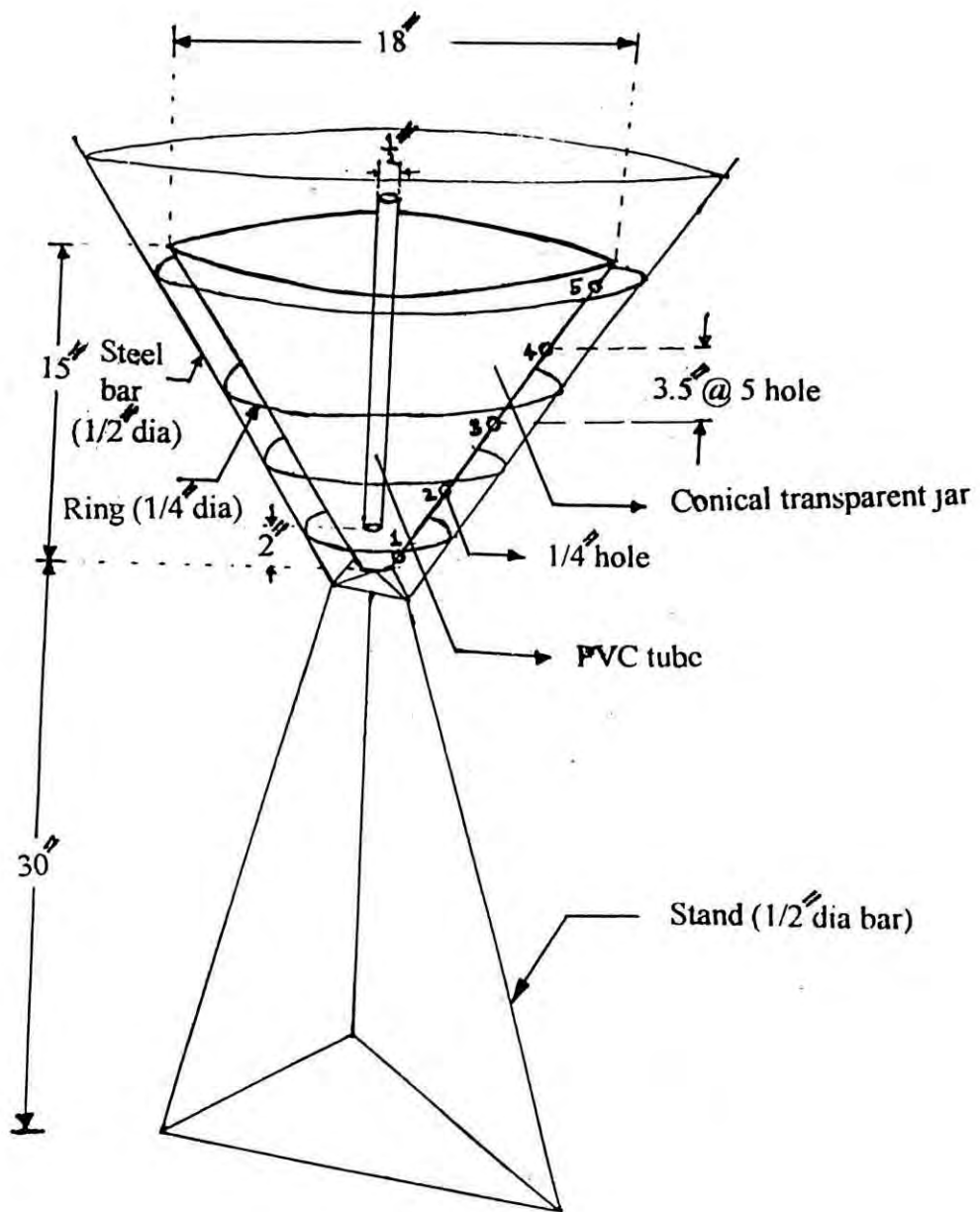


Figure 3.2: Instrumental Set-up of a Sludge Blanket Clarifier

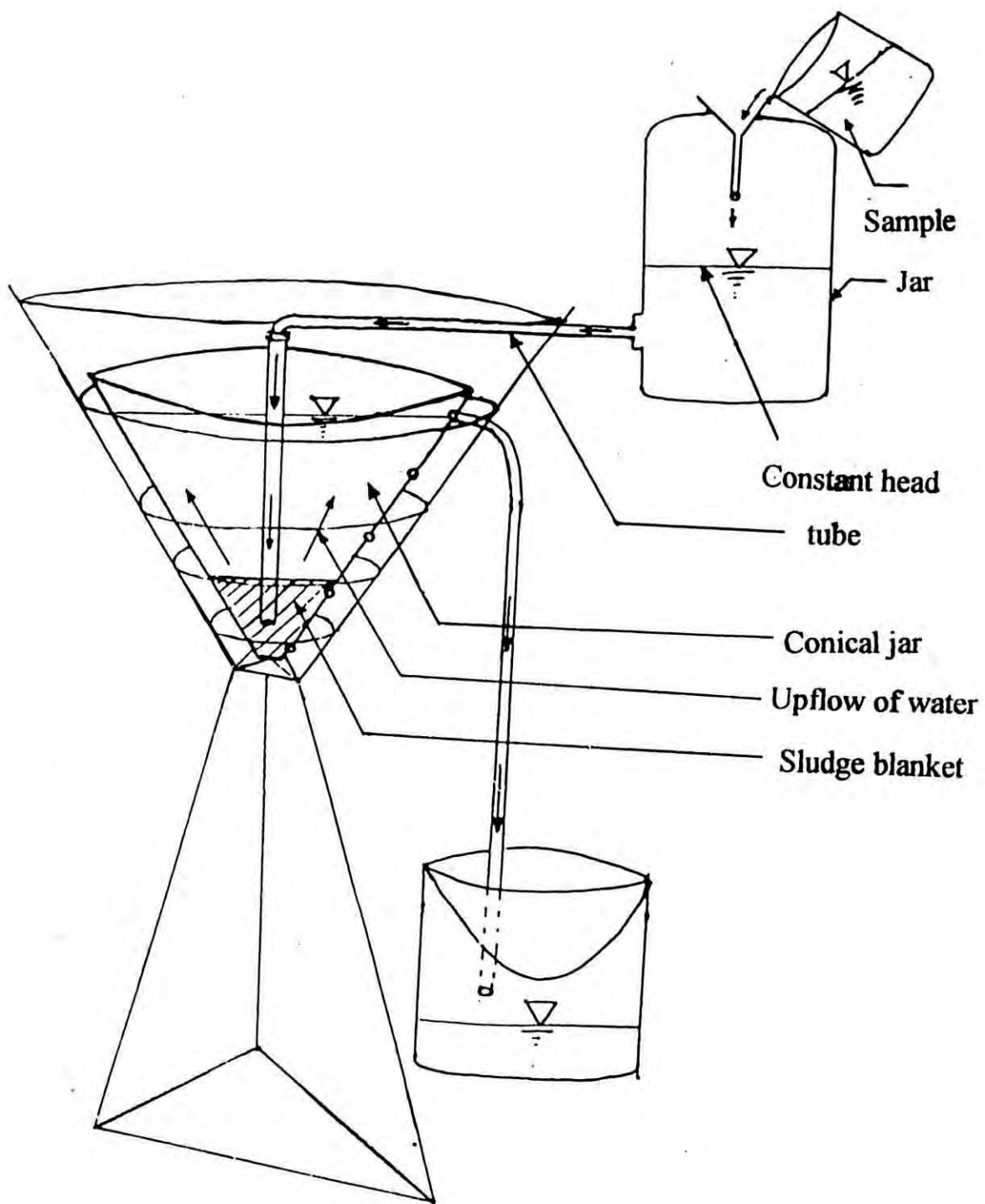


Figure 3.3 : Continuous flow in the sludge blanket clarifier

through jar. A constant head had to maintain in the jar while inflow in the clarifier. Floc dispersion, and discharge at 0, 15, 30, 60 minutes has been measured at each test. Air bubble was formed at the water surface of the clarifier, which was controlled by Na_2SO_3 . To avoid initial dispersion of floc, flow has to be increased slowly at the beginning. Then a constant rate of flow in the clarifier would be achieved without disturbing sludge blanket. It was done for each test in the laboratory analysis. Influence of chloride on clarifier's performance has also been studied by using different chloride dose.

CHAPTER FOUR

PERFORMANCE OF MOHARA WATER TREATMENT PLANT

4.1 Introduction

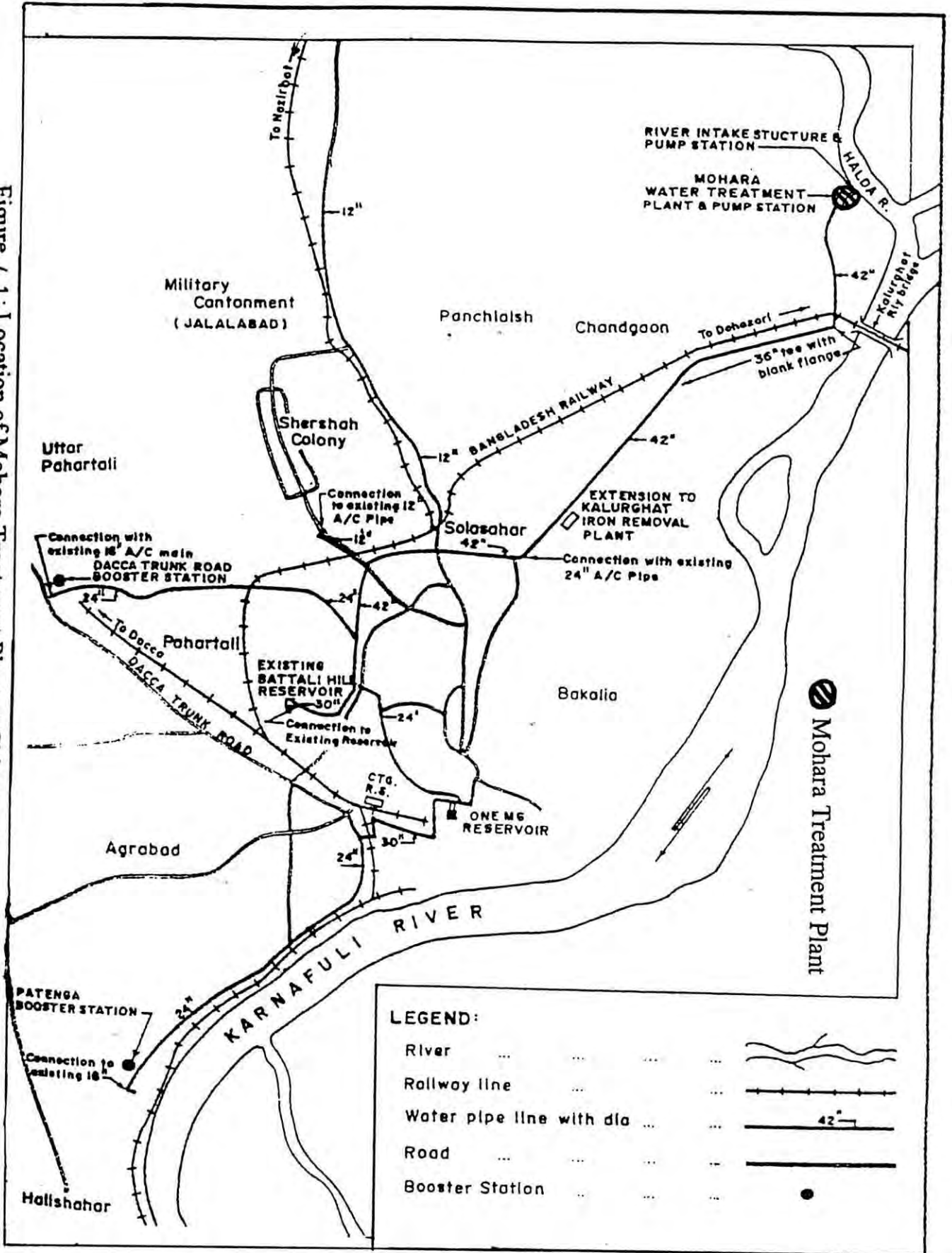
One of the major objectives of the study was to study the recent performance of Mohara Treatment Plant for seven selected parameters. Water samples have been collected at inlet and outlet of each unit. The results have been discussed in this chapter. Details of the plant and limitations of the plant have also stated here.

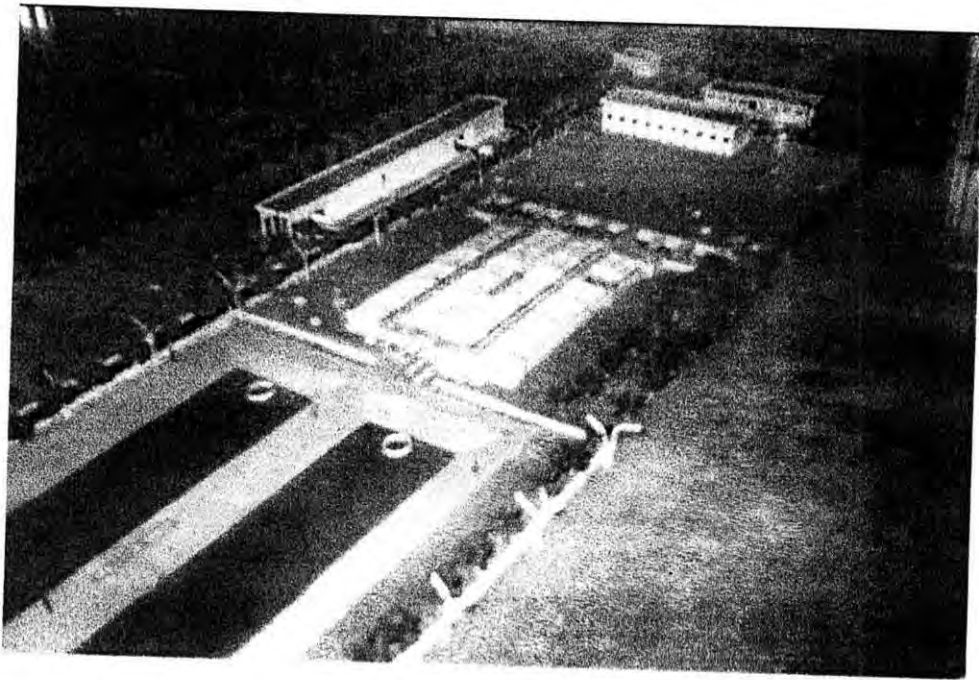
4.2 Location and Details of Mohara Treatment Plant

Mohara Surface Water Treatment Plant with 20 million gallon per day (90 million litre per day) capacity of CWASA was commissioned in December, 1987 (Figure 4.1). Water from river Halda at a point nearly half a mile upstream from its confluence with the river Karnafully has been chosen as the source of supply for Mohara Surface Water Treatment Plant. This was decided after careful study and consideration of the Halda river water quality and quantity at the present point at Mohara (MotMacDonald and Partners Ltd., et al, 1988). Model of the plant and intake point of river Halda have been shown in Figure 4.2. The plant posses a very simple treatment method. They are sequentially Sedimentation, Coagulation (Flash mixer and Clarifier), Filtration and Disinfection methods. It can be seen from Model of the plant (Figure 4.2).

Mohara Surface Water Treatment Plant is of 20 mgd capacity with necessary provision and space for expansion up to 40 mgd. Although the present treatment plant is of 20 mgd, the intake and raw water pumping station on the

Figure 4.1 : Location of Mohara Treatment Plant at Chitagong
(MacDonald, 1987)





Model of Mohara Treatment Plant

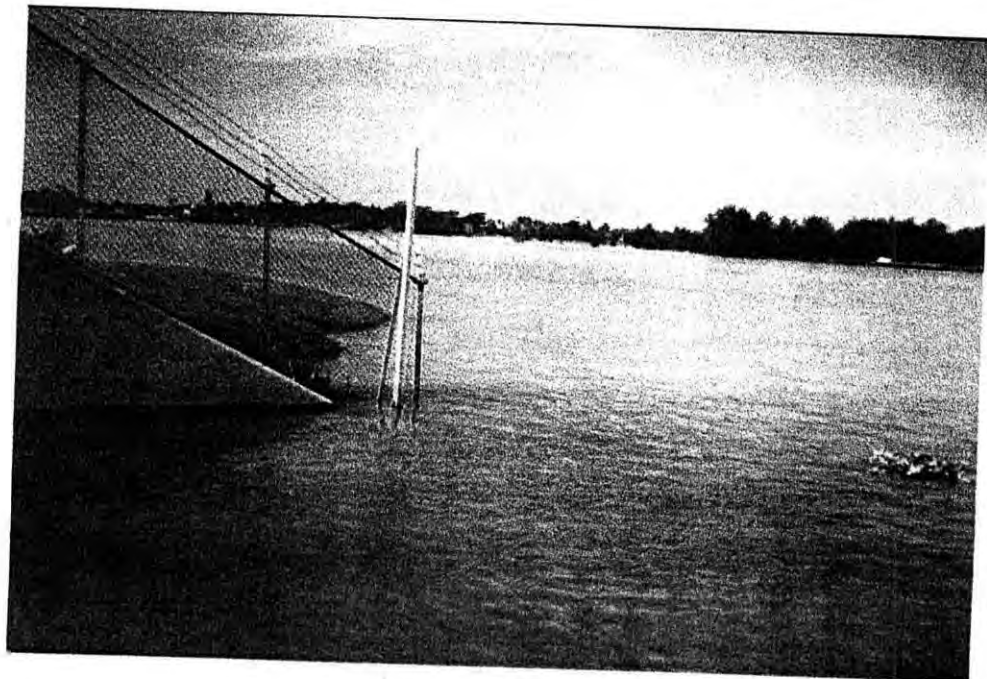


Figure 4.2: Model of the plant and intake point of Mohara Treatment Plant at river Halda

bank of Halda river at Mohara has been constructed for 40 mgd capacity to meet the future requirement. Design values for different parameters of finished water at the plant are given in Table 4.1.

Table 4.1: Design Value of different parameters of finished water at the Mohara Treatment Plant (Source: MacDonald, 1987)

Parameters	Raw Water	Finished Water	Standard Value	Production MGD
pH	6.4-7.8	7.0-7.5	6.5-8.5	19-20 MGD
Turbidity (NTU)	20-780	0.4-0.9	5.0	
Chloride (mg/l)	4-14	4-14	150-600	
Total Alkalinity(mg/l as CaCO_3)	40-60	30-60	Not Yet Set	
Total Hardness as CaCO_3		60-70	200-500	
Aluminium (mg/l)	0.2	0.2	0.2	
Calcium (mg/l)	11.9-14.8		75	
Magnesium (mg/l)	4.86		30-50	
Iron (mg/l)	0.2-0.3		0.3-1.0	
Sulphate (mg/l)	0.02-0.18		400	
Phosphate (mg/l)	0.012-0.42		6	
Ammonia (mg/l)	0.3		0.5	
Nitrate (mg/l)	0.018-1.48		10.0	
Nitrite (mg/l)	0.0		1	
Fluoride (mg/l)	0.7		1	
C.O.D.	8-10			
B.O.D.	1-2			
Electrical Conductivity (m mhos/cm)	150-250			

The following are the major components of the plant:

- Intake and raw water pumping station
- Desilting basins
- Rapid mixers
- Clarifiers
- Filters
- Clearwell and high lift pump station
- Chemical
- Sludge and back wash facilities
- Power supply and standby generator
- Laboratory

- Plant monitoring system

Site plan of the plant can be seen from Figure 4.3. Provision of sludge and waste removal is shown in the figure. Figure 4.4 shows plan and section of sedimentation basin. Flash mixer unit of the plant has been shown in Figure 4.5. Alum is injected in this unit. Detention time is 10 seconds per chamber in the flash mixer. Conical upflow settling type clarifiers have been used at this plant. Clarifier's plan and section have been shown in Figure 4.6. Physical model of sludge blanket clarifier, which has been set-up for this study (Figure 3.1) is similar to Mohara's clarifier. Filter beds are provided after clarifier unit at the plant. Influent-splitting type filters are used at this plant through mono-media sand. Figure 4.7 shows filtration chamber of the plant. Figure 4.8 and Figure 4.9 show some major units of the plant. Photographs of sedimentation basin, rapid mixer and clarifier of the plant have been shown in Figure 4.8 and Figure 4.9. All the components are described in Table 4.2.

Table 4.2: Mohara Treatment Plant design data
(Source: CWASA Mohara Surface Water Treatment Plant's Manual of Operation and Maintenance, MacDonald, 1987)

Design data	91 ml/d (20 imp mgd)
Capacity	
Raw water pumps	
Number- duty/standby	2/1
Capacity- each	45 ml/d (12.7 imp mgd)
Power- each	110 kw (132 hp)
Desilting basins	
Number	2
Overflow rate	0.18 mm/s (312 imp gpd/sq ft)
Detention time	120 min
Flash mixers	
Number	2
Detention time	10 sec. per chamber
Power- each	5.6 kw (7.5 hp)

Clarifiers	
Number	24
Type	Upflow solids contact
Detention time	1.2 hours
Overflow rate	0.75 mm/s (1333 imp gpd/sq ft)
Minimum upflow velocity	0.75 mm/s (8.9 fph)
Filters	
Number	8
Area- each	22.3 m ² (480 sq. ft) each half 2.44 m 0 9.1 m (8 ft 0 30 ft)
Controls	Influent-splitting, back washing unsized,
Media type	mono- media sand
Media size	0.85- 1.2 mm
Media depth	1.22 m (4 ft)
Loading	3.1 mm/s (3.8 imp gpm/ sq ft)
Backwash rate	16. 3 mm/s (20 imp gpm/sq ft)
Clearwell	
Chlorine contact zone	
Volume	2.27 ml (500,000 imp gal)
Detention time	30 min at 91 ml/d (20 imp mgd)
Clearwell volume	11.4 ml (2.5 mil imp gal)
Standby power Generation	
Number	2
Type	Diesel fuel
Size	1000 kw
High-Lift pumps	
Number- duty/standby	4/1
Capacity- each	22.5 ml/d (5 imp mgd)
Power- each	350 kw (468 hp)
Sludge backwash facility pumps	
Number- duty/standby	3/1
Capacity- each	645 l/s (2250 imp gpm)
Power- each	22.4 kw (30 hp)

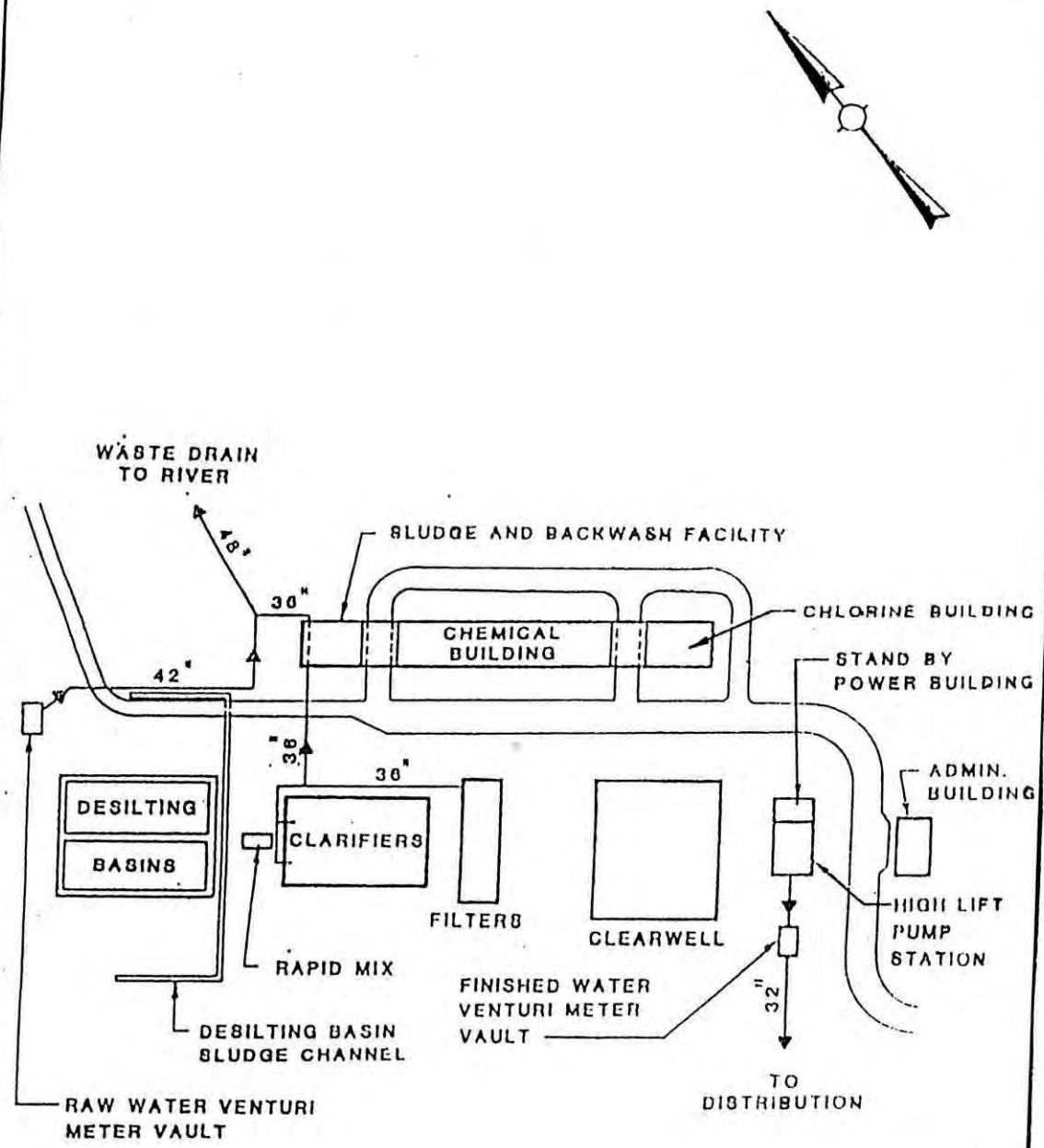
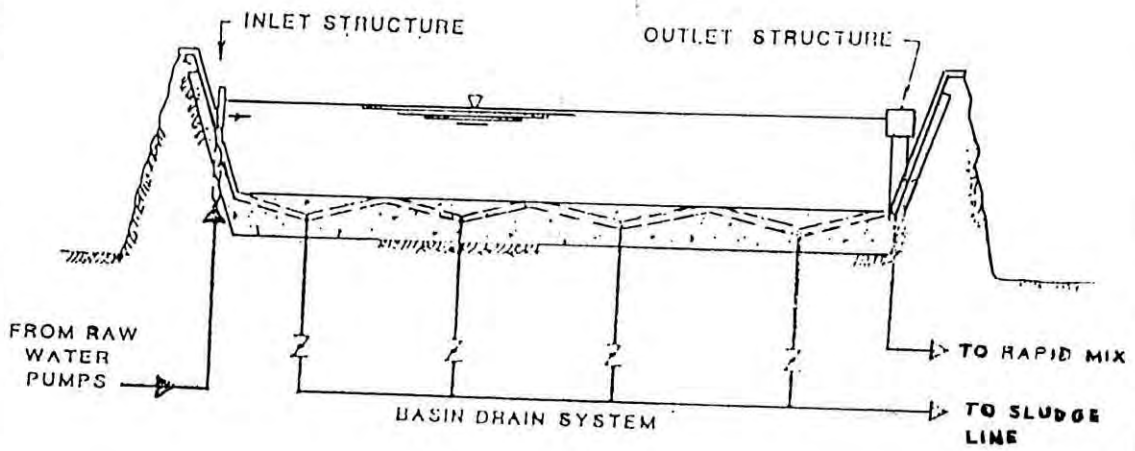
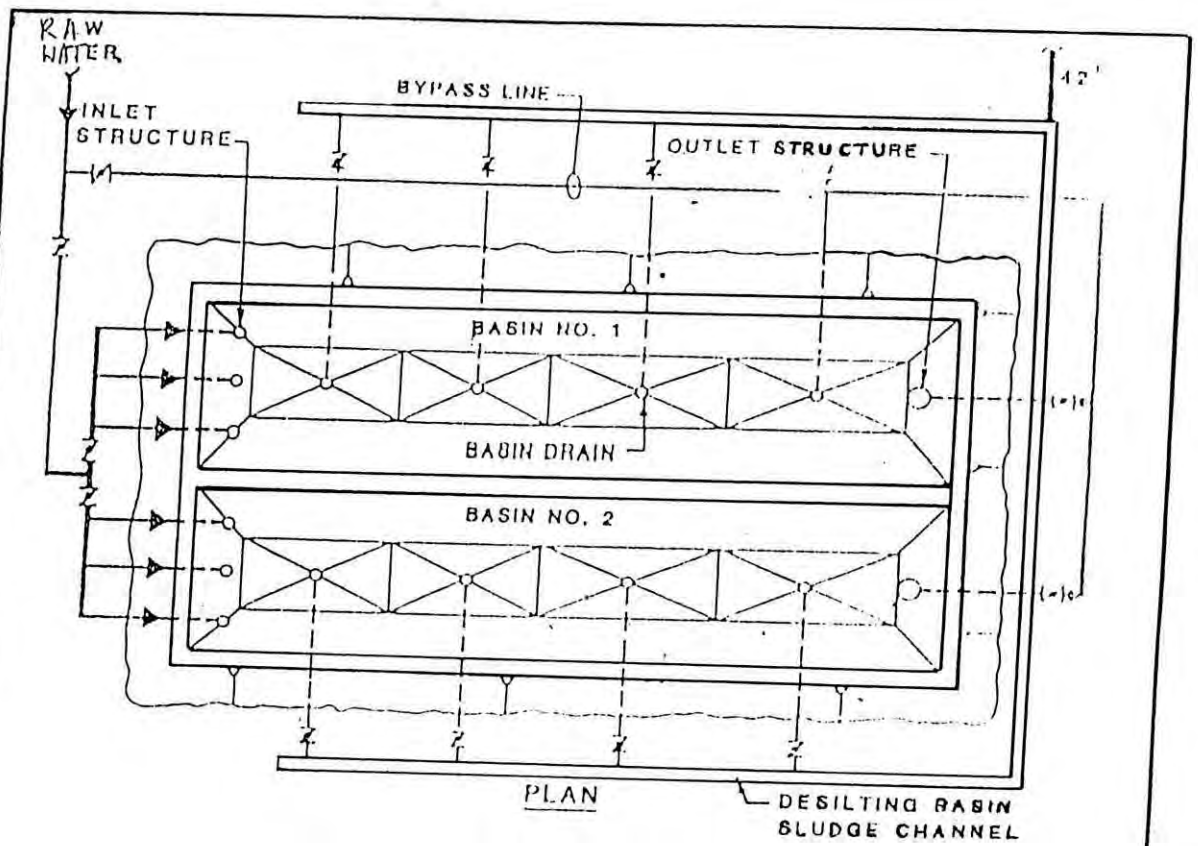


Figure 4.3 : Mohara WTP Site Plan (MacDonald, 1987)

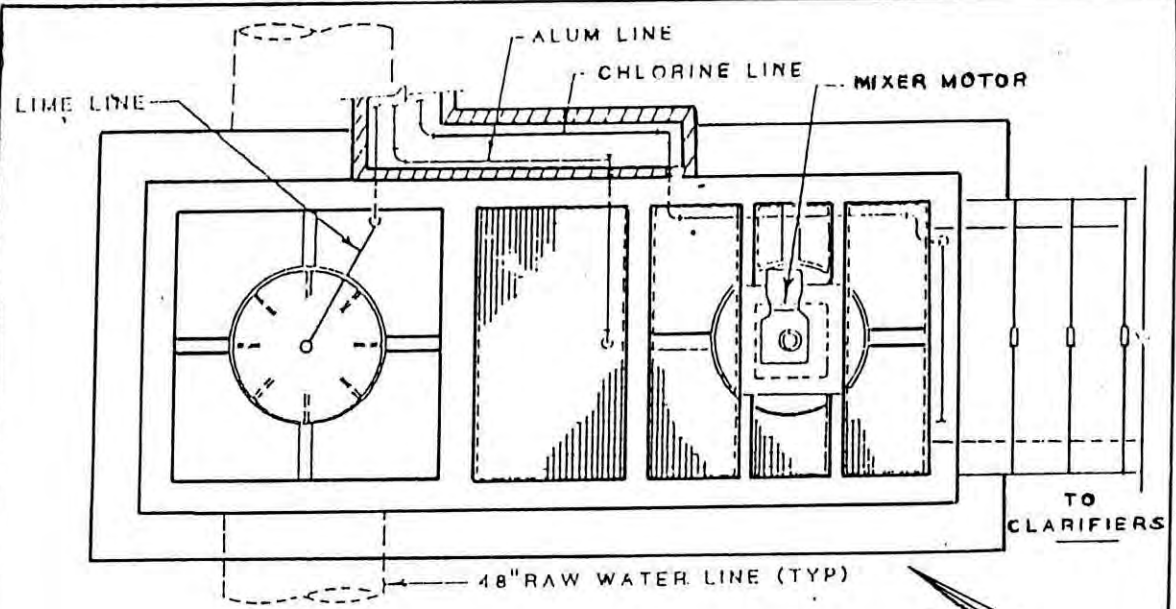


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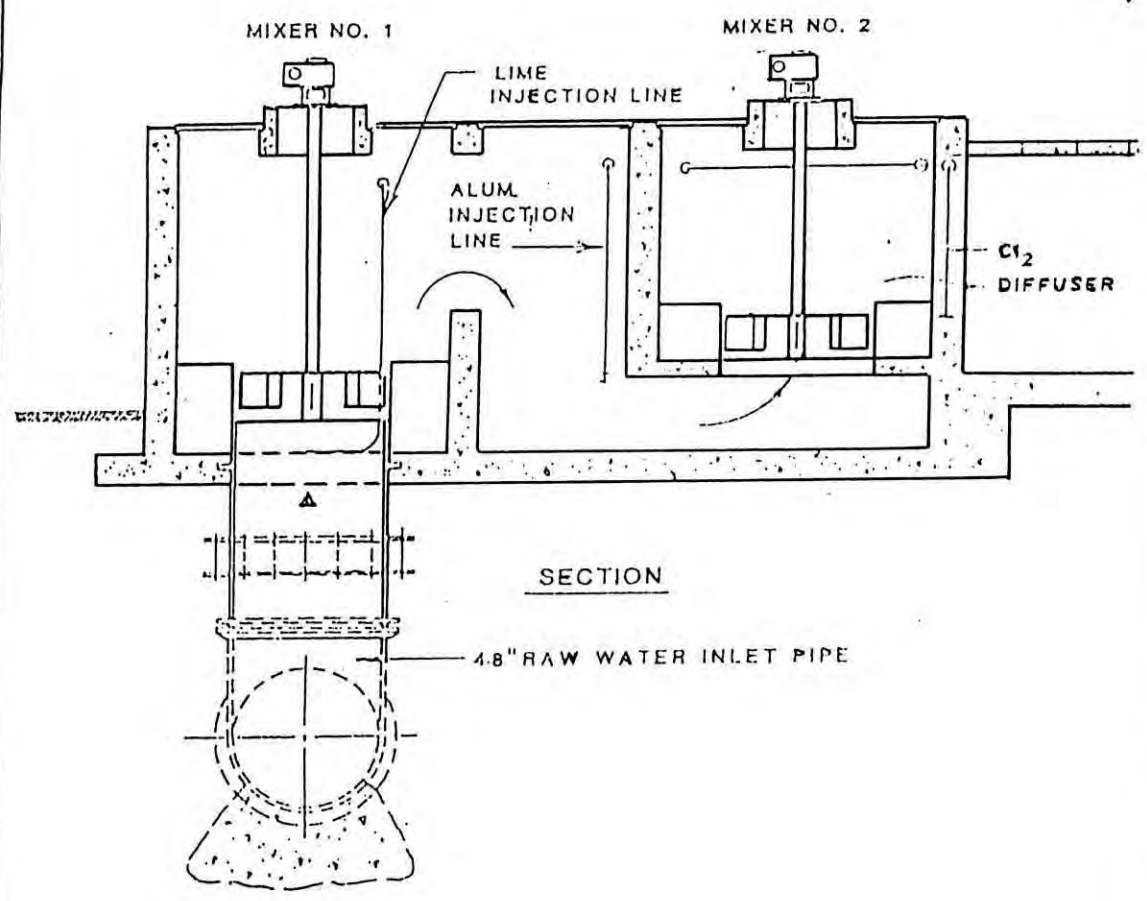
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SECTION

Figure 4.4 : Desilting Basin Plan and Section (MacDonald, 1987)



PLAN



SECTION

Figure 4.5 : Flash Mixture Plan and Section (MacDonald, 1987)

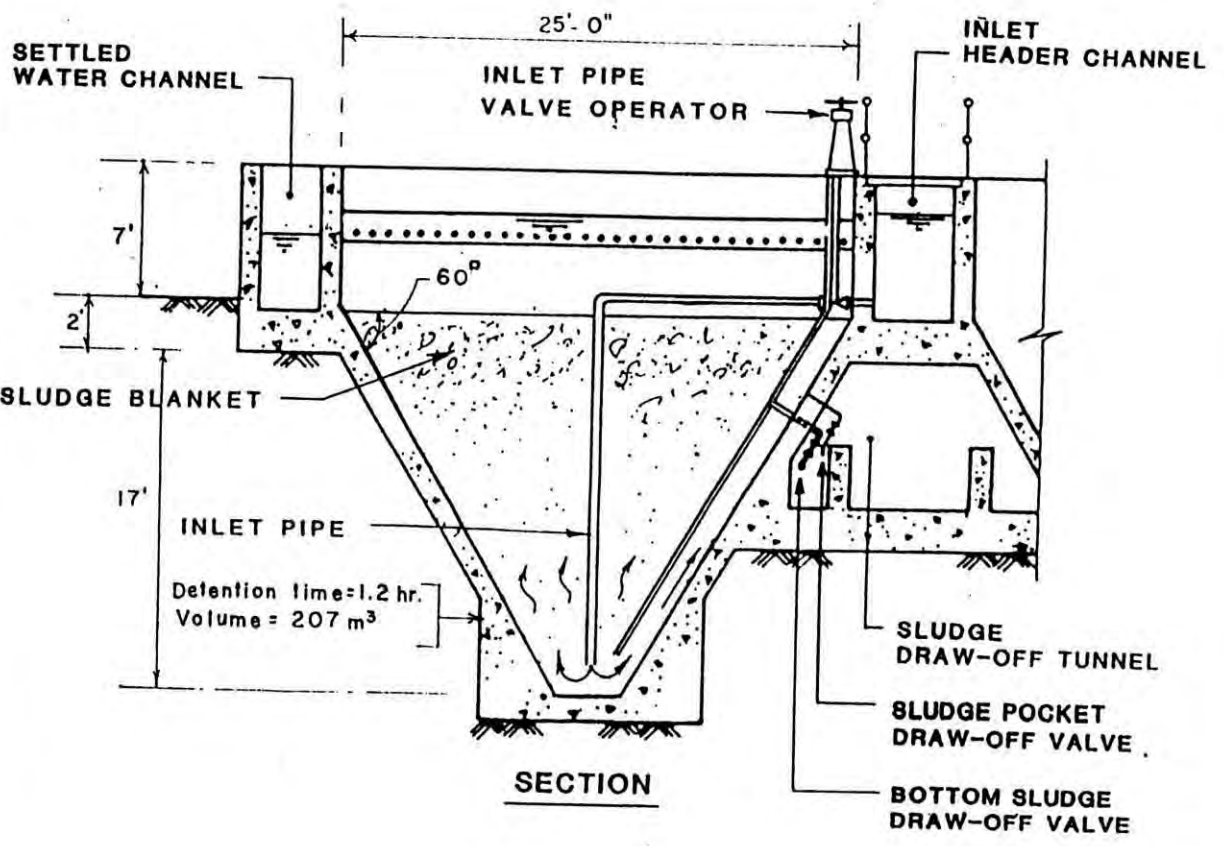
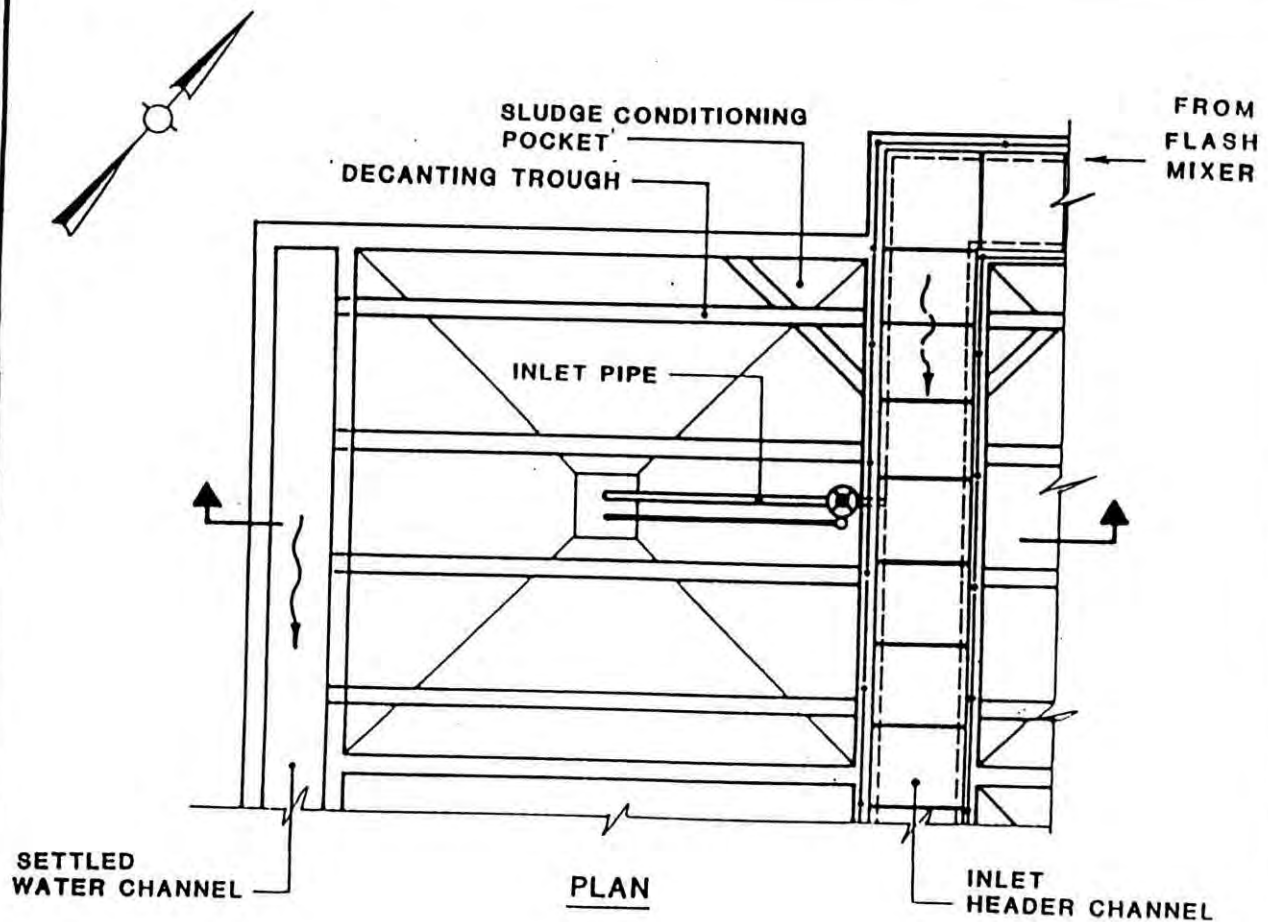
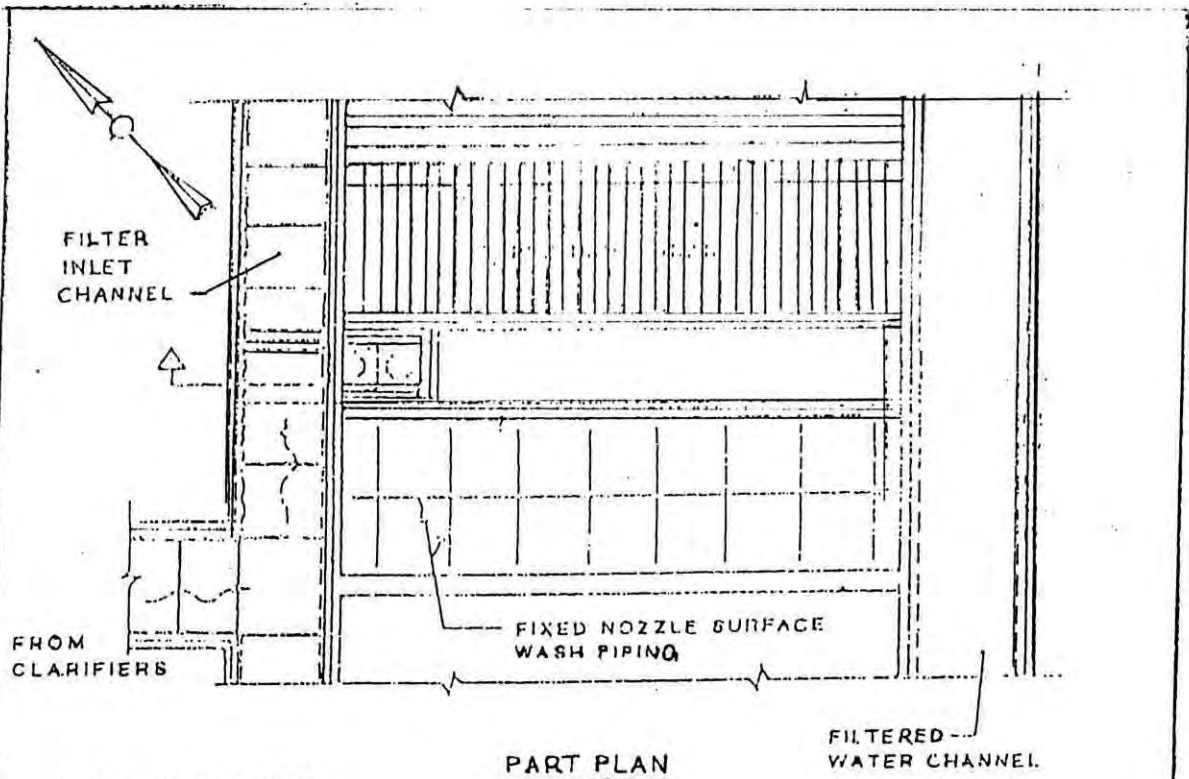
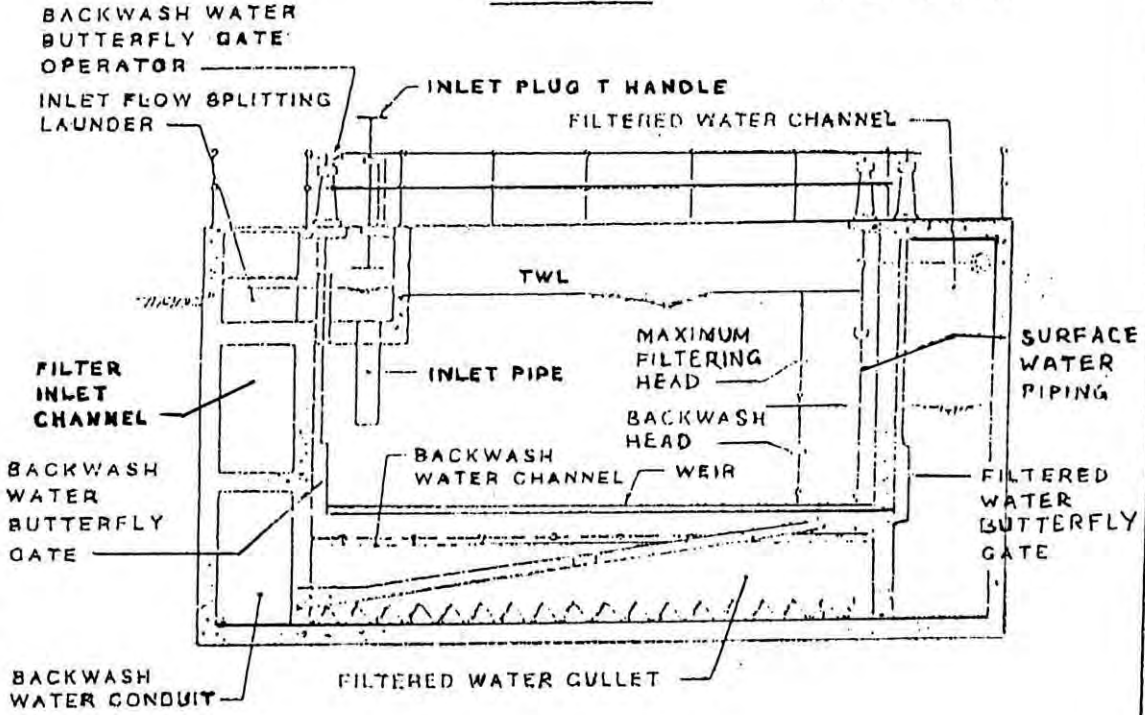


Figure 4.6 : Clarifiers Plan and Section (MacDonald, 1987)



PART PLAN

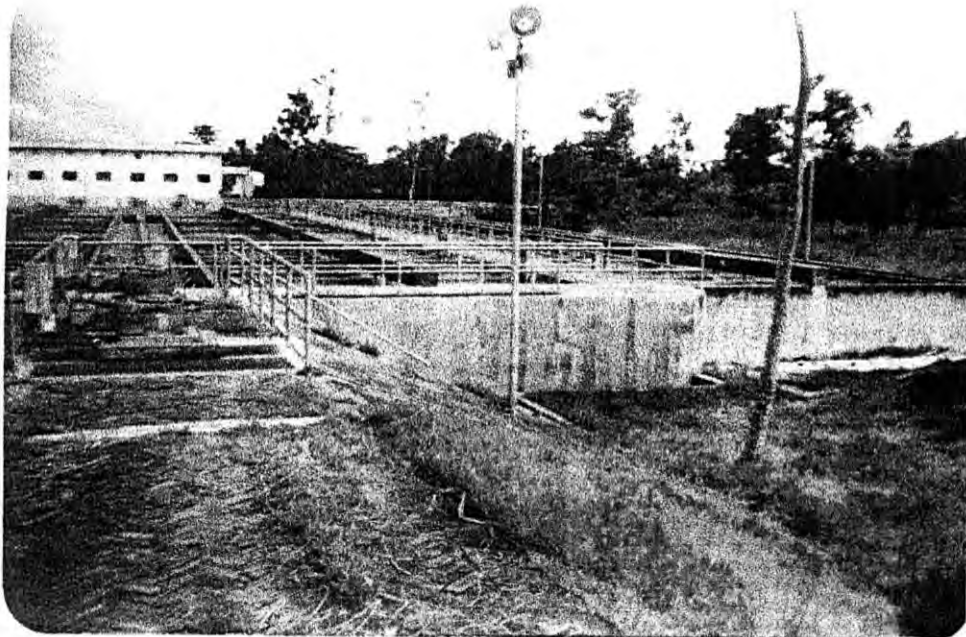


SECTION

Figure 4.7 : Filters Plan and Section (MacDonald, 1987)



Sedimentation basin of the plant (Basin was used for desludging)



Rapid mixer and clarifier of the plant

Figure 4.8: Sedimentation basin, rapid mixer and clarifier of the plant

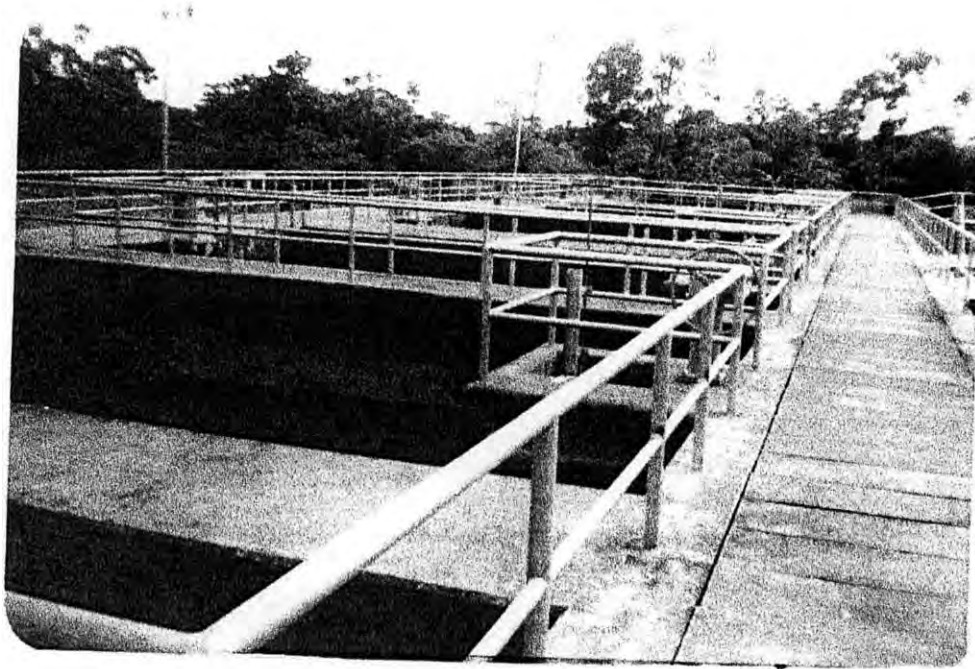


Figure 4.9: Sludge blanket clarifier of the plant

4.3 Seasonal Variation of Raw Water Quality of Halda

Field investigation of surface water quality of Halda river has been made since the late 1960s. These data have been collected by the survey team to determine salinity, turbidity, and other physical and chemical characteristics of water of Halda. Preliminary analysis indicates that maximum chloride concentration at the intake was below 8 mg/l. Table 4.3 indicates the range of values in certain key chemical parameters taken during high and low tides at the Mohara intake.

Table 4.3: Range of chemical values of Halda waters (Source: Parsons, 1978)

Parameter	Unit	Value
pH	$-\log(H^+)$	6.5 to 7.6
Total alkalinity	mg/l as $CaCO_3$	12 to 58
Turbidity	JTU	35 to 260
Electrical conductance	mhos* 10^{-6}	65 to 200
Chloride	mg/l	1 to 5
COD	mg/l	20 to 96
SS	mg/l	32 to 473

These values are consistent with MacDonald (1987) study, shown in raw water values in Table 4.1. Table 4.1 shows that chloride values of raw water were always below 14 mg/l at normal condition. Recent study measures raw water quality of Halda for selected parameters, e.g., turbidity, colour, pH, alkalinity, chloride and TSS. TDS was not possible to measure. The results can be seen from Table 4.4. The study has been done during winter.

Table 4.4: Results of raw water quality at intake of Halda (Author's study)

Parameter	Unit	Value
pH	$-\log(H^+)$	7.01 to 7.26
Total alkalinity	mg/l as $CaCO_3$	48 to 60
Turbidity	NTU	76 to 100
Chloride	mg/l	5 to 6
Colour	TCU	100 to 140
T.S.S.	mg/l	92
T.D.S.	mg/l	-----

Author's study (Table 4.4) gives consistent results of raw water quality of Halda with previous studies.

4.4 Sampling Method of the Study

Samples have been collected at inlet and outlet of each unit of the Mohara Treatment Plant to measure the values of turbidity, colour, pH, alkalinity, chloride, TS and TDS. Samples were collected manually on 13/10/97, 22/10/97, 5/12/97 and on 28/1/98. The study has been done during winter at low flow condition. Plastic bottles were used as sampler in collecting samples. Bottles were cleaned before use. Two samples were taken at a time at every point of sampling. Samples have been taken at intake of Halda, inlet of sedimentation basin, inlet of flash mixer, outlet of clarifier and at distribution point. Samples have been taken twice a day at two hours interval. Detention time in sedimentation basin and clarifier are 2 and 1.2 hours respectively. So, sampling has been done at two hours interval, which gives proper data.

Sampling has been done at noon during high tide period. It should have done at evening during low tide period in a day. Sampler, sampling locations and collection method could effect data. Sampling should be done during pumping hour also.

4.5 Performance of the Plant

CWASA's Mohara treatment plant has been running since 1987. A performance study was done for seven selected parameters, e.g., pH, TSS, TDS, turbidity, colour, alkalinity and chloride. Design efficiency is about 70% for removal of turbidity and TSS at the sedimentation unit while turbidity,

colour and TDS removal efficiencies are about 95% for coagulation (flash mixer and clarifier) unit. Design removal efficiencies of colour and organism are 99% at the filtration unit. Samples were collected during winter at low flow conditions of Halda. Samples had been taken from inlet and outlet of each unit to testify these parameters in the laboratory. Results of different units of the plant for the selected parameters have been shown in Table 4.5. Results of Filtration unit were not possible due to inaccessibility.

Table 4.5: Observed range of selected parameters at different treatment units
(Sample collected on 13/10/97, 22/10/97, 5/12/97 and 28/01/98)

Source of Collected samples	Turbidity (NTU)	Colour (TCU)	pH	Alkalinity (mg/l)	Chloride (mg/l)	TDS (mg/l)	TSS (mg/l)
Raw water	76-100	100-140	7.01-7.2	48-60	5-6	--	92
Sedimentation outlet	58-76	65-90	7.09-7.4	44-55	5-7	85	37
Coagulation outlet	2.9-3.4	5-10	7.12-7.1	38-52	5-6	60	45
Finished water	0.35-0.6	5-10	7.12-7.1	35-50	4-6	80	33

Efficiencies of different units for these parameters for the collected samples are shown in Table 4.6. Table 4.6 shows removal efficiencies of turbidity, colour, chloride, TDS and TSS at different units. Alkalinity and pH were always in the range.

Table 4.6: Range of efficiencies of different units for selected parameters
(sample collected on 13/10/97, 22/10/97, 5/12/97 and 28/01/98)

Treatment unit	Turbidity removal efficiency (%)	Colour removal efficiency (%)	Chloride removal efficiency (%)	TDS removal efficiency (%)	TSS removal efficiency (%)
Sedimentation unit	20-25	30-40	10-20	-	35-40
Coagulation unit	75-95	75-90	0-15	25-30	-
Filtration unit	80-85	-	-	-	-
Disinfection unit	-	-	10-15	-	-

It is seen that coagulation unit's efficiency in removing turbidity and colour are high and the unit is in good condition. Turbidity and TSS removal efficiencies of sedimentation unit were about 20-25% and 35-40%. These are far below than design removal efficiency, which are about 70%. Table 4.7 shows the comparison of parameters for the raw and finished water to evaluate the overall performance of the Plant. Table 4.6 shows performance of each unit while Table 4.7 shows performance of the whole plant for selected parameters. Table 4.7 shows that Mohara Water Treatment Plant is performing well in removing turbidity and colour. Alkalinity, pH, TDS and chloride of finished water were always in the range of WHO guideline. Analysis of TSS was not possible in details. Finished water had 33 mg/l of TSS, which is tolerable. Finally, it can be said that the finished water quality is good and the plant is running well.

Table 4.7: Comparison of parameters of raw and finished water of the plant with the WHO Guideline (Raw water was in low flow condition)

Parameters	Raw Water		Finished Water	
	Expected range (MacDonald, 1998)	Observed range (Recent Study)	Expected range (WHO guideline)	Observed range (Recent study)
Turbidity (NTU)	20-780	76-100	0.40-0.90	0.35-0.60
Colour (TCU)	-	100-140	15	5-10
pH	6.40-7.80	7.01-7.26	7.00-7.50	7.12-7.15
TSS (mg/l)	-	92	-	33
TDS (mg/l)	-	-	500 (laxative)	80
Alkalinity(mg/l)	40-60	48-60	30-60	35-50
Chloride (mg/l)	4-14	5-6	4-14	4-6

4.6 Limitation of the Mohara Treatment Plant Study

CWASA had salinity problem, which was described in section 1.1 in details. It is observed that clarifier can't perform well in presence of salinity. Another problem arising is that high silt intrusion at intake of Halda during monsoon. It creates operational problem. CWASA does not have any data during these periods. Performance study during salinity and during high silt intrusion period at intake is necessary, which was not possible in the recent study. Performance study of filtration unit, which was not possible due to inaccessibility, is also required. TDS and TSS were measured only once, as measuring instruments of TDS and TSS were out of order. Hence, it was not possible to get range of TDS and TSS data for each unit of the plant. Sampling data should be tested at high and low tide in a day. Sampling method, use of sampler and sampling locations could effect on results.

CHAPTER FIVE

INFLUENCE OF SALINITY ON COAGULATION

5.1 Introduction

The main purpose of the study was to observe influence of salinity on performance of sludge blanket clarifier. Clarifier is used to remove floc, hence it is a coagulation technique. So, it was necessary to measure influence of salinity on coagulation to compare influence of salinity on clarifier. This chapter stated the influence of salinity on rapid and slow mixing coagulation. Representative sample of Mohara and optimum alum dose have also been measured and been discussed here.

5.2 Fixing of Representative Samples

Synthetic water sample of Mohara Treatment Plant was required for laboratory analysis. It was obtained by using different kaolin doses in water, especially 400 mg/l and 1000 mg/l of kaolin doses. Table 5.1 shows the results of mixing turbidity after using kaolin.

Table 5.1: Measuring representative sample of Mohara Treatment Plant

Kaolin dose (mg/l)	pH	Initial Turbidity (NTU)
400	7.0	216
1000	6.9	422

It was observed that inlet turbidity at Mohara intake was not more than 100 NTU during low flow condition (see Table 4.5). High flow condition of river Halda gives higher initial turbidity. Even at high flow condition, turbidity at outlet of sedimentation basin would be close to intake turbidity at low flow

condition. Maximum turbidity at inlet of clarifier would be close to 200 NTU, which was observed at 400 mg/l of kaolin dose. 400 mg/l of kaolin was selected as representative sample for laboratory analysis at optimum pH range.

5.3 Estimation of Optimum Alum Dose

Alum dose depends on pH, alkalinity and turbidity of water, must be kept optimum. Optimum pH range for alum is 5.5 to 7.8. Experiments were done to get optimum alum dose for 400 mg/l of kaolin at this pH range where alkalinity was in range. It was fixed through slow mixing coagulation. Residual turbidity, which was measured after 30 minutes of sedimentation for different alum dose can be seen from Figure 5.1. It shows that the optimum alum dose is 20 mg/l for 400 mg/l of kaolin. Afroze (1998) study shows that for 400 mg/l of kaolin and at pH = 6.0, optimum alum dose was 25 mg/l. Comparison between the previous and recent study for optimum alum dose is shown in Appendix.

5.4 Influence of Salinity in the Rapid Mixing Coagulation

Both slow and rapid mixing coagulation has been done by using paddles. Fayer, et. al (1967) expressed energy dissipation (P) in the following way,

$$P = 5.74 \times 10^{-4} C_D \int [(1-k)n]^3 \cdot r^3 A \text{ for a single blade in paddle mixing.}$$

Both side paddle was used in the laboratory where, $r = 0.125$ ft and $A = 0.02$ ft². Again, $C_D = 1.8$, $K = 0.25$, water temperature = 25°C, $\mu = 1.89 \times 10^{-5}$ lb force.sec/ft² and n is rpm.

$$\text{Paddle velocity} = 2 \pi r n = (0.013 * n) \text{ ft/s}$$

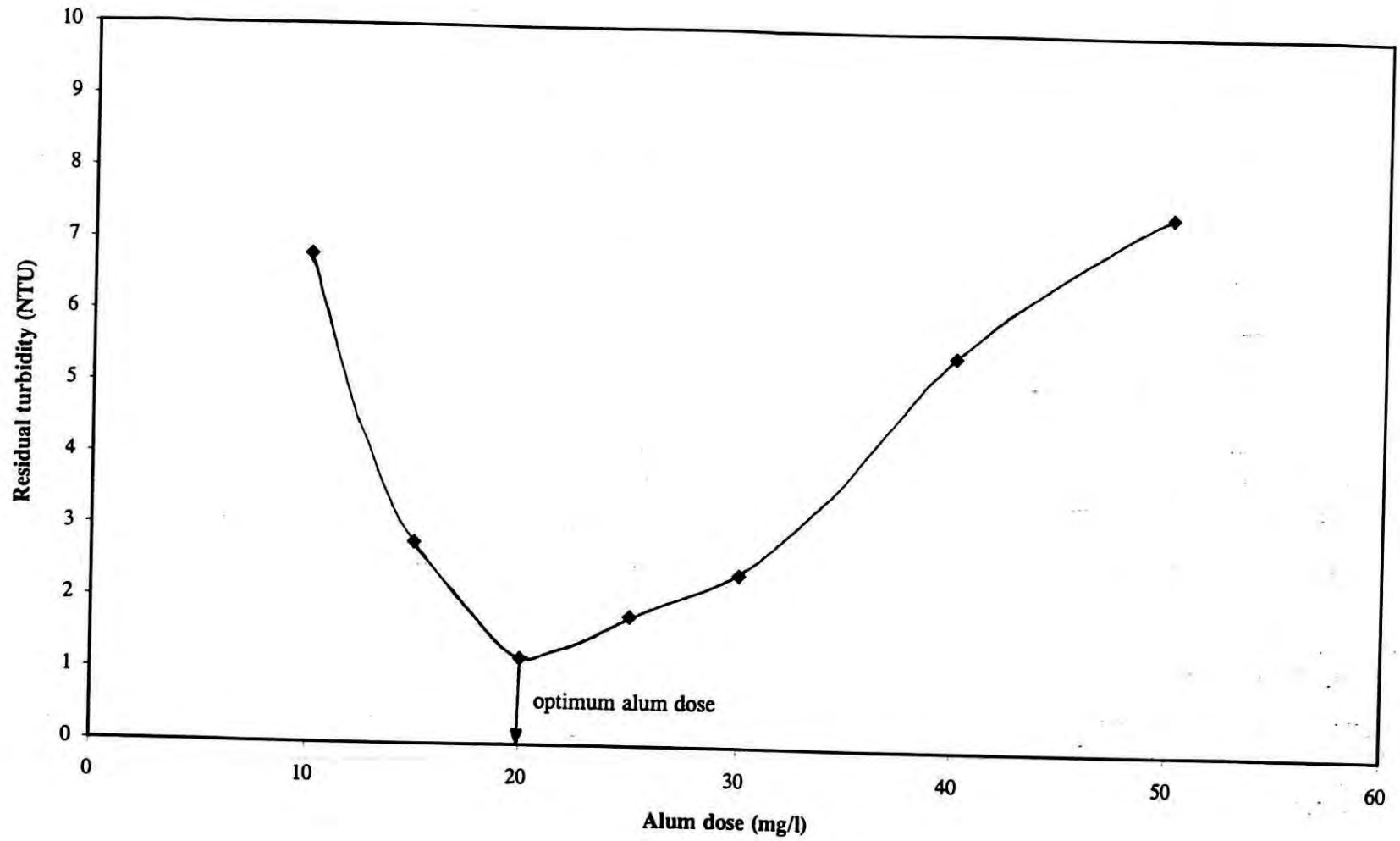


Figure 5.1: Fixing optimum alum dose by slow mixing coagulation

Relative velocity of Paddle = $(1-k) V_i = (1-0.25) * 0.013 * n$

Hence, $V = (9.82 * 10^{-3} * n)$ ft/s

Using C_D , K , r and A values in the above expression of P , it can be written that,

$P = (6 * 10^{-11} * n^3)$ Horse power for pure water, and

$P = (3.1 * 10^{-11} * n^3 * \rho)$ Horse power for varying salt.

Using the values of P in the velocity gradient's expression, $G = \sqrt{(P/\mu V)}$, G can be simplified,

$G = \sqrt{(0.05 n^3)}$ for pure water, and

For varying salt, $G = \sqrt{(4.83 * 10^{-7} * n^3 * \rho / \mu)}$

Hence, it is clear that salinity has direct influence on velocity gradient during slow and rapid mixing coagulation.

400 mg/l of kaolin and 20 mg/l of alum dose were used as representative sample in every case to investigate effect of salt on coagulation. 0-5000 mg/l of NaCl were added initially, and finally investigation was fixed upto 2000 mg/l of NaCl. Only NaCl was used in this study. Different alum doses (0, 10, 20, 30, 40 mg/l of alum) were also used in different salt dose to get the combined effect of salt and alum on rapid mixing coagulation. Rapid mixing coagulation is done at 300 rpm for 30 seconds. Thirty seconds is the optimum timing of alum mixing for rapid mixing coagulation (optimum Camp No=17430) which can be seen from Figure 5.2. Effect of varying alum and salt dose on turbidity has been shown in Figure 5.3. pH was always in the range, which was 6.5-7.6. Figure 5.3 shows that 485-730 mg/l of chloride is a critical range at different alum dose, where alum floc growth and breakage were

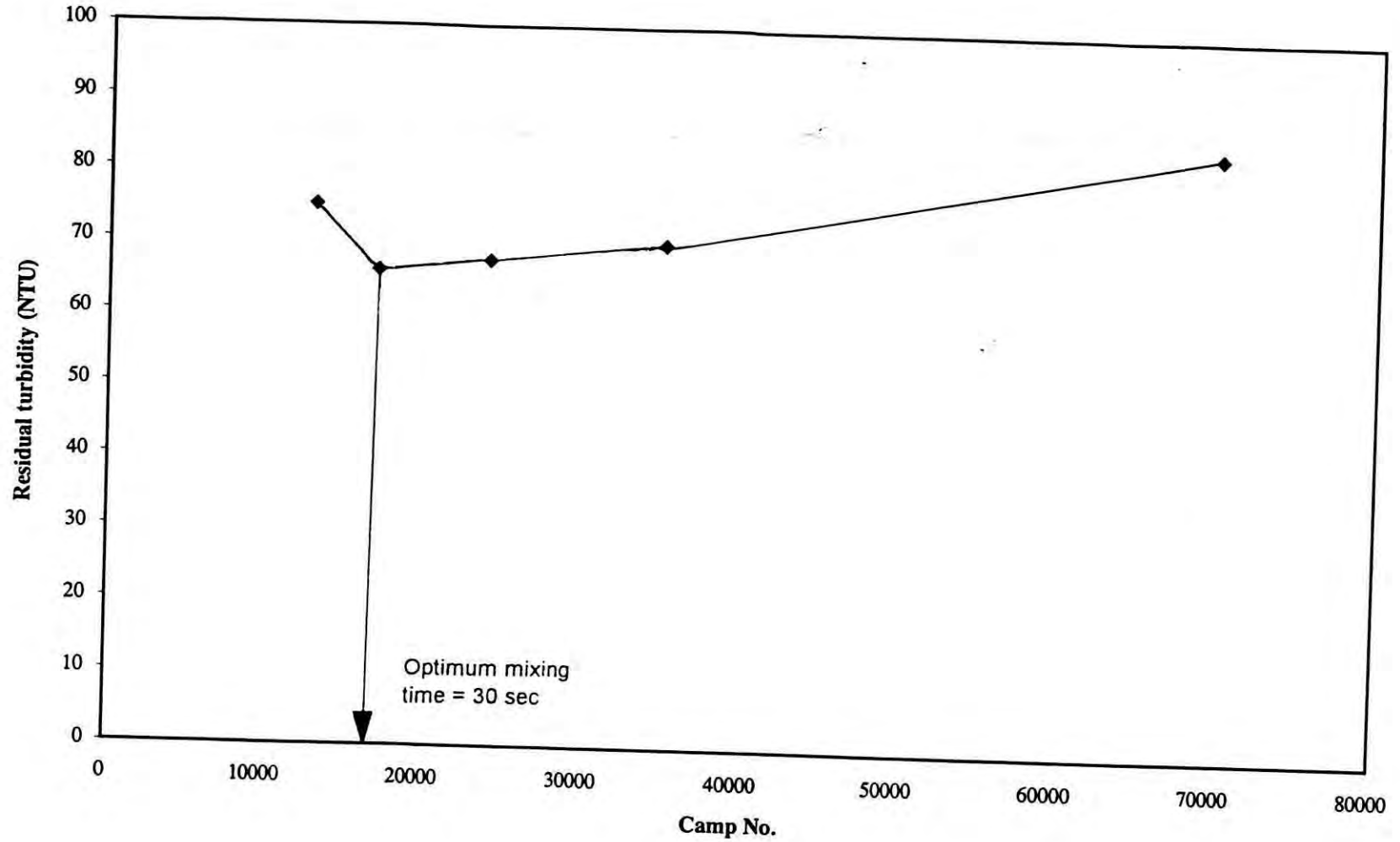


Figure 5.2: Measurement of optimum mixing time in the rapid mixing coagulation

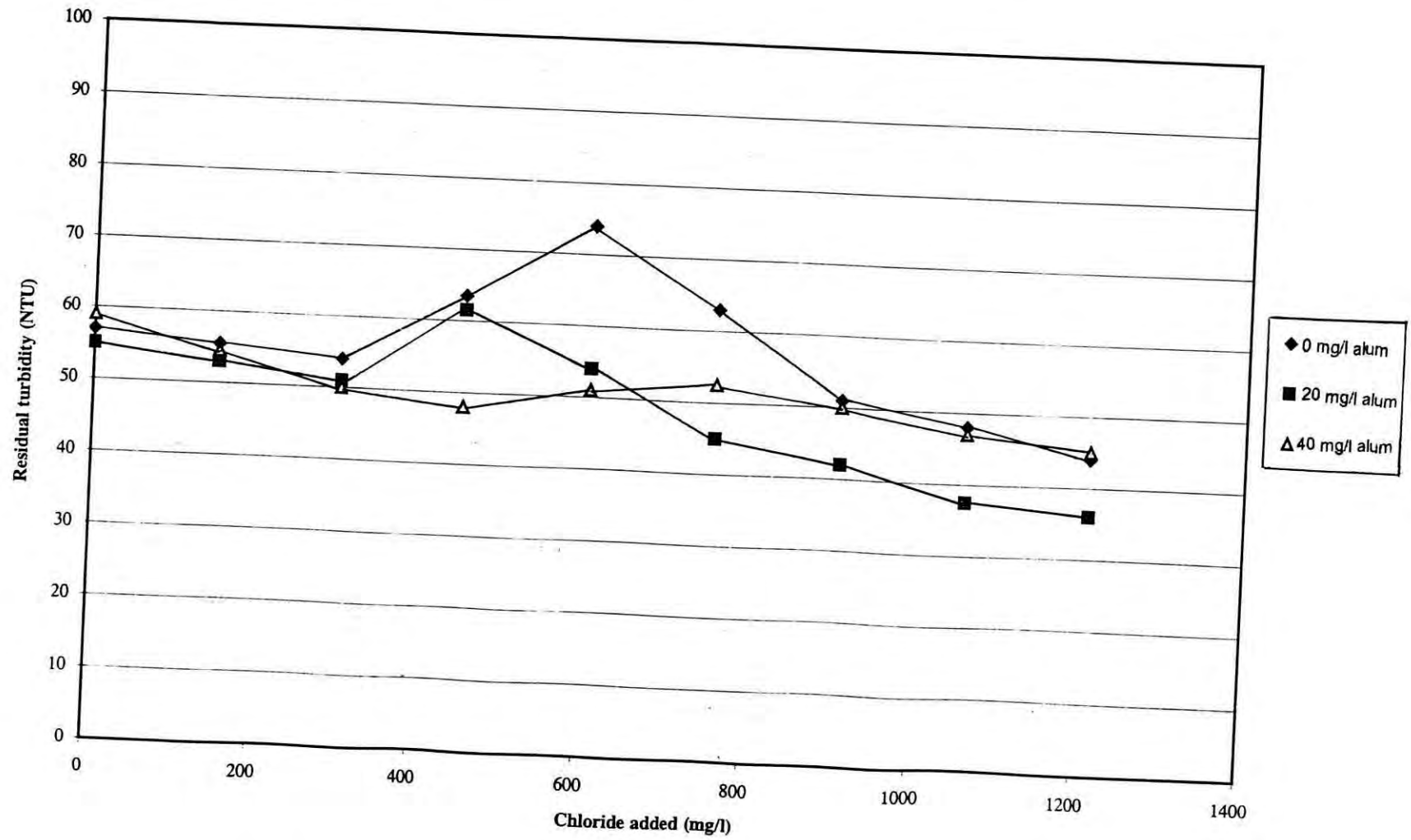


Figure 5.3: Effect of salt and alum dose on turbidity in the rapid mixing coagulation and sedimentation

observed. Residual turbidity was always above standard value (5 NTU) at any chloride dose, even at zero chloride. Effect of salt on rapid mixing coagulation has been shown in Appendix.

It was observed that G is very high in the rapid mixing coagulation (about 1000/sec) which breaks alum flocs. It is clear from Figure 5.3 that, rapid mixing is not suitable as a coagulation method at any salt and alum doses.

5.5 Influence of Salinity in the Slow Mixing Coagulation

In the slow mixing coagulation, 40 rpm for first 5 minutes and then 20 rpm for 10 minutes were used. In the first 5 minutes flocs are formed and then lower rpm helps in growth of more floc without disintegration. Lower rpm controls velocity gradient within limit.

pH, residual turbidity and conductivity were measured in the slow mixing coagulation for different chloride and alum doses. 400 mg/l of kaolin with 20 mg/l of alum dose have been selected as representative sample for different chloride doses. Upto 20,000 mg/l of added NaCl, no floc breakage was observed. Ionic loading doesn't have any effect on floc breakage in the slow mixing coagulation. Influence of chloride in slow mixing coagulation can be seen from Figure 5.4.

Figure 5.4 shows that residual turbidity were always below WHO guideline (10 NTU) for different alum and chloride doses. It is clear that chloride has no effect on slow mixing coagulation. When no alum was used, turbidity was always found above 40 NTU. pH was in between 6.7-7.2. Conductivity increases proportionately when salt is added, it can be seen in Appendix.

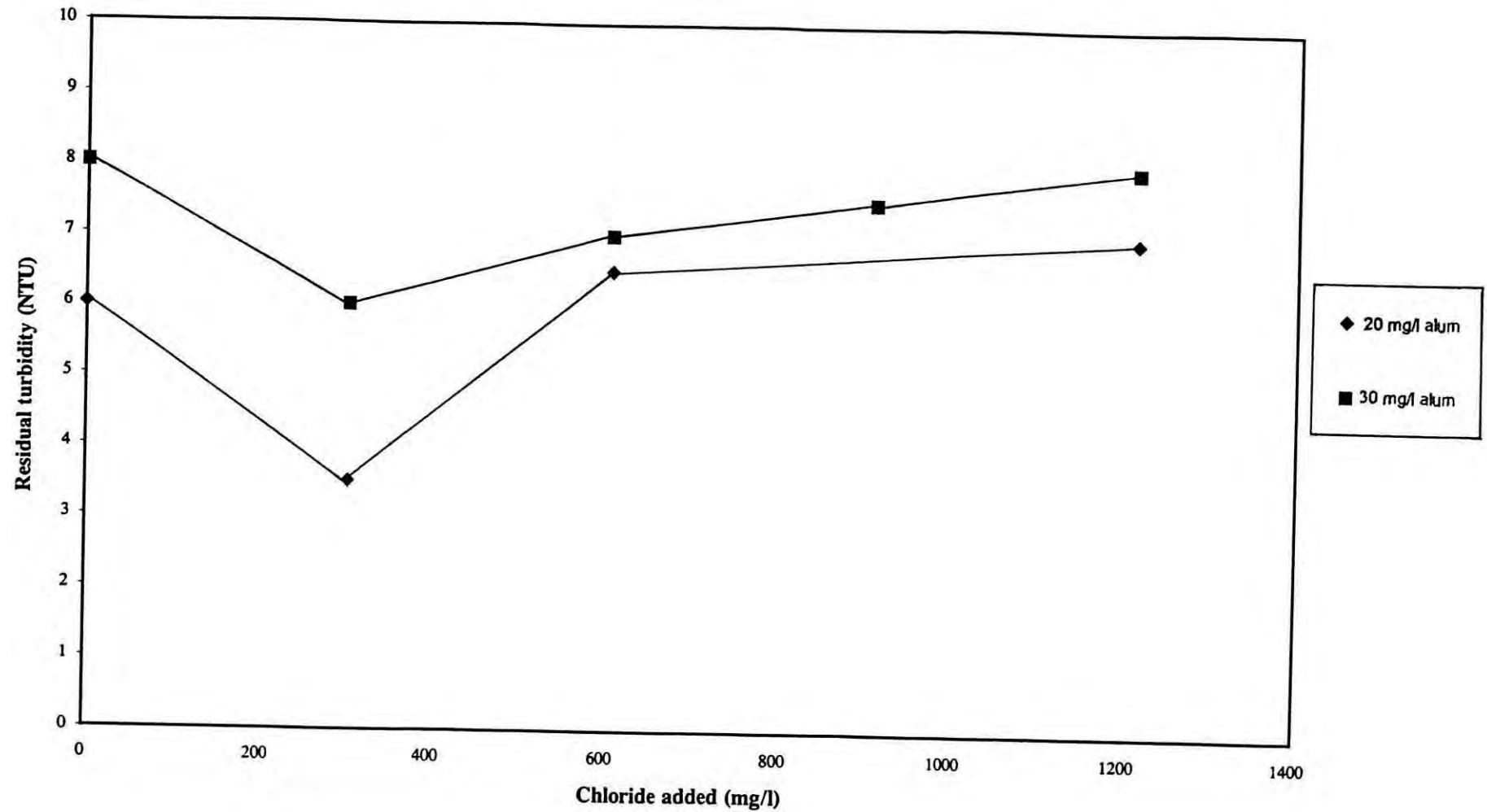


Figure 5.4: Effect of salt and alum dose on turbidity in the slow mixing coagulation and sedimentation

Floc regrowth was tested in varying salt by the following sequential steps:

- 40 rpm for 5 minutes
- 75 rpm for 15 seconds
- 20 rpm for 10 minutes

At 75 rpm for 15 seconds, flocs were broken due to sudden increase in rpm. But, 20 rpm for 10 minutes enhanced flock regrowth. The result can be seen in Appendix.

There might be a probability of floc breakage during slow mixing coagulation if revolution or camp number could be increased in varying salt. It has been tested by using 40 rpm for 15 minutes (Camp No. of 51300), but residual turbidity was always below 10 NTU. Results can be seen from Figure 5.5. It shows that both chloride and Camp no. don't have any effect on turbidity in the slow mixing coagulation.

5.6 Comparison Between Rapid and Slow Mixing Coagulation

Comparison of influence of salinity on rapid and slow mixing coagulation can be seen in Appendix. Rapid mixing's velocity gradient (G) is 1000/sec, which is about 20 times higher than that of slow mixing. This G value is much higher than tolerable G value (25/sec to 100/sec), mentioned in section 2.2. Slow mixing's G was about 50/sec which is allowable. And, energy dissipation (P) in the rapid mixing is about 1000 times than that of slow mixing. Very high values of G and P cause floc breakage in the rapid mixing coagulation. On the other hand, salinity has no influence on slow mixing coagulation. It is clear that only slow mixing coagulation is suitable during salinity.

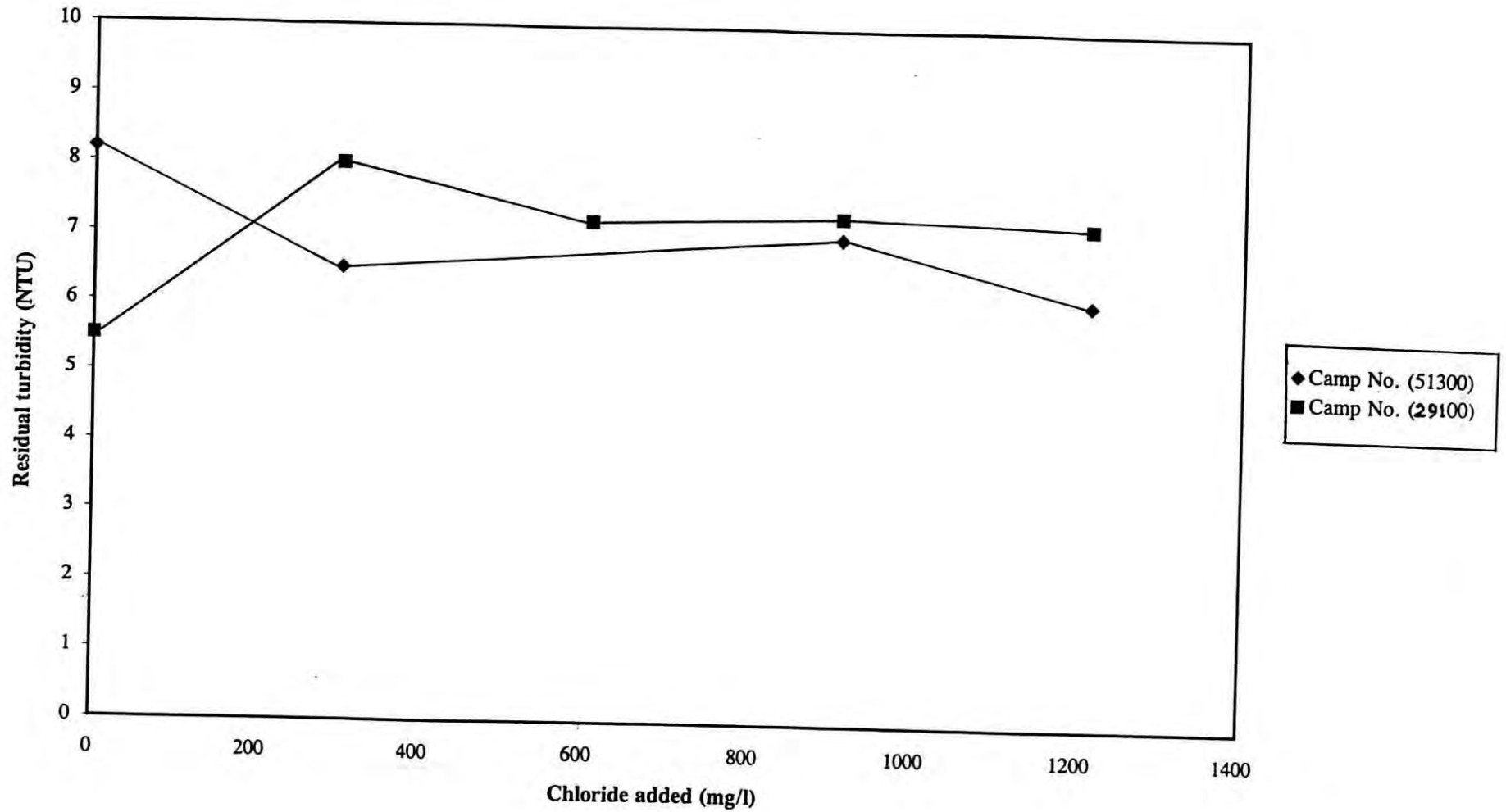


Figure 5.5: Comparison between Camp No. (51300) and Camp No. (29100) in slow mixing coagulation

CHAPTER SIX

PERFORMANCE OF A SLUDGE BLANKET CLARIFIER

6.1 Introduction

The chapter discusses on sludge blanket clarifier, its performance and controlling parameters. Sludge blanket clarifier works as a coagulation, sedimentation and filter media. These are discussed here. Controlling parameters of sludge blanket clarifier are discharge, sludge depth and angle of clarifier. Influence of salinity on its performance has also been discussed. A discharge-chloride relationship has also been established and shown in this chapter.

Water sample with 400 mg/l of kaolin and 20 mg/l of alum dose was used to flow into the clarifier. pH, residual turbidity, conductivity were measured at different points (2,3,4 and top) of clarifier. At start and final sludge depth, and initial floc fluidisation were measured for different tests. Flow at the inlet of clarifier for 0, 15, 30, 60 minutes were measured. Performance of clarifier has been estimated by measuring efficiency of clarifier from initial and residual turbidity of water at inlet and outlet of clarifier respectively for each test.

6.2 Controlling Parameters of Sludge Blanket Clarifier

Sludge blanket clarifier is used to remove turbid and colloid particles, i.e., alum floc. It works as a sedimentation basin, filter media and as a flocculator. Fair, et al (1967) stated velocity gradient (G) for a sludge blanket clarifier in the following way,

$$G = [(g/\nu) (S_s-1) (1-f_e) (h_2-h_1)/(C/Q)]^{1/2} \dots\dots\dots(6.1)$$

where, g is acceleration due to gravity, ν is kinematic viscosity, S_s is specific gravity of floc, f_e is relative pore space, (h_2-h_1) is flocculation zone, h_1 is sludge depth, C is capacity of clarifier and Q is discharge. Values of S_s and f_e were measured in the laboratory analysis. 40 ml sample of sludge has been taken in a beaker. The sludge was weighted and dry volume of floc was also measured. Experiment shows, $S_s = 1.09$ and $f_e = 0.60$ which can be seen from Table 6.1.

Table 6.1: Experimental values of specific gravity of the flocs (S_s) and relative pore space of the flocculation zone (f_e)

Volume of Sludge	Wt. of sludge	Volume of floc	Density of sludge, S_s	Porosity, f_e
40 ml	43.451 gm	16 ml	$(43.451/40)$ = 1.09 gm/cc	$((40-16)/40)$ = 0.6

Again, we know that $g = 981 \text{ cm/s}^2$, and angle of clarifier with horizontal (α) = 60° for used sludge blanket clarifier which is similar to Mohara's clarifier. Fair, et al (1967) expressed capacity of clarifier (C) as the following way,

$$C = \frac{\pi}{3} \cot^2 \alpha (h_2^3 - h_1^3) \dots\dots\dots(6.2)$$

Using $\alpha = 60^\circ$ for the used clarifier, C can be written as,

$$C = 0.35 * (h_2^3 - h_1^3) \dots\dots\dots(6.3)$$

Using the values of g , S_s , f_e and C in equation 6.1, we get;

$$G = \left[\frac{112.11 * \mathcal{J} * Q * (h_2 - h_1)}{\mathcal{M} * (h_2^3 - h_1^3)} \right]^{1/2} \dots\dots\dots(6.4)$$

Equation 6.4 clarifies that, velocity gradient depends on \mathcal{M} , \mathcal{J} , h_2 , h_1 , and Q . For normal condition (without salt condition) \mathcal{M} and \mathcal{J} are constant. Hence, for normal condition, it is clear that;

$$G = f(Q, h_1, h_2)$$

For varying salinity, velocity gradient can be written;

$$G = f(\mathcal{J}, \mathcal{M}, Q, h_1, h_2)$$

Using the value of C from equation 6.2 for any angle of clarifier, G can be simplified as,

$$G = \left[\frac{981 * 0.1 * 0.4 * \mathcal{J} * Q * (h_2 - h_1)}{\mathcal{M} * \cot^2 \alpha (h_2^3 - h_1^3)} \right]^{1/2} \dots\dots\dots(6.5)$$

Equation 6.5 clarifies that, velocity gradient depends on α , \mathcal{J} , \mathcal{M} , h_2 , h_1 , and Q . For normal condition (without salt condition) \mathcal{M} and \mathcal{J} are constant. Hence, for normal condition, it is clear that;

$$G = f(Q, \alpha, h_1, h_2)$$

For varying salinity, velocity gradient can be written;

$$G = f(\mathcal{J}, \mathcal{M}, Q, \alpha, h_1, h_2)$$

Velocity gradient (G) is the key parameter in growth of alum floc, hence G controls clarifier's performance. From the above expressions, it is clear that angle of clarifier with horizontal, discharge, sludge depth and flocculation zone (h_2-h_1) are the major controlling parameters on the performance of a sludge blanket clarifier at normal condition. Influence of discharge, sludge depth and angle of clarifier on clarifier's performance have been discussed in this chapter.

6.3 Influence of Sludge Depth

Different tests on the performance of a sludge blanket clarifier were done at constant discharge in the clarifier to measure the influence of sludge depth. Clarifier's shape was fixed (similar to Mohara's clarifier) in these experiments. Sludge blanket depth was increased upto 17.5 cm. Maximum efficiency of sludge blanket clarifier obtained was below 90% at 12-15 cm sludge depth while it was about 99% at 17.5 cm sludge depth. Figure 6.1 shows that efficiency of clarifier is higher when sludge depth is increased. Increased depth increases filtration zone and performance of clarifier is improved.

6.4 Influence of Discharge

A concentrated force has been developed at the inlet of clarifier while inflow. The force (F) can be expressed,

$$\begin{aligned}
 F &= 0.5 * m * v^2 = 0.5 * \text{density} * \text{volume} * v^2 \\
 &= 0.5 * \pi * r^2 * h * \rho * v^2
 \end{aligned}$$

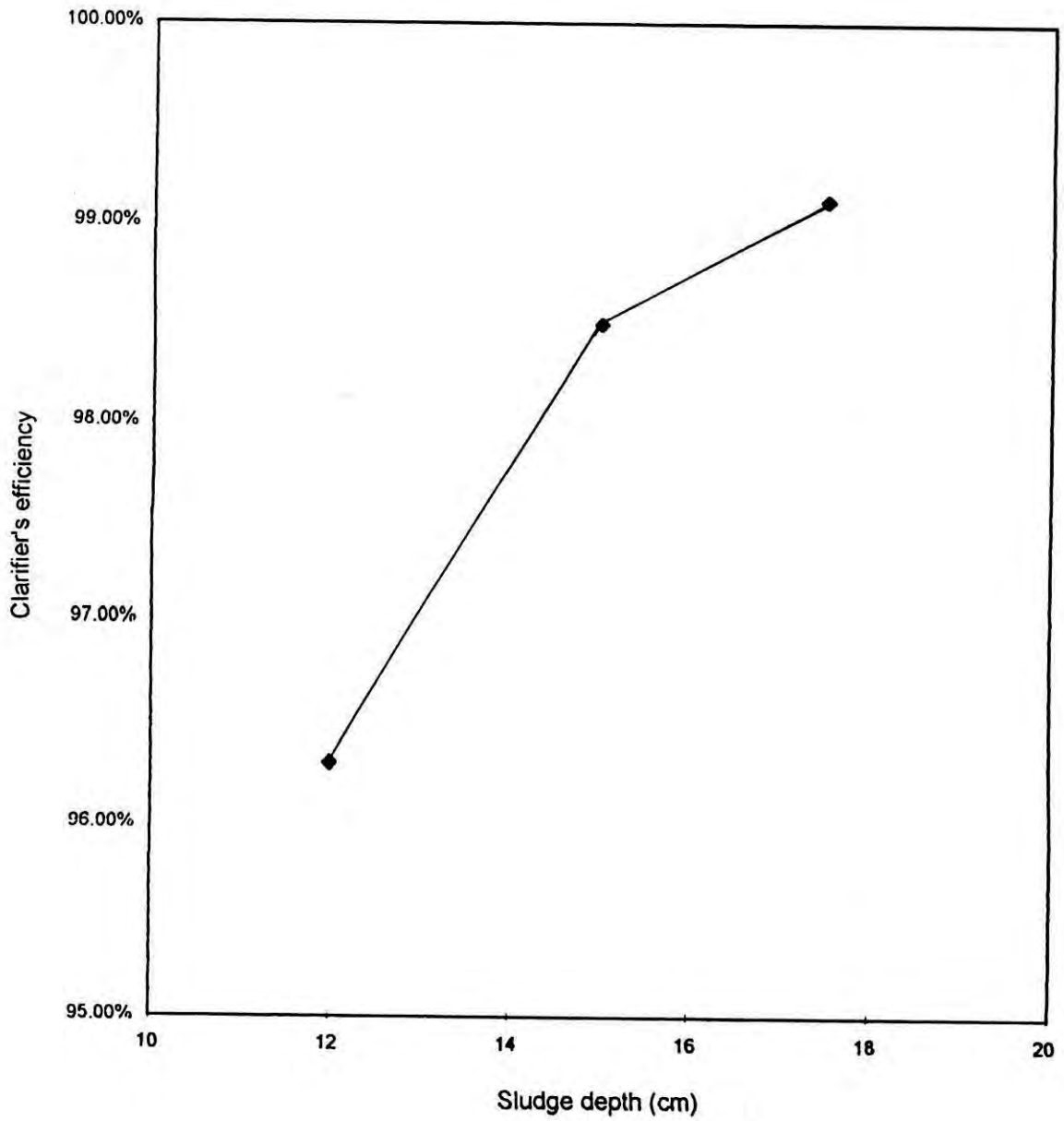


Figure 6.1: Relation between clarifier's efficiency with sludge depth
(At constant flow of $535 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge)

where, m is mass of water entering into the clarifier, r is radius of water entering into the clarifier, h is unit length, v is velocity of water at the bottom of clarifier and ρ is density of water. F depends on r , h , ρ and v . In the recent study, $h = 1$ cm and $r = 0.4$ cm. Hence, F can be written as;

$$F = 0.5 * \pi * r^2 * h * \rho * v^2 = 0.251 * \rho * v^2$$

$$F = f(\rho, v)$$

At without salt condition $\rho_{20^{\circ}\text{C}} = 1.507$ gm/cc, which was measured in the laboratory. Density for different chloride dose can be seen from Appendix. Using the density value, F can be simplified,

$$F = 0.379 * v^2$$

Velocity of water (v) at the bottom of clarifier can be measured from velocity of inlet water (u) at clarifier in the following way;

$$v^2 = u^2 + 2 * g * s$$

where, $g = 981$ cm/s², $s = (50.8$ cm PVC pipe $- 17.5$ cm sludge depth) $= 33.3$ cm. v can be written as,

$$v^2 = u^2 + 65335$$

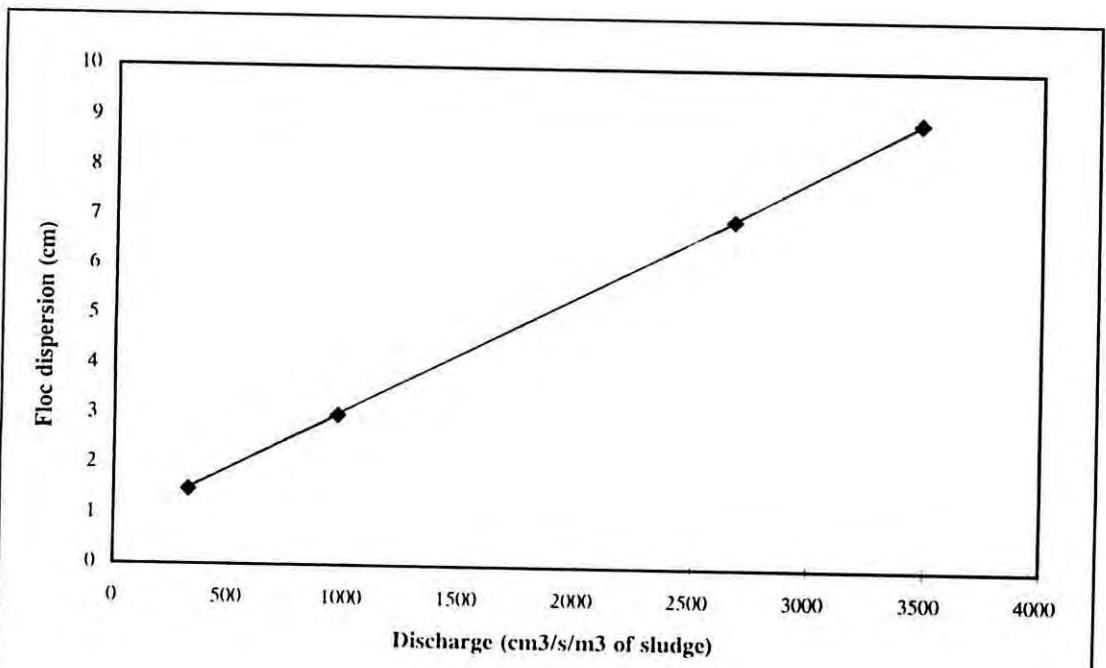
u can be measured from discharge (Q) using continuity equation, i.e., u is proportional to Q. Hence, v is proportional to discharge (Q). F can be simplified as;

$F = f(Q)$ at without salt condition, and during salinity

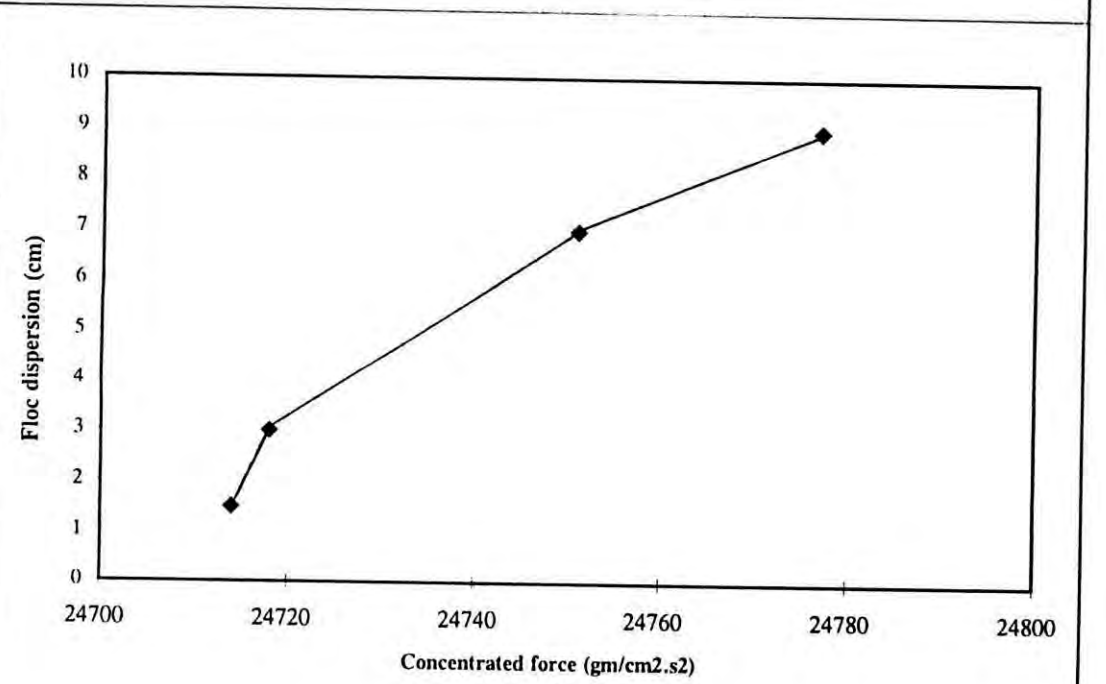
$$F = f(f, v) = f(f, Q)$$

In the clarifier, this concentrated force (F) is proportional to discharge (Q). F controls initial impact of Q in the clarifier. Initial impact means dispersion of floc at inlet of clarifier due to sudden fall of water into the clarifier. Increased Q helps in increasing F, which enhances initial dispersion of floc (x). Initial dispersion of floc increases initial turbidity at entrance of flocculation zone in the clarifier. Relation between Q vs. x and F vs. x can be seen from Figure 6.2. It shows that Q is the main controlling parameter on the performance of a clarifier at constant sludge depth. Controlled Q controls x, and decreases upflow velocity of water in the clarifier, which improves sedimentation of alum floc.

Optimum discharge range for good performance of clarifier is required, and was measured at without salt condition. Sludge depth was constant (17.5 cm) and clarifier's shape was also fixed (similar to Mohara's clarifier) while measuring optimum discharge. Residual turbidity was about 7.5 NTU at the optimum discharge. Optimum discharge range was about 134 to 936 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge, which can be seen from Figure 6.3. Here pH was always in the range. Critical discharge has been considered when residual turbidity was about 5 NTU. It was found about 670 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge.



(a)



(b)

Figure 6.2: (a) Relation between discharge (Q) and dispersion of floc (x), and (b) relation between concentrated force (F) and dispersion of floc (x) on the clarifier's performance

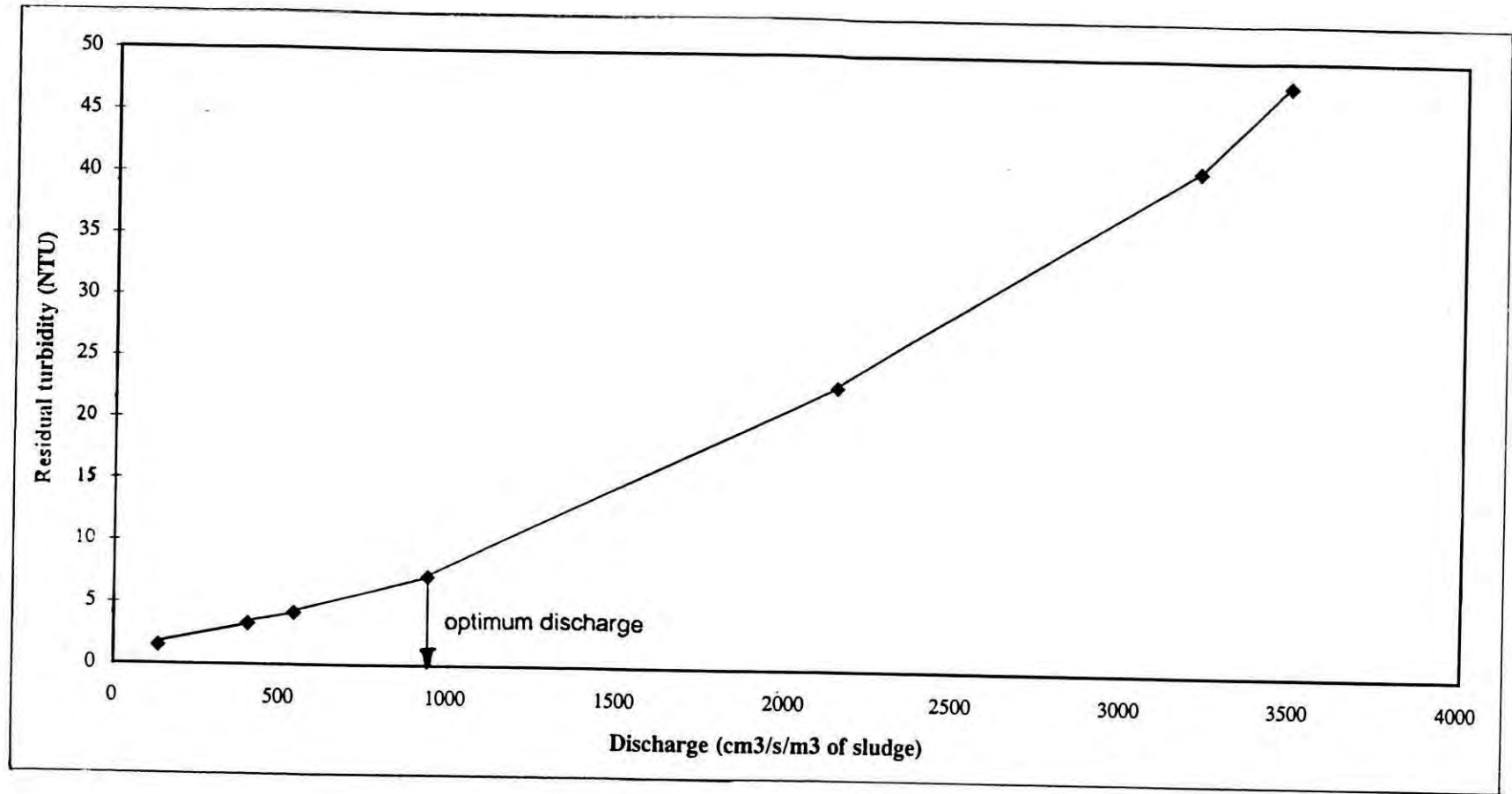


Figure 6.3: Measurement of optimum discharge in the sludge blanket clarifier

Maximum allowable discharge in the clarifier used at without salt condition was $1.75 \text{ cm}^3/\text{s}$. Velocity at the inlet of clarifier (u) was about 3.48 cm/s for the maximum discharge. Hence, v would be;

$$v^2 = (3.48)^2 + 65335, \text{ i.e., } v = 255.63 \text{ cm/s.}$$

255.63 cm/s is the maximum allowable velocity at the bottom of clarifier. Maximum tolerable concentrated force would be,

$$F = 0.379 * (255.63)^2 = 24764 \text{ c.g.s. unit}$$

$24764 \text{ gm.cm}^2/\text{s}^2$ (c.g.s. unit) is the limiting concentrated force at 17.5 cm sludge depth above which clarifier used in the laboratory can't perform well.

6.5 Influence of Change in Angle of Clarifier

From equation 6.5, G can be written as;

$$G = f(\mathcal{J}, \mathcal{M}, Q, \alpha, h_1, h_2)$$

At constant discharge (Q) and at without salt condition, G can be simplified as;

$$G = f(\alpha, h_1, h_2)$$

Angle of clarifier with horizontal (α), sludge depth (h_1) and h_2 are the main controlling parameters when shape has been changed. Influence of angle change of clarifier has been studied by providing another clarifier with higher

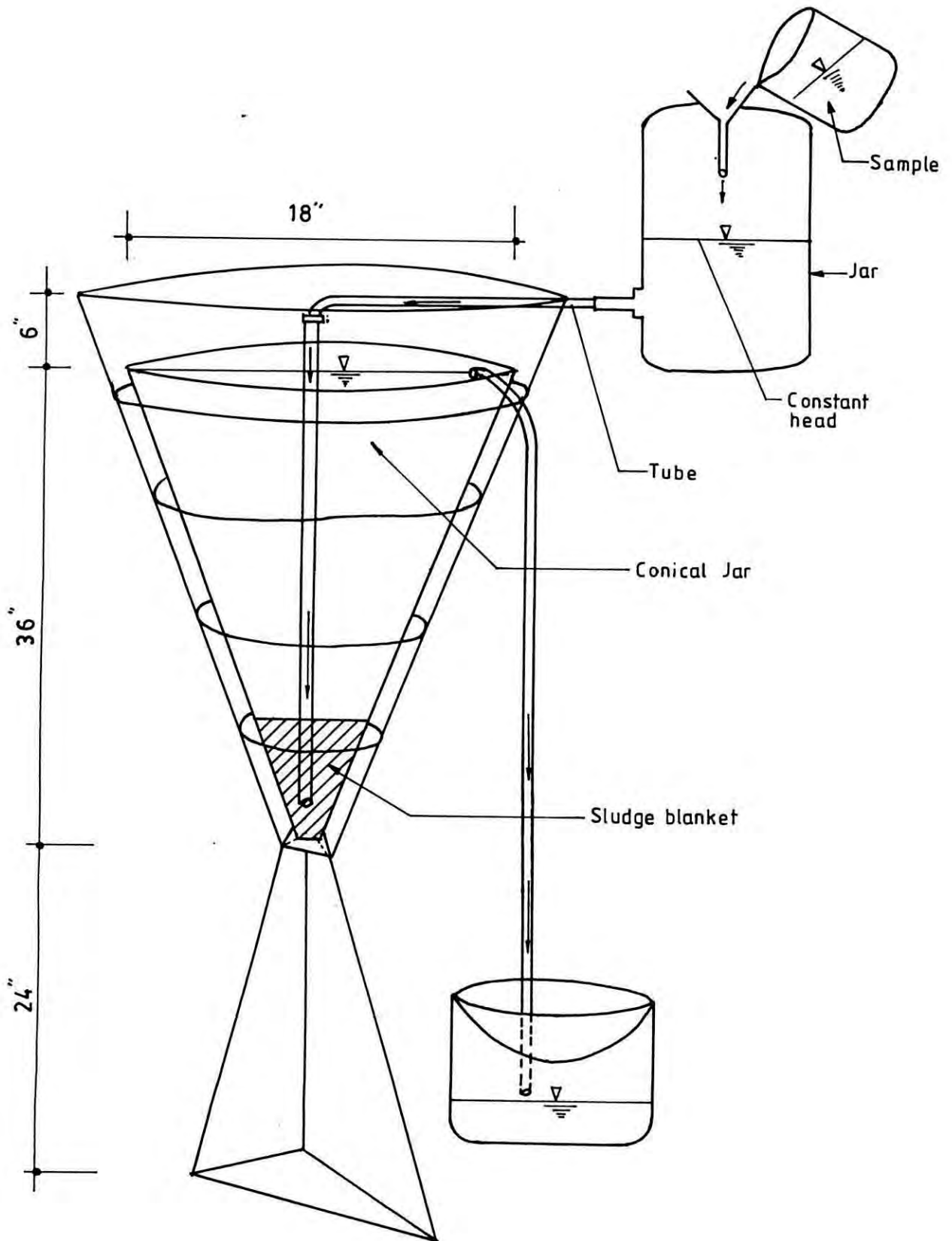


Figure 6.4: Continuous flow in the sludge blanket clarifier with higher angle

angle (75°), which can be seen from Figure 6.4. Test has been done at constant optimum discharge and at without salt condition. Sludge depth was constant during the test which was about 17.5 cm. Efficiency of the clarifier was about 92%, which is not satisfactory comparing previous clarifier with lower angle (60°). Result has been given in Appendix. Influence of change in angle of clarifier shows that, performance of clarifier increases at lower angle provided angle is in between 45° to 65° (See section 2.6).

6.6 Performance of Sludge Blanket Clarifier as Filter Media

Sludge blanket clarifier works as a filter media through sludge. Without sludge only flocculation and sedimentation are occurred in the clarifier. Sludge provides filtration. Effect of sludge on clarifier's performance has been tested at without sludge condition. Test has been done at optimum discharge range and at without salt condition. Efficiency was found about 82 to 84% which is far below than the normal sludge condition. The result has been shown in table 6.2.

Table 6.2 : Performance of clarifier at with and without sludge condition

Discharge	Sludge condition	Initial turbidity	Residual turbidity	Efficiency
4.00 cm ³ /s	With sludge	456 NTU	24 NTU	93.22%
	Without sludge		79 NTU	82.70%
1.33 cm ³ /s	With sludge	259 NTU	8 NTU	97.00%
	Without sludge		40 NTU	84.00%

Table 6.2 shows that with-sludge condition is good on performance of clarifier. Sludge serves as filter media and turbidity removal efficiency increases due to presence of sludge. Sludge blanket clarifier works as coagulation, filtration and

sedimentation unit. Without sludge, only coagulation and sedimentation are occurred. Hence, sludge is required to remove alum floc.

6.7 Limitations of Sludge Blanket Clarifier

Sludge blanket clarifier has combined effect of flocculation, filtration and sedimentation. Its performance largely depends on optimum discharge and sludge depth. Experience reveals some limitations on the performance of a sludge blanket clarifier. They are:

- Air bubbles form at the inlet surface of water in clarifier while flow occurs, which may disperse floc. Na_2SO_3 can be used to remove bubbles.
- To avoid initial dispersion of floc, flow has to be increased slowly at the beginning. Then a constant rate of flow in the clarifier would be achieved without disturbing sludge blanket. It was done for each test in the laboratory analysis.
- A concentrated force occurs at the inlet of the clarifier while inflow, which increases turbidity of water and disperses floc in the water. As a result, sludge blanket has become fluidised initially at high discharge.

6.8 Addition of Salt on Clarifier's Performance

NaCl was added to check the performance of the sludge blanket clarifier during salinity. 400 mg/l of kaolin with 20 mg/l of alum samples were used at 0 to 6060 mg/l of chloride for different discharges.

Equation 6.5 shows that,

$$G = f (J, M, \alpha, Q, h_1, h_2)$$

h_2 is dependent on Q . At constant α , h_1 ; G can be written as,

$$G = f(\mathcal{J}, \mathcal{M}, Q)$$

$$G = f(\text{Salinity, Discharge})$$

6.8.1 Effect of salt at constant discharge:

Residual turbidity increases when chloride is added for any fixed discharge in the clarifier. Salt is the controlling parameter on the performance of a sludge blanket clarifier during salinity at constant discharge. It can be seen from Figure 6.5. From two fixed discharges, i.e., 134 and 2144 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge, it was found that, salt makes clarifier's performance worsen. Increased salt increases density of water, and hence concentrated force is also increased. Dispersion of initial floc is increased due to increased force. pH was found in between 6.7-7.4.

6.8.2 Effect of discharge at constant chloride:

Sludge blanket clarifier's performance is influenced by salinity. At the fixed chloride, it was observed that discharge is the controlling parameter. For 606 mg/l of chloride value and at 3484 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge discharge residual turbidity was found 40 NTU turbidity. And at 134 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge, residual turbidity was 1.58 NTU while 2144 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge gives 24 NTU residual turbidity at the same chloride dose. It can be seen from Figure 6.6. Figure 6.6 shows that at lower discharge sludge blanket performs well during salinity. Discharge has an optimum range for good performance even in salinity. This optimum range is 134 to 936 $\text{cm}^3/\text{s}/\text{m}^3$ of sludge, can be seen from contour

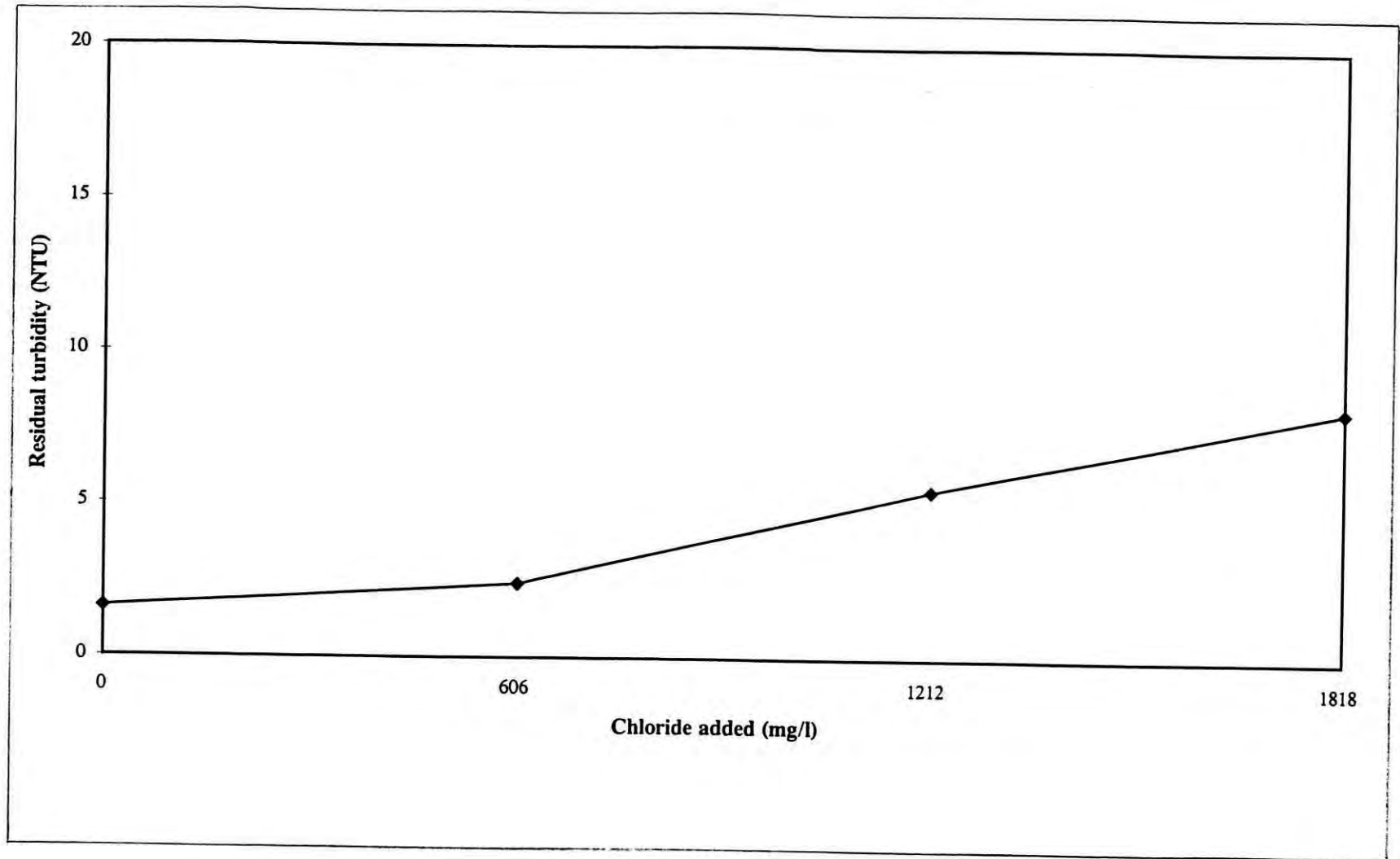


Figure 6.5: Influence of chloride on the sludge blanket clarifier at constant discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge

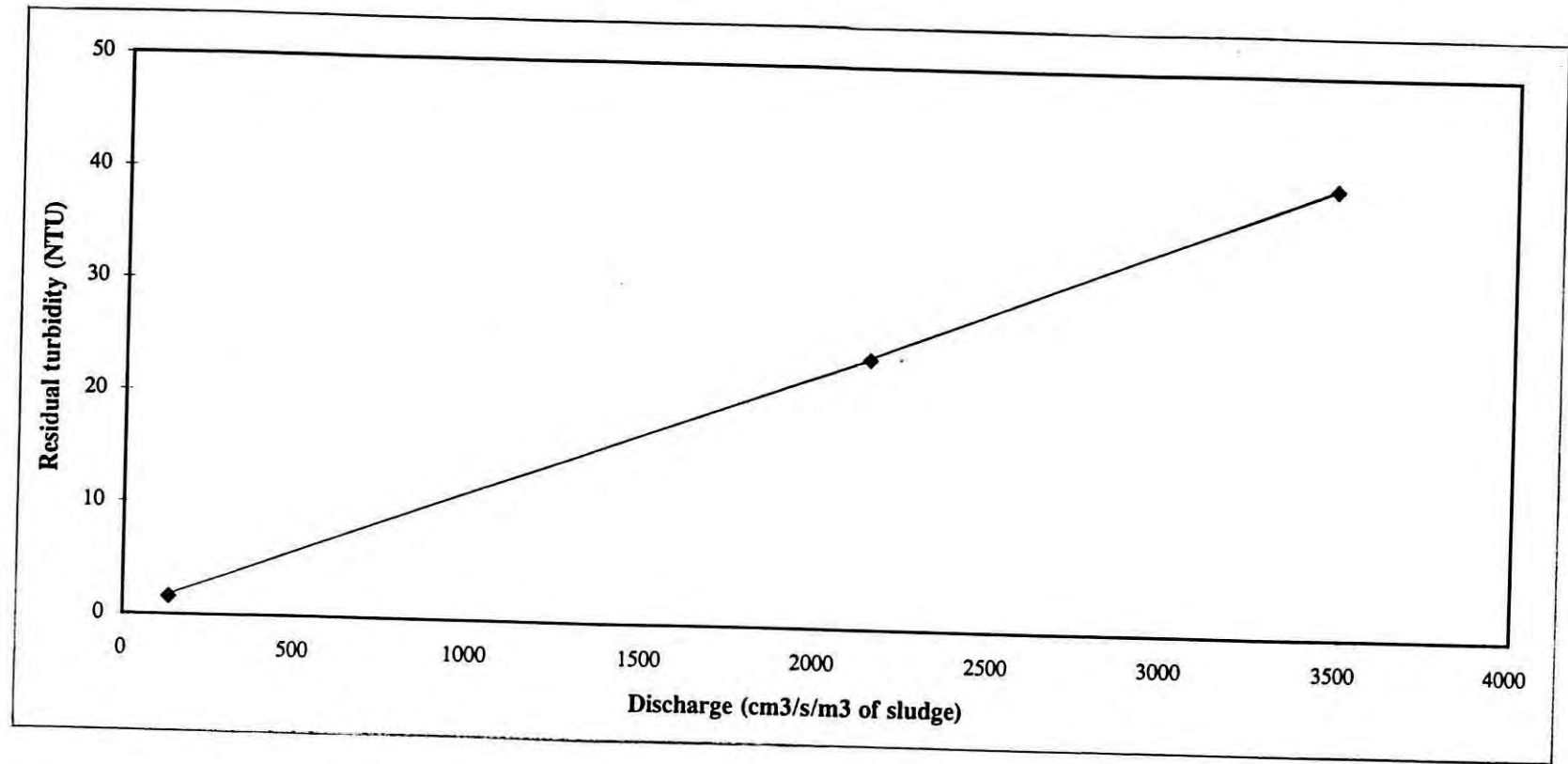


Figure 6.6: Influence of discharge in the sludge blanket clarifier at 606 mg/l of chloride

map of residual turbidity for different chloride and discharge (Figure 6.7). Figure 6.7 shows that, both discharge and chloride have a maximum limit upto which clarifier used in the laboratory can perform well.

Relation between chloride and discharge for good performance of clarifier as individual treatment unit has been established which can be seen from Table 6.3. Residual turbidity was considered below 10 NTU for good performance of clarifier. 10 NTU is the allowable turbidity for Bangladesh.

Table 6.3: Discharge-chloride relationship for good performance of sludge blanket clarifier (Allowable residual turbidity = 10 NTU)

Chloride value (mg/l)	Allowable discharge in the clarifier used, cm ³ /s (from Figure 6.7)	Maximum tolerable discharge per unit volume of sludge (cm ³ /s/m ³ of sludge)
0	1.75	936
500	1.67	893
1000	1.60	856
1500	1.50	802
2000	1.33	711
2500	1.00	535
3000	0.63	337
3400	0.15	80
4000	----	----
5000	----	----

Mohara Treatment Plant has filtration unit after clarifier unit. Removal efficiency of filtration unit of the plant in removing turbidity was about 80-85% (see Table 4.6). 25 NTU has been chosen as allowable turbidity for good performance of clarifier at Mohara. This flexibility of residual turbidity was

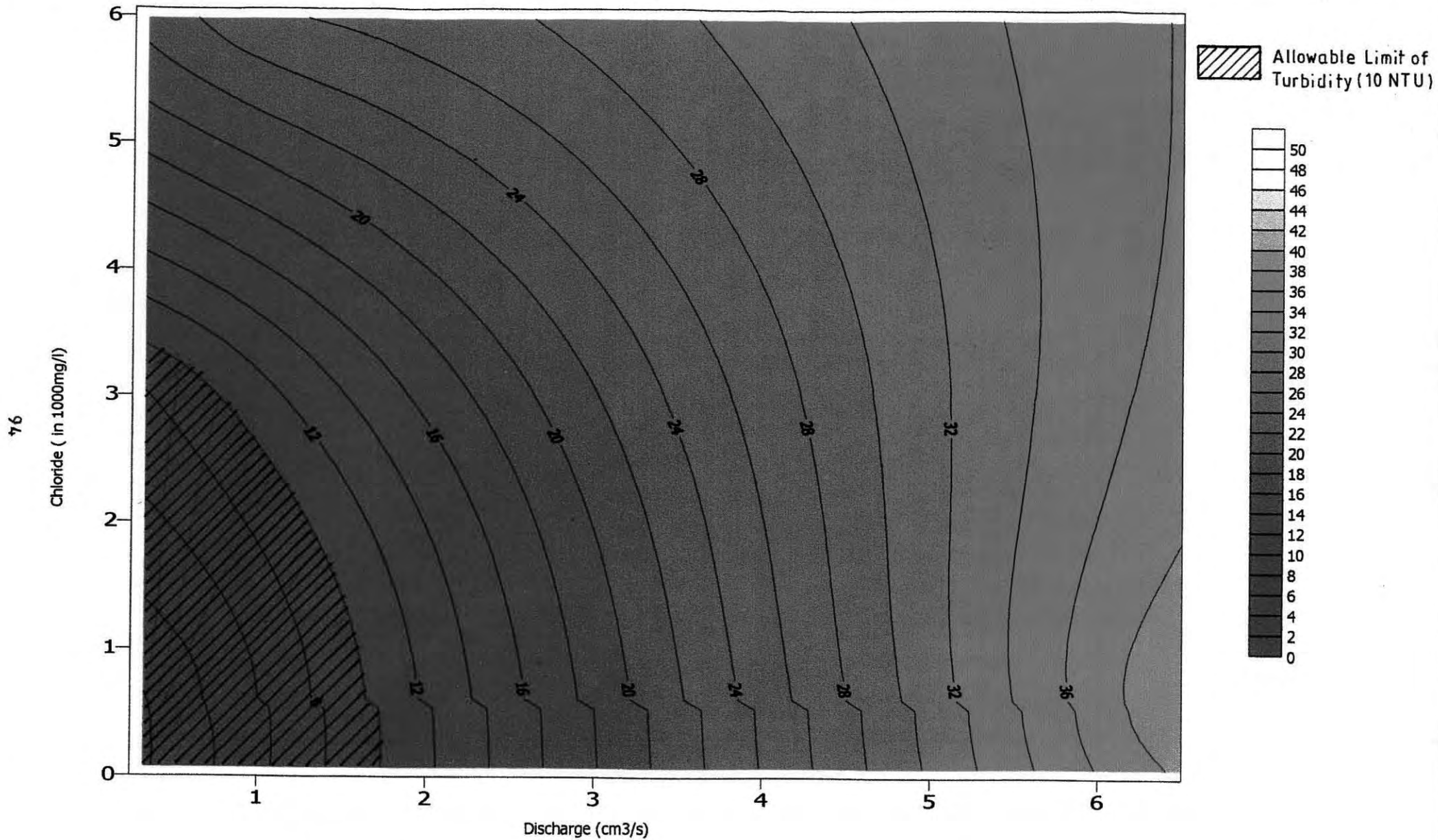


Figure 6.7: Contour of allowable residual turbidity at different discharge and chloride dose for the clarifier used in the laboratory
(At 17.5 cm sludge depth, angle of clarifier 60° and volume of sludge 0.00187 m³)

possible because of presence of filtration unit after clarifier. Allowable contour of residual turbidity for the clarifier of Mohara can be seen from Figure 6.8. Relation between allowable chloride and discharge for good performance of clarifier at Mohara has been established, which can be seen from Table 6.4. Tolerable discharge at the clarifier of Mohara has been measured per unit volume of sludge from discharge of the clarifier used in the laboratory. Table 6.4 shows maximum allowable chloride is 6800 mg/l at minimum discharge of 80 cm³/s/m³ of sludge, while maximum allowable discharge is 2219 cm³/s/m³ of sludge at minimum chloride of 500 mg/l for Mohara Treatment Plant. Normal discharge at individual clarifier of Mohara is about 43400 cm³/s and volume of individual clarifier is 207 m³.

Table 6.4: Allowable discharge-chloride relationship for sludge blanket clarifier of Mohara (Allowable residual turbidity = 25 NTU)

Chloride value (mg/l)	Allowable discharge, cm ³ /s (from Figure 6.8)	Maximum tolerable discharge per unit volume of sludge at clarifier of Mohara (cm ³ /s/m ³ of sludge)
0	4.20	2246
500	4.15	2219
1000	3.95	2112
1500	3.90	2086
2000	3.85	2059
2500	3.80	2032
3000	3.75	2005
4000	3.30	1765
5000	2.60	1390
6000	0.80	428
6800	0.15	80
7000	----	----

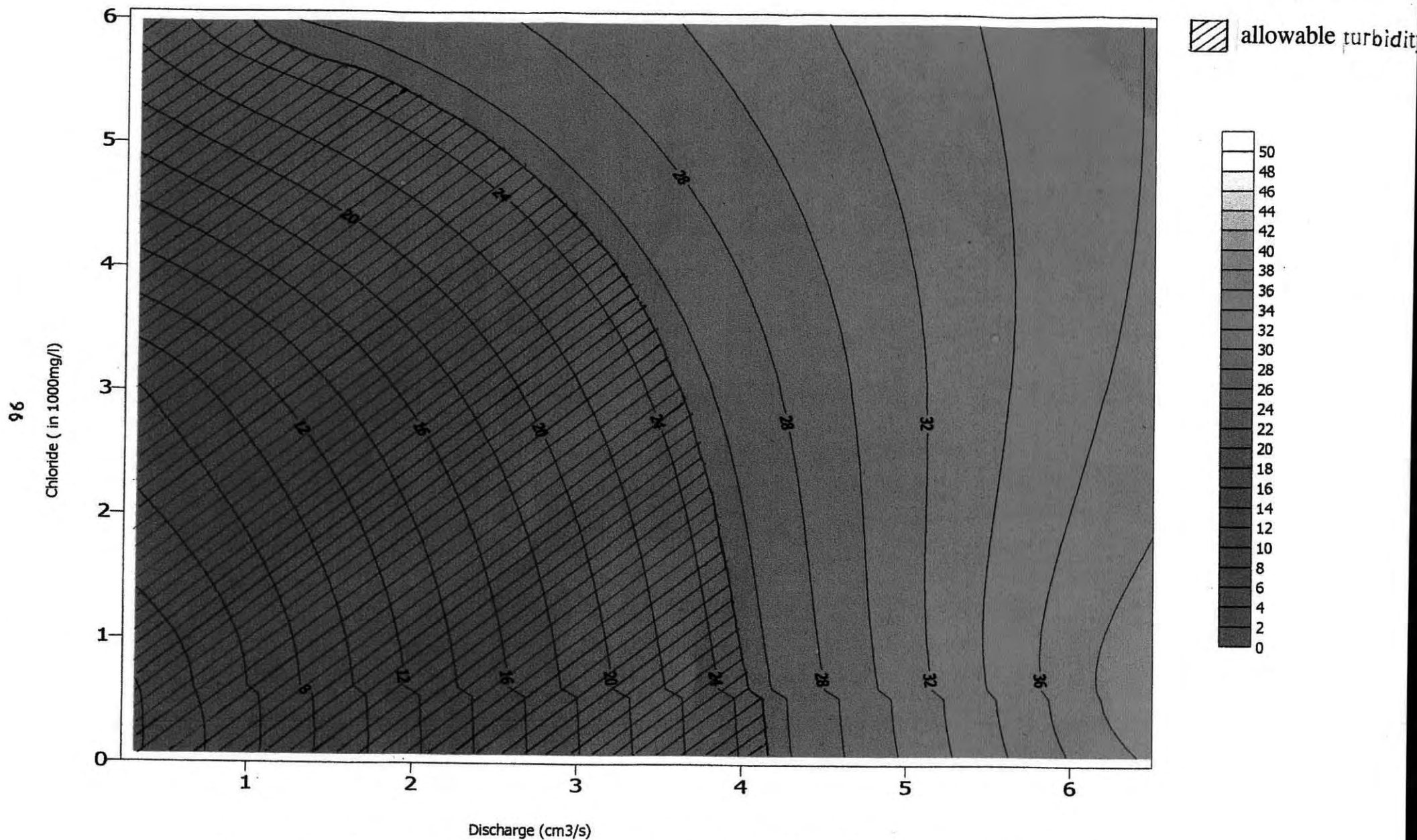


Figure 6.8: Contour of allowable residual turbidity for the clarifier of Mohara (Discharge measured at 0.00187 m³ of sludge from the clarifier used in the laboratory)

6.8.3 Measuring critical salinity value:

Sludge blanket clarifier tolerates 3400 mg/l of chloride at minimum discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge, which can be seen from Figure 6.9. Above 3400 mg/l of chloride, there is a sudden increase in residual turbidity for varying chloride. 3400 mg/l of chloride is the transition value of chloride for allowable performance of clarifier during salinity.

6.8.4 Measuring tolerable discharge at Mohara:

Sludge blanket clarifier of Mohara tolerates maximum $2219 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge at minimum chloride of 500 mg/l (see Table 6.4). Actual volume of sludge at clarifier of Mohara is required to get maximum tolerable discharge at minimum chloride. Percentage of tolerable discharge would be measured from normal discharge ($43400 \text{ cm}^3/\text{s}$) for individual clarifier at Mohara.

6.8.5 Limiting chloride from limiting concentrated force:

Limiting concentrated force was found 24764 c.g.s. unit at 17.5 cm of sludge depth for the clarifier used in the laboratory (see section 6.4). Limiting chloride has been measured from limiting concentrated force at constant discharge of $1.00 \text{ cm}^3/\text{s}$, which can be seen from Table 6.5.

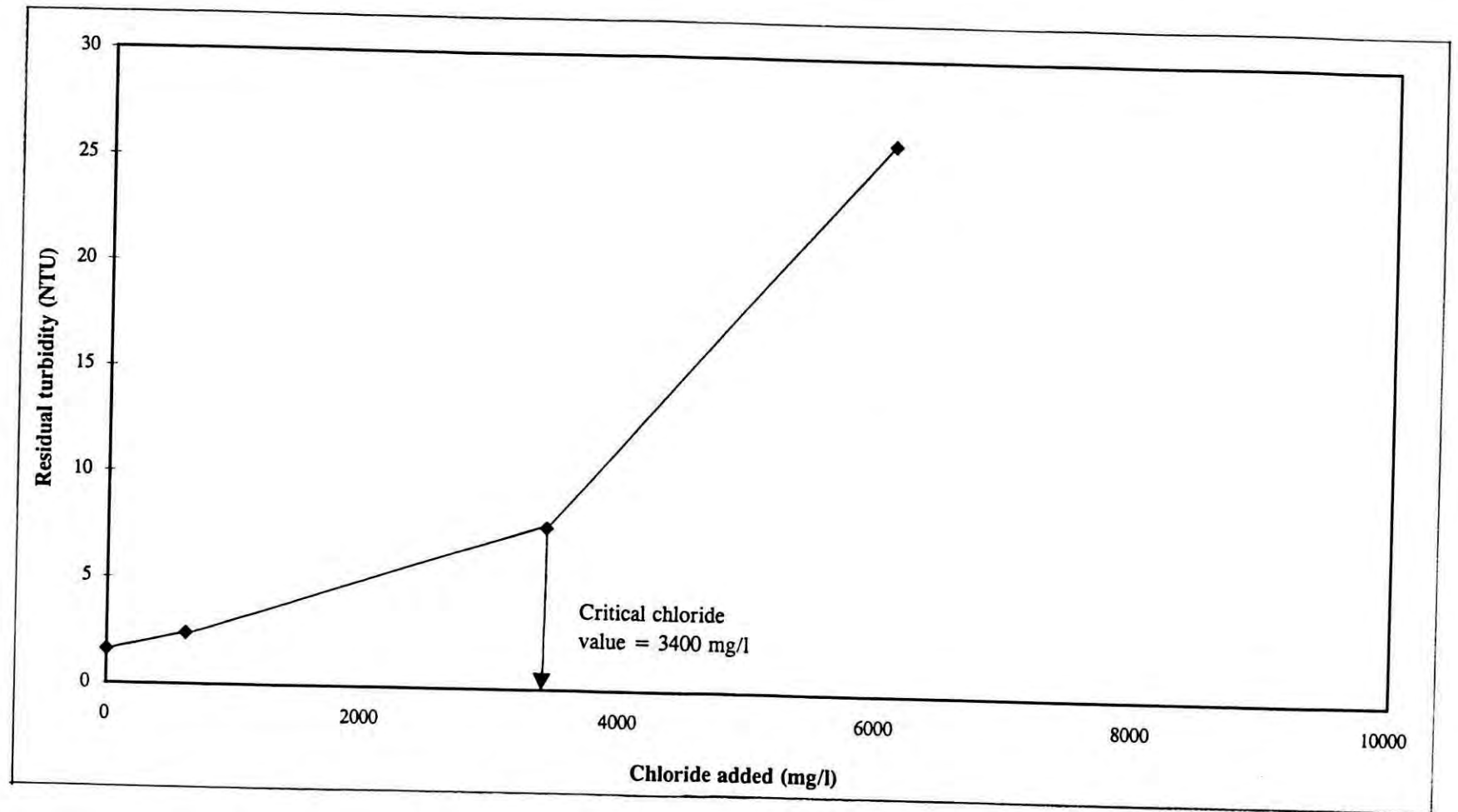


Figure 6.9: Measurement of critical chloride in the sludge blanket clarifier at $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge

Table 6.5: Effect of chloride on concentrated force at constant discharge of 1.00 cm³/s

Chloride (mg/l)	$\int_{20^{\circ}\text{C}}$ (gm/cc)	Discharge, Q (cm ³ /s)	u (cm/s)	v (cm/s)	Concentrated force, F (c.g.s. unit)
0	1.507	1.00	1.99	255.614	24715
500	1.509	1.00	1.99	255.614	24748
1000	1.510	1.00	1.99	255.614	24764
1200	1.5108	1.00	1.99	255.614	24777

Table 6.5 shows that at 1000 mg/l of chloride, limiting concentrated force were obtained. Again, at different discharge (within range), limiting concentrated force was also found at 1000 mg/l of chloride. It can be seen from Appendix. Hence, 1000 mg/l is the limiting chloride for limiting concentrated force.

6.8.6 Turbidity and time relationship:

A study has been done to measure residual turbidity and time relationship at different chloride. It has been shown in Appendix. It shows that residual turbidity decreases when time increases. Higher time means higher detention period in the clarifier. It took about 4 hours to get below 5 residual turbidity at the lower depth of clarifier at different chloride.

6.8.7 Comparison between slow, rapid mixing coagulation and clarifier:

Effect of salt on slow and rapid mixing coagulation and on sludge blanket clarifier has been studied. Comparison has been shown in Appendix.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The study had four major parts: performance study of Mohara Treatment Plant, salinity influence study on slow and rapid mixing coagulation and on sludge blanket clarifier. It has the following outcomes:

- ◆ Performance of the clarifier decreases with increasing salt content at any discharge and performance of clarifier also decreases with increasing discharge at any chloride level in water. Limiting chloride was found 1000 mg/l from limiting concentrated force of 24764 c.g.s. unit at 17.5 cm sludge depth for the clarifier used in the laboratory.
- ◆ Maximum 3400 mg/l of chloride can be allowed at minimum discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge and maximum discharge of $893 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge can be allowed at minimum 500 mg/l of chloride for good performance of a sludge blanket clarifier during salinity. Again, maximum tolerable discharge for clarifier of Mohara during salinity was about $2219 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge at minimum 500 mg/l of chloride, while maximum tolerable chloride was about 6800 mg/l at minimum discharge of $80 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge.
- ◆ Discharge, angle of clarifier with horizontal and sludge depth are the major controlling parameters of a sludge blanket clarifier. Optimum discharge was upto $936 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge and optimum sludge depth was 17.5 cm. Performance of clarifier is good when discharge and sludge depth are in the optimum range. Angle of clarifier in range (45° to 65°) provides good performance.

- ◆ Overall performance of the Mohara Treatment Plant is satisfactory. Efficiency of sedimentation unit in removing turbidity is about 20-25% and for clarifier unit is about 85-95% at the plant.
- ◆ No floc breakage was observed in addition of chloride and at high camp number in the slow mixing coagulation. Rapid mixing is not suitable as a method of coagulation.

7.2 Recommendation

The study has the following recommendations:

- Mohara Treatment Plant needs further investigation, especially when flow is much higher. Water quality during salinity influence and during high siltation at intake of Halda river are need to be studied.
- Mixture of different salts is required to provide natural salinity condition for laboratory analysis. Temperature during laboratory analysis has to be controlled.
- Test could be done at 80 rpm for 15 minutes, i.e., at high camp no., to check floc breakage during slow mixing coagulation.
- Discharge must be kept at the optimum range, i.e., below $936 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge, in a sludge blanket clarifier. Angle of clarifier with horizontal should be in range, e.g., in between 45° to 60° and sludge depth should be atleast optimum depth while using sludge blanket clarifier.
- AgNO_3 could be added at the flash mixture with alum dose in the Mohara Treatment Plant to control chloride within limit before entering into the clarifier. Discharge should be kept below $2219 \text{ cm}^3/\text{s}/\text{m}^3$ of sludge at 500 mg/l of chloride.

- A study on relationship of discharge and sludge depth for a sludge blanket clarifier is required. Again, another study is required to check clarifier's performance at higher sludge depth than used in the study.

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APPENDIX

Table 1: Results of Influence of Salinity in the Rapid Mixing Coagulation

Chloride range (mg/l)	Alum mg/l	Change in velocity gradient	Change in pH
0-303	10	No change	Decreases
	20		”
	30		”
	40		”
	X		Increases
303-485	10	No Change	Decreases
	20		”
	30		”
	40		”
	X		Increases
485-728	10	No change	No change
	20		
	30		
	40		
	X		
728-910	10	No change	-
	20		Increases
	30		Decreases
	40		Increases
	X		No change
910-1214	10	No change	-
	20		Decreases
	30		
	40		
	X		No change

Table 2: Comparison between Rapid and Slow Mixing Coagulation due to influence of salt

Method Used	Coagulation Criteria	Salt added, (mg/l)	Density Of water, $\rho_{20}(\text{gm/cc})$	Viscosity of water, $\mu_{20}^{\circ}\text{C}$ (gm/cms)	Velocity Gradient (/sec)	Camp No. = Gt	Energy (HP) $P = 3.1 \times 10^{-11} \times \int \times n^3$
Slow mixing coagulation	40 rpm for 300 sec &	0	1.40	1.39	57/sec &	29100	5.38x10 ⁻⁶ HP & 6.72x10 ⁻⁷ HP
	20 rpm for 600 sec (30 min. sedimentation)	500	1.43	1.45	56.4/sec &	28860	5.49x10 ⁻⁶ HP & 6.86x10 ⁻⁷ HP
		800	1.435	1.49	19.9/sec &	28530	5.51x10 ⁻⁶ HP & 6.89x10 ⁻⁷ HP
		1200	1.44	1.52	55.7/sec &	28290	5.53x10 ⁻⁶ HP & 6.91x10 ⁻⁷ HP
		1500	1.45	1.60	19.7/sec &	27690	5.57x10 ⁻⁶ HP & 6.96x10 ⁻⁷ HP
		2000	1.46	1.71	54.1/sec &	26850	5.61x10 ⁻⁶ HP & 7.0x10 ⁻⁷ HP
					19.1/sec &		
Rapid mixing coagulation	300 rpm for 30 sec (30 min. Sedimentation)	0	1.40	1.39	890/Sec	26700	1.31x10 ⁻³ HP
		500	1.43	1.45	881/Sec	26430	1.34x10 ⁻³ HP
		800	1.435	1.49	872/Sec	26160	1.35x10 ⁻³ HP
		1200	1.44	1.52	864/sec	25920	1.35x10 ⁻³ HP
		1500	1.45	1.60	845/sec	25350	1.36x10 ⁻³ HP
		2000	1.46	1.71	820/sec	24600	1.37x10 ⁻³ HP

Table 3: Influence of salt on rapid and slow mixing coagulation, and on sludge blanket clarifier (Initial turbidity were always above 300 NTU)

Method	Residual turbidity (NTU) of water at salt value							Remarks
	0 (mg/l)	500 (mg/l)	1000 (mg/l)	1500 (mg/l)	2000 (mg/l)	5000 (mg/l)	10000 (mg/l)	
Slow mixing coagulation	6.0	8.5	8.0	7.0	6.5	-	-	No effect of salt
Rapid mixing coagulation	56.0	50.0	51.0	41.0	35.5	-	-	Turbidity is always high
Sludge blanket clarifier ($1\text{cm}^3/\text{s}=\text{Q}$)	5.2	5.5	6.3	6.5	6.9	11.8	25.0	5000 mg/l of salt is the critical salt value

Table 4: Combined effect of salt and discharge on sludge blanket clarifier

NaCl added (mg/l)	Discharge (cm ³ /s/m ³ of sludge)	Detention time, t _d (minutes)	Initial turbidity (NTU)	Residual turbidity (NTU)
0	2422	94	240	28.0
0	134	80	305	1.6
500	2674	78	228	31.0
1000	134	100	316	2.4
1000	3476	----	401	40.0
5000	401	75	453	7.6
10000	535	183	403	26.0

Table 5: Initial effect of discharge on sludge blanket clarifier at without salt condition

Discharge per unit volume of sludge (cm ³ /s/m ³ of sludge)	Concentrated force, F (c.g.s. unit)	Dispersion of floc (x), cm	Remarks on fluidization of floc
321	24714	1.5	Only local fluidization
963	24718	3.0	Slow fluidization
2674	24751	7.0	Half fluidization
3476	24777	9.0	Almost complete fluidization

Table 6: Effect of angle change on sludge blanket clarifier

Angle of clarifier (α)	Discharge per unit volume of sludge (cm ³ /s/m ³ of sludge)	Initial turbidity (NTU)	Residual turbidity (NTU)	Efficiency (%)
60°	711	313	1.50	99.60%
75°	775	265	22.00	92.00%

Table 7: Density of water at different chloride dose
(Water having 400 mg/l of kaoline and 20 mg/l of alum dose)

Chloride (mg/l)	Density, $\rho_{20^{\circ}\text{C}}$ (gm/cc)
0	1.507
500	1.509
1000	1.510
2000	1.514
3000	1.517
5000	1.524

Table 8: Effect of discharge on concentrated force at constant chloride of 1000 mg/l

Discharge, Q (cm ³ /s)	u (cm/s)	v (cm/s)	Chloride (mg/l)	$\rho_{20^{\circ}\text{C}}$ (gm/cc)	Concentrated force, F (c.g.s. unit)
0.25	0.497	255.607	1000	1.51	24763
0.50	0.995	255.608	1000	1.51	24763
1.50	2.984	255.623	1000	1.51	24766

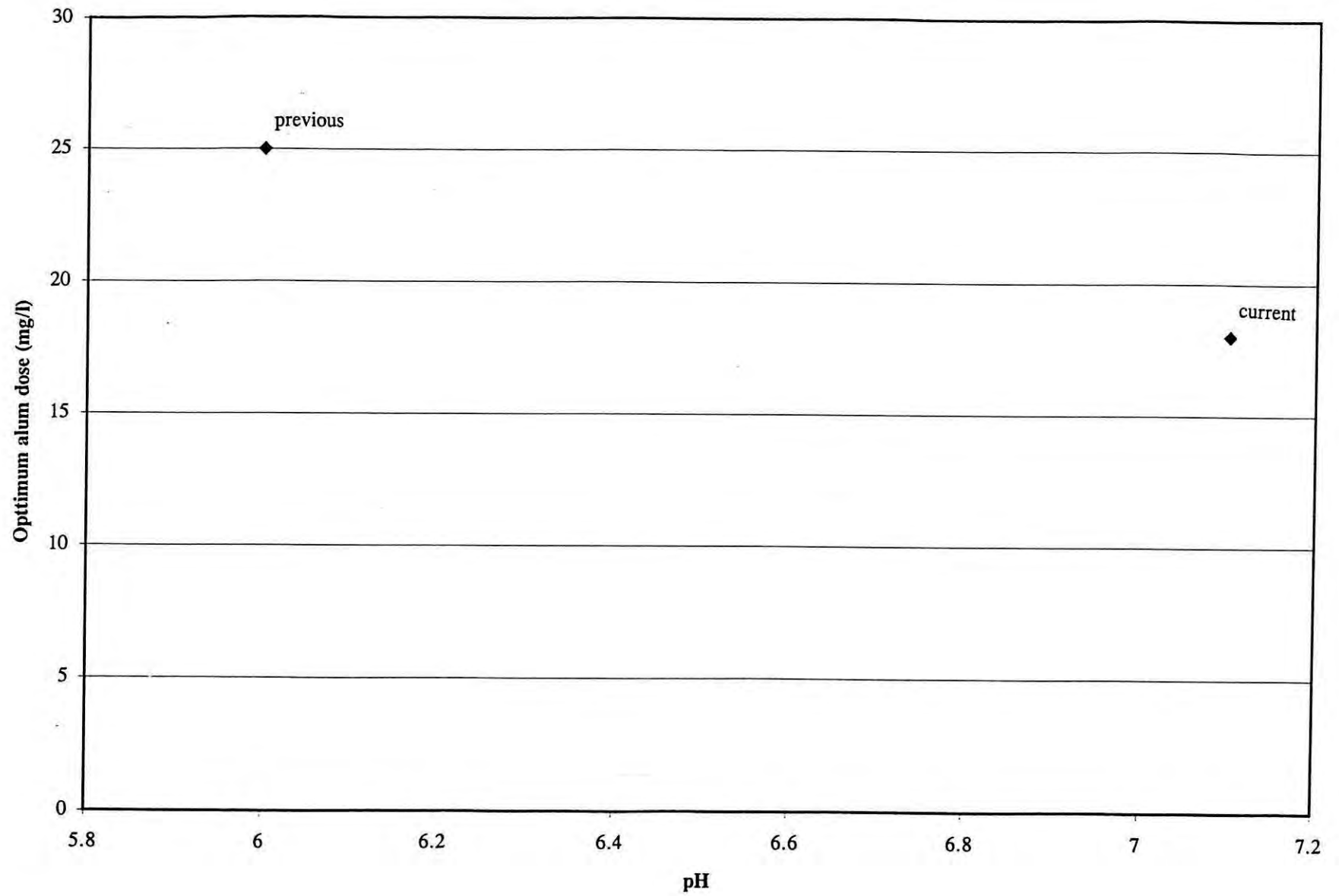


Figure 1 : Comparison of optimum alum dose between current and previous studies

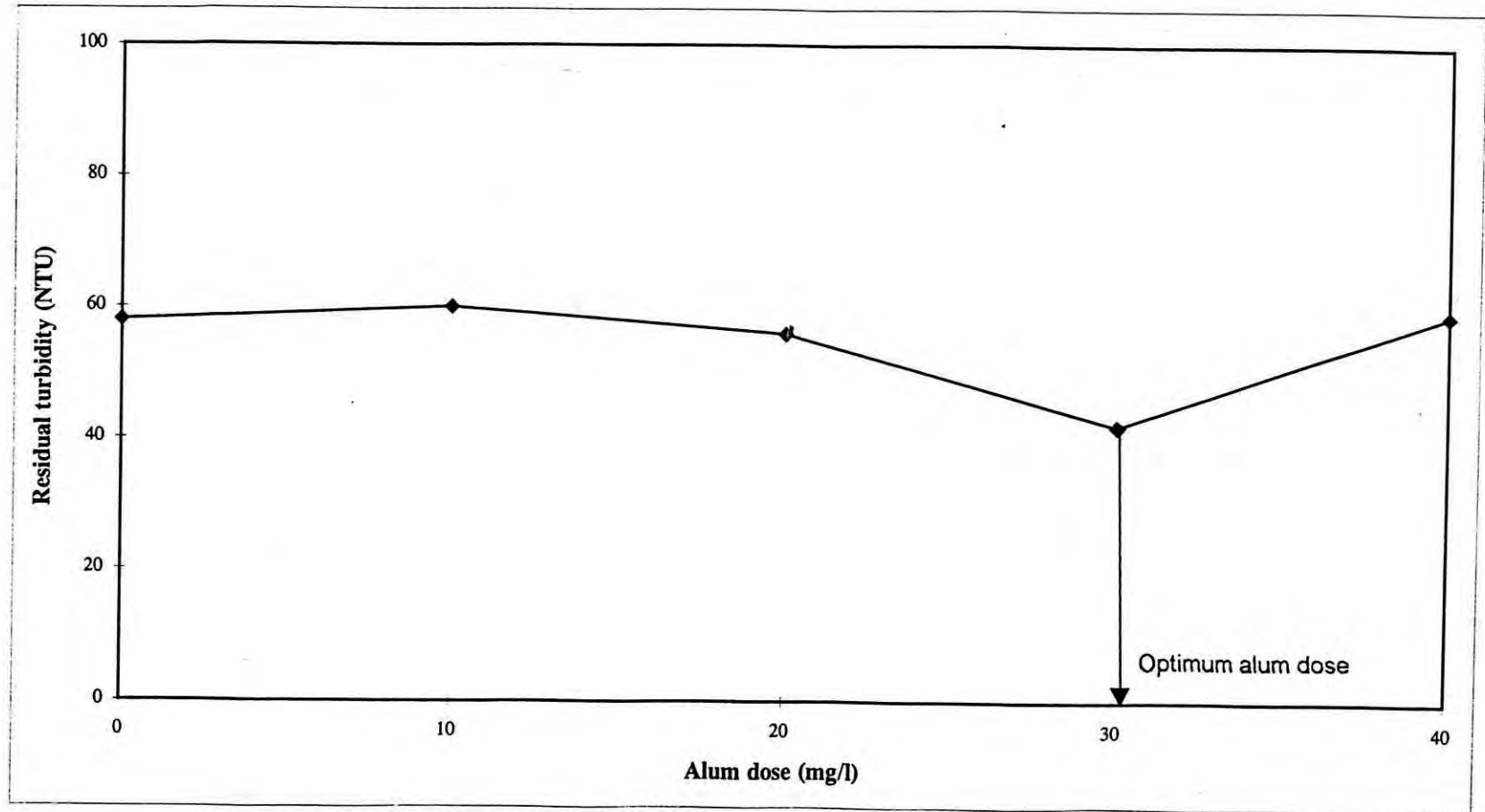


Figure 2 : Optimum alum dose at without salt condition (Observed in the rapid mixing coagulation)

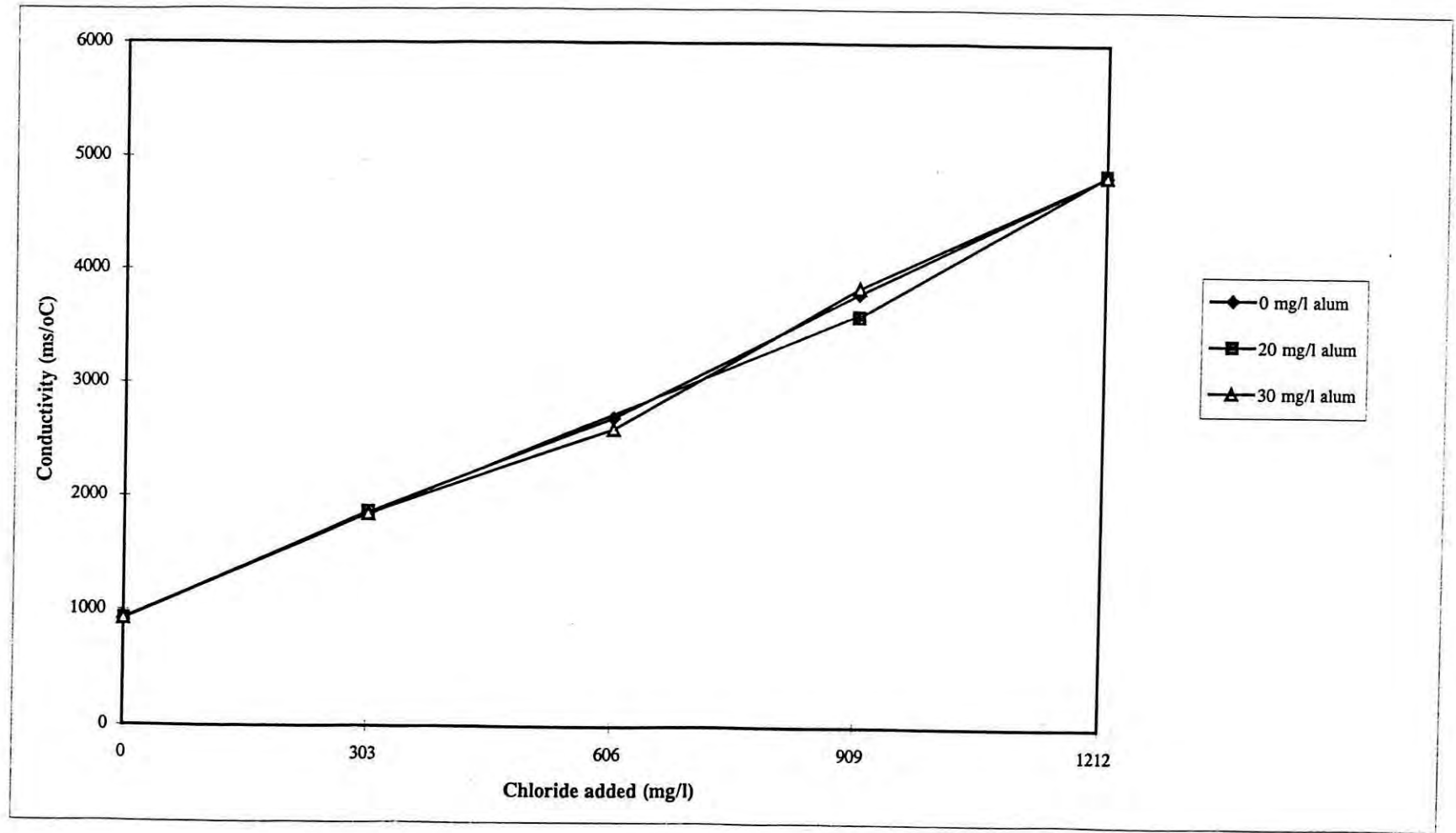


Figure 3 : Effect of salt and alum dose on conductivity in the slow mixing coagulation

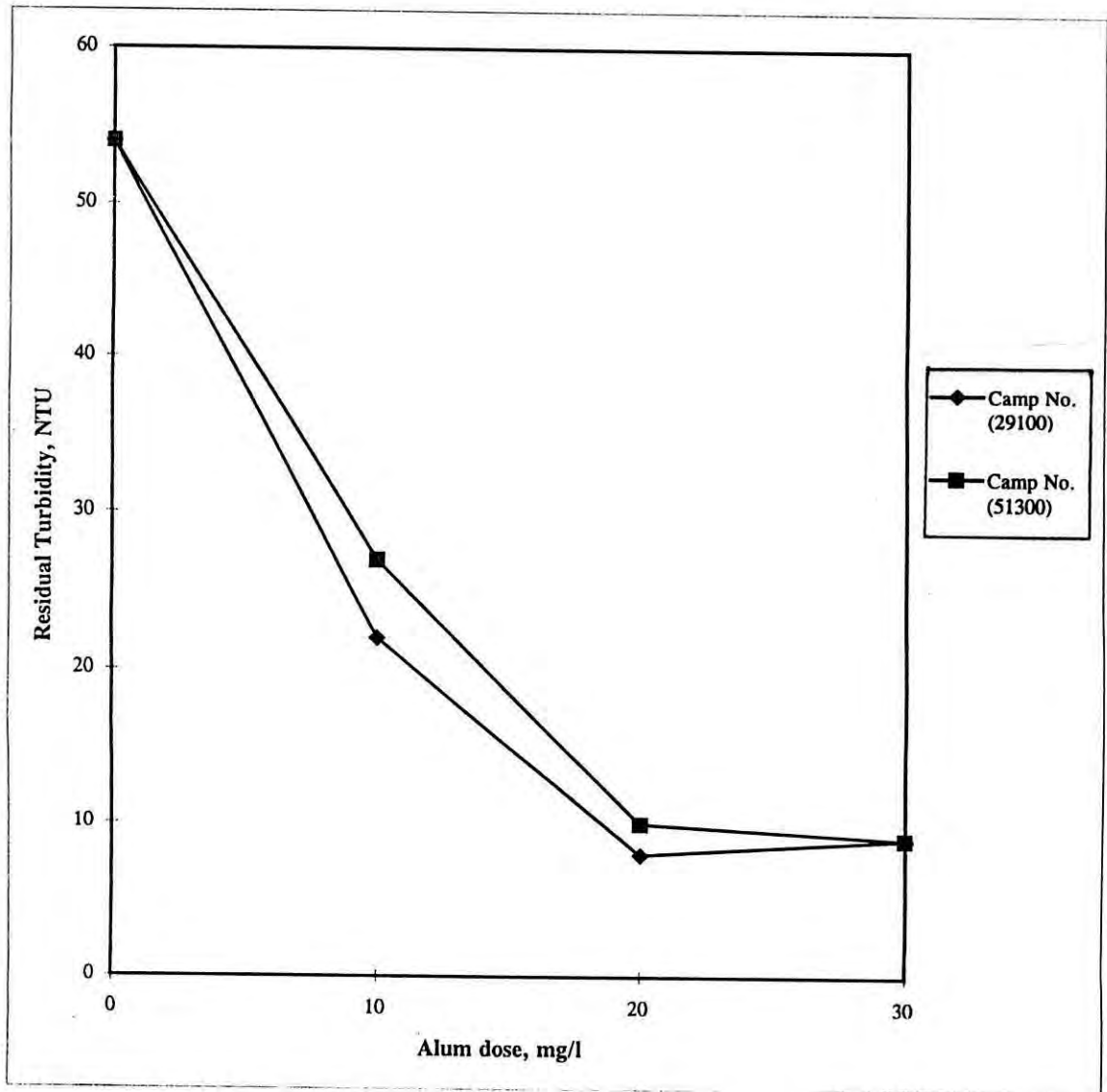


Figure 4 : Optimum alum dose at without salt condition (Observed in the slow mixing coagulation)

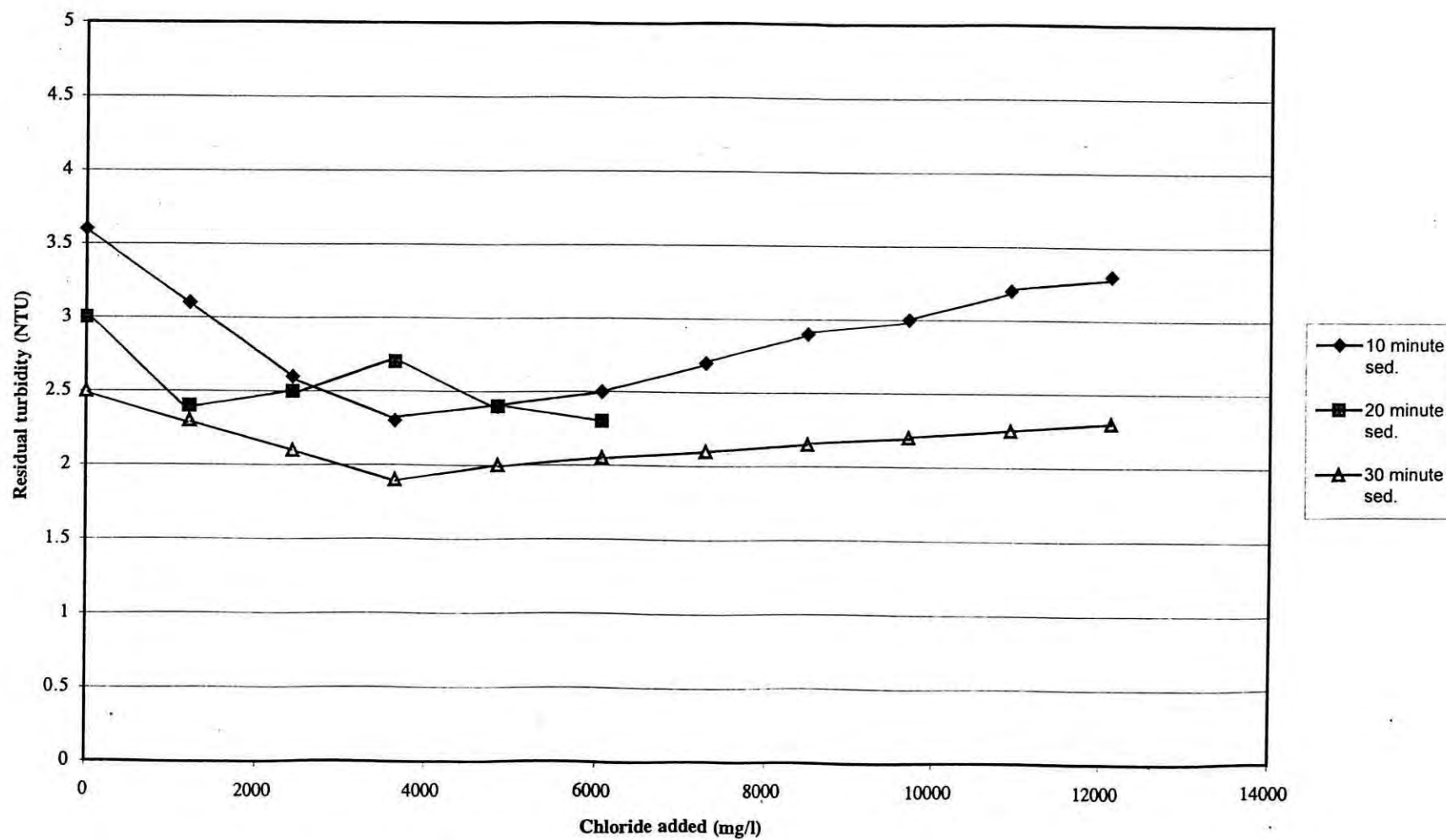


Figure 5: Impact of sudden increase and decrease of Camp No. in slow mixing coagulation

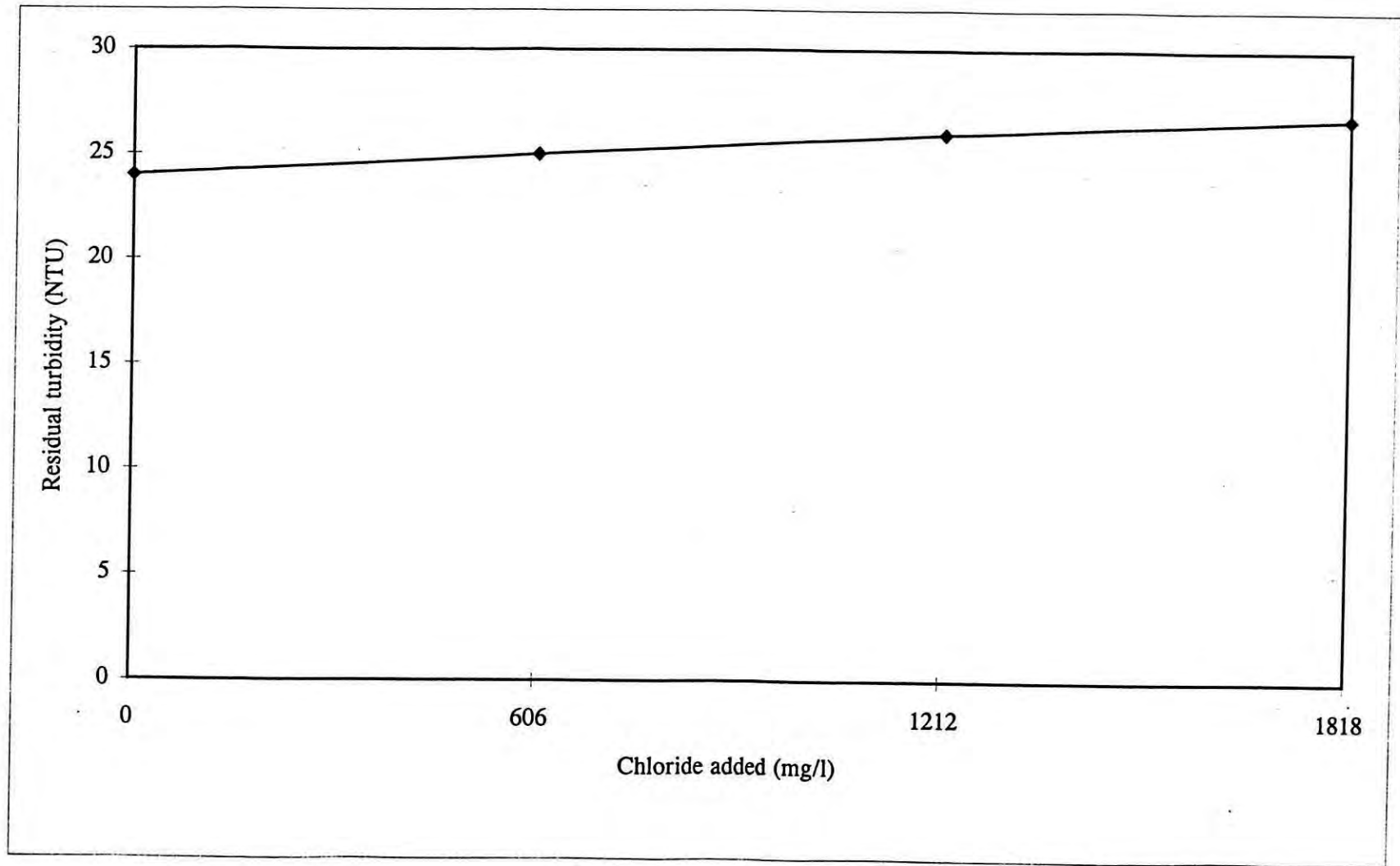


Figure 6: Effect of salt at constant discharge ($4 \text{ cm}^3/\text{s}$) in the sludge blanket clarifier

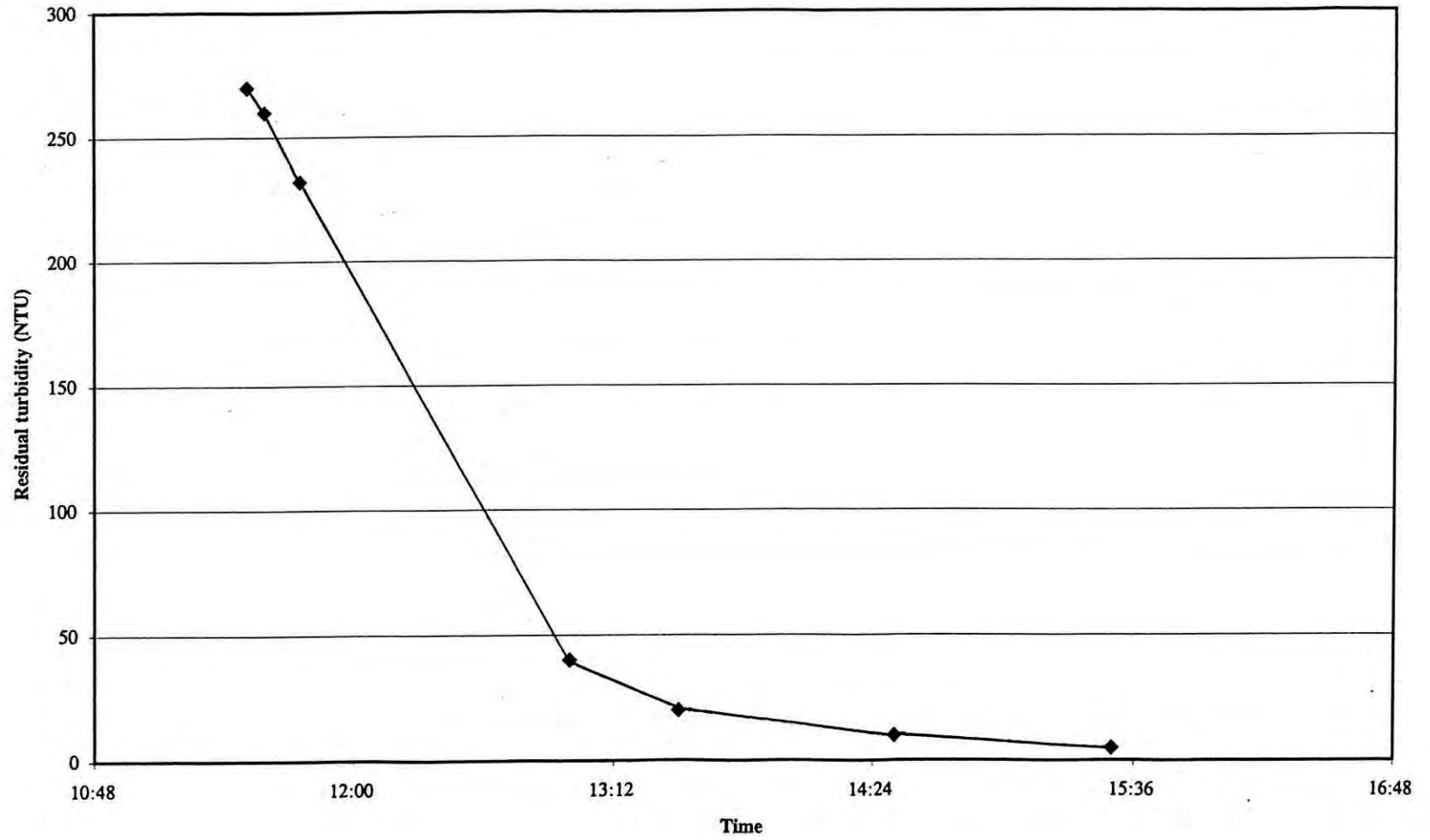


Figure 7: Relationship of residual turbidity and time at 200 ml chloride dose
(Source: Aktar, 2000)

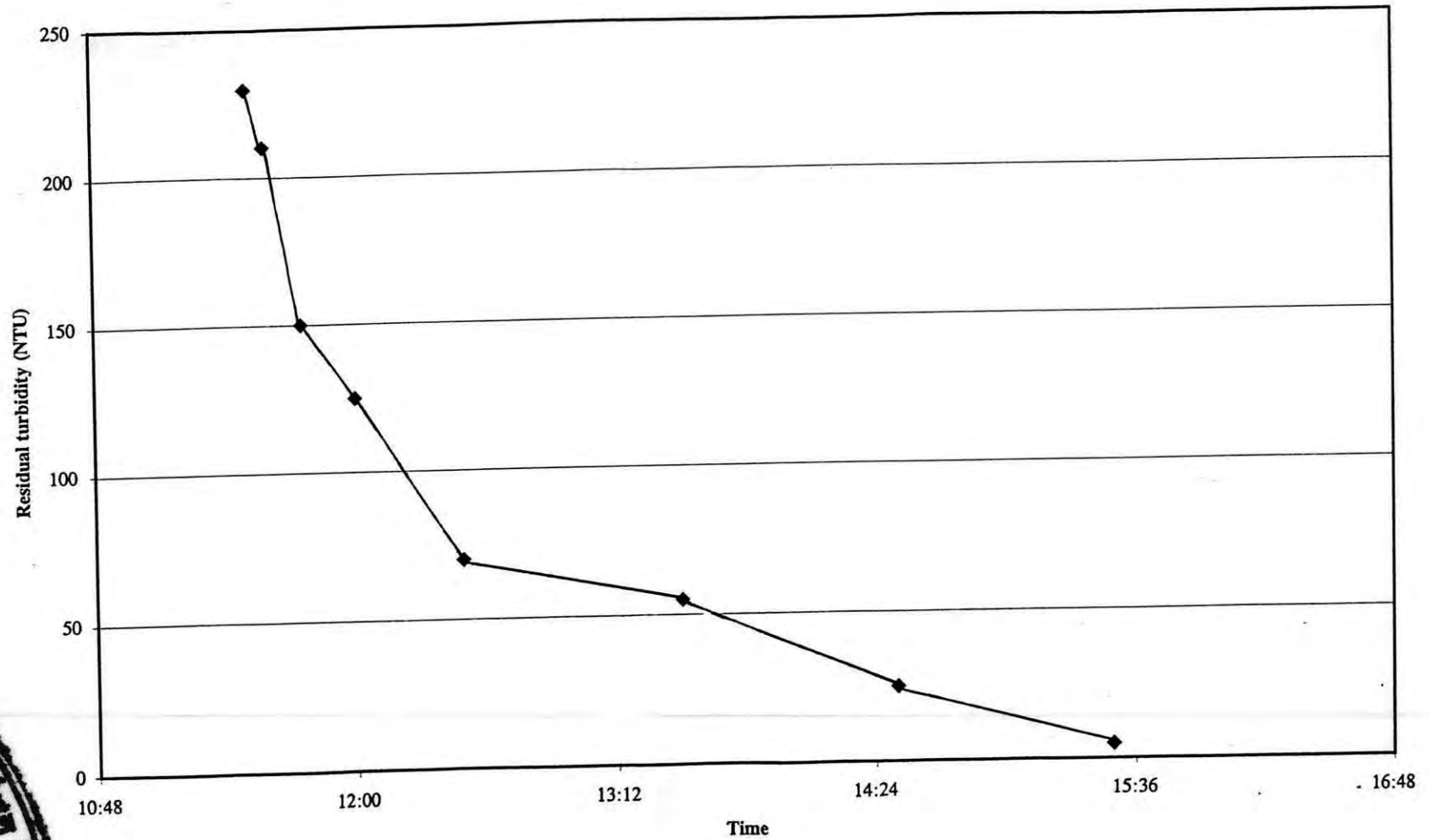


Figure 8: Relationship of residual turbidity and time at 100 ml chloride dose
(Source: Aktar, 2000)

