CHEMICAL TREATMENT OF SURFACE WATERS

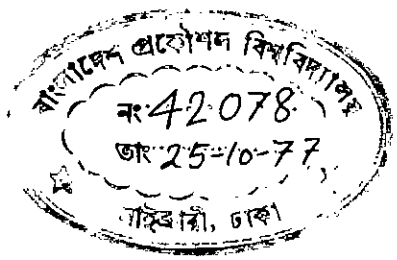
FOR

PUBLIC WATER SUPPLIES IN DACCA

A Thesis

by

M. Feroze Ahmed



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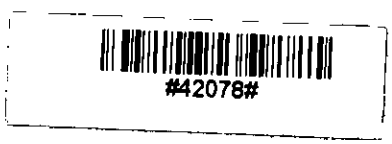

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ABSTRACT

This thesis represents an attempt to show experimentally the chemical methods of treatment of surface waters for public water supplies.

Clarification and disinfection are the two basic requirements of surface water treatment. Complex phenomena involved in chemical processes of water treatment required for clarification and disinfection are critically reviewed from an extensive literature survey.

The major parameters considered to be significant in the surface water clarification are colour and turbidity. The chemical process of coagulation-sedimentation was found to be satisfactory to these two water quality parameters to achieve higher degree of clarification. Within the limits of variation of temperature and pH of water samples the coagulant required to reduce the colour and turbidity to the limiting value recommended by the International Drinking Water Standards is observed to be dependent on their concentrations. On the basis of the experimental results, some quantitative relationships are developed to correlate the variables; colour, turbidity, and coagulant dosage.

In the process of disinfection by chlorination, significant reduction of chlorine requirements has been observed for the water clarified by chemical coagulation.

Some related studies were made on the suitability of different coagulants and mixing methods for the best floc formation and the consequent effect of chemical coagulation upon pH of water.

The limitations and shortcomings of the experimental works are discussed, conclusions drawn, and recommendations made for further studies.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Treatment of water is "to reduce harmful and objectionable polluting matter to limiting concentrations or tolerances consistent with intended water uses"[1]. The main objectives of water treatment are to make water potable, i.e. to make water "safe to drink, pleasant to taste, and suitable for domestic uses"[2].

Surface water treatment has gained increasing importance in recent years with the increasing demand of potable waters in Bangladesh. This increasing demand is due to the higher population growth rate in the country. As a result, there exists persistently a chronic shortage of potable water supplies all over Bangladesh. Even in the City of Dacca there is an acute shortage of potable water. The present population of Dacca is 1.31 million and the number is expected to be 3 millions in the next 20 years[3]. To satisfy the demand of this population, about 80 mgd of water is required only for domestic uses, the actual total demand is double the quantity. Of this total demand of 80 mgd, only 40 mgd (3.5 mgd from surface source and 36.5 mgd from tubewell system) is supplied by the Dacca WASA[4]. Therefore, only a small percentage of the population of the City of Dacca has the access to safe drinking water.

Supply of drinking water is also scare in the rural areas of Bangladesh. The drinking water supply through handpump tube wells by the Directorate of Public Health Engineering under the

UNICEF-WHO aided programme is not sufficient to meet the total requirements in rural areas. People, therefore, use surface waters and waters from katcha wells, the potability of which is questionable. Surface water supply is, therefore, a must for the people of Bangladesh.

Surface water is abundant in this country, but it is poorer in quality which requires elaborate treatment. To overcome the chronic shortage of potable water supplies both for urban and rural areas of Bangladesh, development of a simple, efficient but economic process of surface water treatment is of prime importance.

1.2 WATER QUANTITY PARAMETERS

Chemically pure water is not found in nature because of the almost universal solvent power of water. Natural water may be classified as meteorological, surface and ground water. Meteorological water is high in dissolved oxygen, surface waters are high in suspended matter and may be turbid and coloured, and ground waters may be hard, high in dissolved carbon dioxide and relatively high in dissolved minerals. The survey of the quality of water sources furnishes necessary information regarding the treatment process and the cost involved to remove impurities. Turbidity, colour, taste and odour, pH, acidity and alkalinity, carbon dioxide, oxygen, hardness, temperature and microorganisms are the essential parameters for defining physical, chemical, and biological qualities of surface waters.

Turbidity: Turbidity is the measure of the resistance of water to the passage of light through it. Turbidity is caused by the suspended and colloidal matter in the water in which visual depth is restricted. In natural rivers, turbidity is contributed to the greater extent by the organic and inorganic suspended matterials from the treated and untreated domestic and industrial wastes added to the stream. Turbidity may also be caused by the living and dead algae and other organisms[5]. It is an important consideration in the public water supply for three reasons (a) aesthetic (b) filterability, and (c) Disinfection[2]. Turbidity is objectionable from the standpoint of appearance aesthetically; turbid water is not acceptable, rather repulsive to the scene of pollution. Pathogenic and other microorganisms are sometimes encased in turbid particles and are not affected by disinfectants. Turbidity of raw water also control the process of filtration for water purification. Maximum permissible concentration of turbidity in drinking waters are 10 and 5 mg/l as specified by the USPHS and the WHO (Table 1.3) respectively.

Colour: The colour in water, usually results from the solution of extracts of leaves, grasses, woods, all at various stages of decomposition, are called true colour. Colour also may be caused by suspended coloured material such as coloured turbidity in water drained from red soil, termed as apparent colour. Surface waters may become coloured by pollution with highly coloured waste-waters from dying operation in textile industry,

from pulping operation in paper industry and other industrial processes. Natural colour in water is usually due to the presence of organic matter in suspension and it exists primarily as negatively charged colloidal particles[1]. Coloured water is not only undesirable because of consumers' objection to its appearance but also it may discolour clothing and adversely affect industrial processes. Maximum allowable limits of colour for drinking water are 20, 15 and 10 mg/l, defined by the USPHS, WHO and WHO (EUROPEAN) respectively.

Teste and Odour: Taste and odour in water may result from any one or a combination of such conditions as the presence of micro-organisms, either dead or alive, dissolved gases such as hydrogen sulphide, methane, carbon dioxide, or oxygen combined with organic matter, mineral substances such as sodium chloride, iron compounds and, carbonates and sulphates of other elements and phenol and other tarry and oily matter, specially after chlorination. Some tastes, such as those imparted by dissolved oxygen and carbon dioxide are desirable. Odour in water changes with temperature, sometimes not being noticeable when the water is cold.

pH: pH is a term universally used to express the intensity of acid or alkaline condition of water or a solution. More exactly, it is a measure of the hydrogen ion concentration in a solution. pH is of vital importance in water supply engineering. It is a qualitative measurement of acidity or alkalinity of water. It

expresses the strength of acid or alkali in water, controls the biological process, chemical coagulation, water-softening, corrosion and almost all the water treatment process. Natural water is alkaline and pH of natural water is largely dependent on the carbon dioxide equilibrium. Permissible limit of pH for drinking water is 7 to 8.5[2].

Acidity and Alkalinity: Acidity and alkalinity is a measure of the amount of acid or alkali present in water. It is a quantitative measurement of acid or alkali in a solution. Acidity is generally undesirable in public water supply but a low acidity is not however determental to potability. Alkalinity is commonly found in natural waters in the form of carbonate of soda, bicarbonate of calcium and magnesium. Caustic alkalinity caused by hydroxides is seldom found in water. Maximum limit of total alkalinity are 120 and 100 prescribed by USPHS and WHO respectively.

Carbon dioxide: Carbon dioxide in water may be a result of decomposition of organic matter or of metabolism of some organisms. Hence, the presence of excessive carbon dioxide indicates biological activity in water[2,7]. Ground water may contain carbon dioxide as much as 50 mg/l without affecting the sanitary quality of water. Carbon dioxide in water is desirable at a concentration known as carbonate balance.

Oxygen: Analysis of water related to oxygen are dissolve oxygen (DO), chemical oxygen demand (COD), and Biochemical oxygen demand (BOD), Dissolved oxygen test indicates oxygen content of water. Surface water of satisfactory quality should be saturated with dissolved oxygen. Under saturation or supper saturation in surface water sometimes indicates pollution[7]. Chemical oxygen demand is the measure of organic matter, particularly carbonaceous matter. In general a water of good quality should be low in oxygen consumed. Biochemical oxygen demand is the amount of oxygen required by the living micro-organisms engaged in utilization and ultimate stabilization of organic matter present in sewage and polluted waters in a specific time (5 days) at a specific temperature ($20^{o}C$)[8]. Hence, BOD is an indirect measure of the amount of decomposable organic matter present in water. Unpolluted water should have less than 5 mg/l BOD[2]. Higher BOD value is a danger signal demanding investigation of the cause before the water is pronounced potable.

Hardness: Hardness in water is caused mainly by the carbonates, bicarbonates and sulphate of calcium and magnesium. Although chloride and nitrate of this two element and of iron and aluminum are effective in lesser degree to the cause of hardness. Hardness is undesirable for domestic water supply for the causes that hard waters consume enough soap for lathering, clog skin, discolour porcelain, stains and shortens the life of fabries, and discolour vegetables and food stuffs.

Temperature: Potable water should be of moderate temperature. The most desirable range of temperature for public water supplies is between 40 to 50°F. Temperature is a controlling factor in the treatment process, chemical requirements and biological growth in water.

Microorganism: The microorganisms, an important group of living creatures found in surface water, are somewhat arbitrary defined in water works practice to include several classes of plants and animals living in common only the characteristics that the microscope is necessary and sufficient for their identification and classification[1]. The microorganisms belong to plant kingdom are chiefly algae, diatoms, fungi, bacteria and viruses. Animals are protoza, metazoa, rotifers, crustraceans, warms and larvae. The growth of microorganisms in water is governed by the food supply and environmental conditions.

The living organisms that have their natural habitat in water and that are introduced in water in course of its use by men are of deep concern. Bacteria, viruses and protozoa are infectious to mean and responsible for the outbreak of serious, sometimes, fetal waterborne diseases[9,10]. The most common pathogenic (disease producing) bacteria and protozoa are Bacillus Typhi, Salmonella Paratyphi, Shigella Dysenteriae, Vibrio comma, Endamoeba Hystolytica.

Other organisms-the algae and related plankton are responsible for the occurance of taste, odour and colour in water

supplies[2,9]. Certain variety of algae are toxic and undesirable in surface waters. Algae may, if left uncontrolled, infest water supplies in such numbers as to render the water unfit for human consumption, be responsible for the sudden death of the cattle and may flourish in water conduits, both open and closed and reduce their capacity.

1.3 WATER-BORNE DISEASES

Water borne diseases are caused by pathogenic microorganisms. Unfortunately, their isolation from natural water is difficult by laboratory means. There is, however, a group of harmless bacteria, known as Escherichia Coli, normally present in the intestinal tract of warm-blooded animals, which can be relatively easily isolated and identified[7]. E. Coli test is a search for E. Coli bacteria, the presence of which is taken to indicate the presence of fecal matter in the water and is a warning that pathogenic bacteria indigenous to the intestinal environment, may also be present. The table 1.1 shows pathogenic bacteria and viruses responsible for some common water-borne diseases.

Table 1.1 Water-borne Diseases and Associated Patnogens

Name of Diseases	Organisms Responsible
Typhoid fever	Bacillus Typhi (Bacteria) Eberthela Typhosa (Bacteria)
Paratyphoid Fever	Salmonella Paratyphi (Bacteria)
Amoebic Dysentery	Endamoeba Hystolytica (Protozoa)
Bacillary Dysentery	Shigella Dysenteria (Bacteria)
Cholera	Vibrio Comma (Bacteria)
Small pox and chicken pox	Dermotropic Viruses
Gastroentaritis	Enteric Viruses
Poliomyelitis	Neurotropic Viruses
Schistosomiasis	Cercarnie (Animal Parasites)
Infectious Hepatitis (Jaundice)	Enteric Viruses
Anthrax	Bacillus Anthracis (Bacteria)
Tularemia	Spirochetes (Bacteria)
Influenga, Colds	Pheumotrophic Viruses
Pheumonia, Broncho-pneumonia	Diplo Coccus Pneumonia (Bacteria)
Diphtheria	Corynebacterium Diphtheria(Bacteria)
Cancer	Viscerotropic Viruses
Polio-like diseases	Enteric Viruses
Urinary Inflamation	Escherichia Coli (Bacteria)
Whooping cough	Hemophilus Pertussis (Bacteria)
Tuberculosis	Mycobacterium Tuberculosis(Bacteria)
Leprosy	Mycobacterium Leprae (Bacteria)

1.4 INTERNATIONAL STANDARDS FOR WATER QUALITIES

(A) Water Qualities of the Source:

Water supplies should be drawn from the best available source. The WHO, in 1963 prescribed the maximum allowable limits of water qualities for water sources[2]. Table 1.2 shows the standards of some important water qualities for a source.

Table 1.2 International Standards of Quality for Water Sources

Qualities	Maximum allowable limits	
Colour	300	mg/l
Total dissolved solid	1500	"
Iron	50	"
Manganese	5	"
Copper and Zinc	1.5	"
NO_3	45	"
Fluoride	1.5	"
Phenolic substances	0.002	"
Arsenic and Lead	0.05	"
COD	10	"
Nitrogen Except NO_3	1	"
BOD	6	"
Bacteriological quality requires:		
Disinfection only	0-50	MPN/100 ml
Usual treatment	50-5,000	"
Extensive treatment	5,000-50,000	"

(B) Drinking Water Qualities:

The USPHS and WHO standardize the physical and chemical parameters measuring water qualities of drinking water. Table 1.3 shows the maximum allowable limits of some important parameters for drinking water[2].

Table 1.3 International Drinking Water Standards (Physical, chemical and Bacteriological).

Qualities	Maximum Allowable Limit in mg/l		
	USPHS(1962)	WHO(1973)	European(WHO)
Physical Qualities			
Total dissolved solid	500	500	250
Turbidity	10	5	5
Colour	20	15	10
Temperature	$50^{o}F$	$50^{o}F$	$50^{o}F$
Taste and odour	Nil	Nil	Nil
Chemical qualities:			
Total hardness	150	100	100
Total Alkalinity	120	100	100
pH	7 to 8*	7 to 8*	7 to 8*
Iron and Manganess	0.3	0.3	0.2
NO_3 Nitrogen	45	45	50
Fluoride	0.6	0.5	0.5
Phenol	0.001	0.001	0.001
Arsenic	0.05	0.005	0.02
Lead	0.05	0.05	0.10
Chloride	250	200	350
Calcium	80	75	75
Bacteriological qualities:			
Pathogenic Microorganism	Nil	Nil	Nil

* No units.

1.5 OBJECTIVES OF THE RESEARCH

The following are the major objectives of this research works:

(1) To study the effectiveness of chemical coagulation with the locally available best coagulant as a single method of treatment for the required degree of surface water clarification i.e. for the removal of colour and turbidity to the limitting concentrations as recommended by the International Drinking Water Standards.

(2) To develope a quantative relationship between the chemical dosage and the water quality measuring parameters like colour and turbidity, so that correct dosage of chemicals, based on the raw water quality of the source, can be applied for the treatment of surface waters for public water supplies.

(3) To study the effect of chemical coagulation upon the subsequent disinfection by chlorination and other related water quality parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

Water supply has its history, literature, science and technology as ancient as human civilization and culture. Waterworks structures are found in the excavation of prehistoric ruins. The remains of lake Moeris in Egypt indicate its construction about 2000 B.C.; this was the largest water supply reservoir of Nile Valley[2]. Amongst others, the supply of water in the city of Jerusalem, Rome, and Mohenjodaro were specially notable. Wells were also used at remote period in ancient Greece, Italy and India to utilize the underground water. Artesian wells were also found to be sunk in China in early times[2,5].

The early water supplies were contaminated by various impurities and people were suffering from various water-borne diseases. This urged the Engineers and Doctors to improve the science and technology required to purify water to make it safe. Amongst the treatment processes, John Gibb designed and constructed the first water filter at Paisley in Scotland, U.K. in 1804[12]. James P. Kirkwood designed and built the first sizeable filter at Poughkeepsie in Newyork, USA, in 1850[2,11].

The use of chemicals for water treatment was first introduced and developed in the later nineteenth censury. In 1884 the first patent on coagulation was granted to Isaiah Smith Hyatt, who, following a suggestion of Col. L.H. Gardner, Supt.

of the New Orleans Water Co., successfully combined the use of perchloride of iron as a coagulant with his system of rapid filtration in the treatment of turbid waters. In his patent Hyatt claimed the use not only of perchloride of iron but of "any other suitable agent which is capable of coagulating impurities of liquid and preventing their passage through filter bed"[11]. In 1885, Somerville and Raritan Water Co. of New Jersey adopted Hyatt's simultaneous coagulation-filtration system in rapid filtration. Rapid filtration had been adopted at Somerville as early as 1881, but there was no record of the use of a coagulant in combination with it before 1885 as a full scale method of treatment[2,11]. In the same year professor Austen and Wilber of Rutgers University published the results of the first scientifically conducted studies on alum as a coagulant. Other coagulants like ferrous sulphate and lime (1898), commercial ferrous sulphate (1902), Chlorinated copperas (1912), activated Silica (1937) were also introduced[11].

The early important experiments on rapid sand filteration were carried out at Providence in 1893-1894 by Weston, at Louisville and Cincinnati by George Warren fuller in 1895-1898. at Pittsburgh in 1897 by Allen Hazen, at Washington D.C. in 1899 by Miller, at New orleans in 1901 by Robert Spurr Eeston, and significant improvement of the water treatment processes were made[11].

The earliest recorded use of chlorine directly for water disinfection was in January 1896 by W.M. Jewell who utilized

chlorine gas for disinfection in the experimental studies conducted at Louisville, Ky., by George Fuller[1]. In 1897 the polluted water supply of Maidstone, England, had been treated with chlorinated lime as a temporary measure during a typhoid epidemic. However, chlorination of water as a continuous part of treatment was first adopted at Middlekerke, Belgium in 1902. The second continuous use of chlorination was in England where Houston and McGown, in 1905, started the application of sodium hypochloride for disinfection of raw water in the slow sand filter plant. The first technically successful application of chlorination in America was made by George A. Johnson, who demonstrated that raw water could be disinfected with a solution of chlorinated lime and the evidence that bacteria could be destroyed without impairing the quality of effluent was considered extraordinary. As a result, Johnson, in co-operation with L. Leal applied chlorinated lime to to the entire 40 mgd supply of Jersey city N.J. in 1908[2,11]. Chlorination of the Poughkeepsie, N.Y. supply was initiated by W.T. Carpenter on March 17, 1909[11,12], and during the next years the process of chlorination for disinfection expended rapidly.

2.2 CHEMICAL PROCESS OF WATER CARIFICATION

2.2.1 Flocculation Sedimentation.

The addition of certain chemicals in water, an insoluble, gelatinous, flocculent snow flake-like precipitates are formed, which in its formation and descent through water absorb and entrain suspended and colloidal matter, hasten its sedimentation and remove turbidity, colour and taste more rapidly than plain sedimentation. The phenomenon is known as flocculation-sedimentation.

Inorganic turbidity in natural waters consists principally of clay particles derived from soil. Organic particles causing turbidity and colour are from the disposal of organic matter in water sources. These particles ranges upto 5 microns in diameter. But the particles of smaller than 1 micron are more stable and are of controlling importance in rapid flocculation[13].

The smaller particles derive their stability from an electrical double layer surrounding each particle[13-16]. The outer layer of the electrical double layer comprises exchangeable cation such as Na^+, K^+, Ca^{++}, Mg^{++}, and H^+ that diffuse into surrounding water medium. The electric double layer and the envelope of the solvent molecules attached on the surface of the colloidal particles causes mutual interaction among the particles in solution. The resultant interaction between the colloidal particles is the sum of the Vander Waal forces and the electrostatic forces of the electrical double layer. At small and larges distances, the attractive forces always predominate (Fig.2.1)[16].

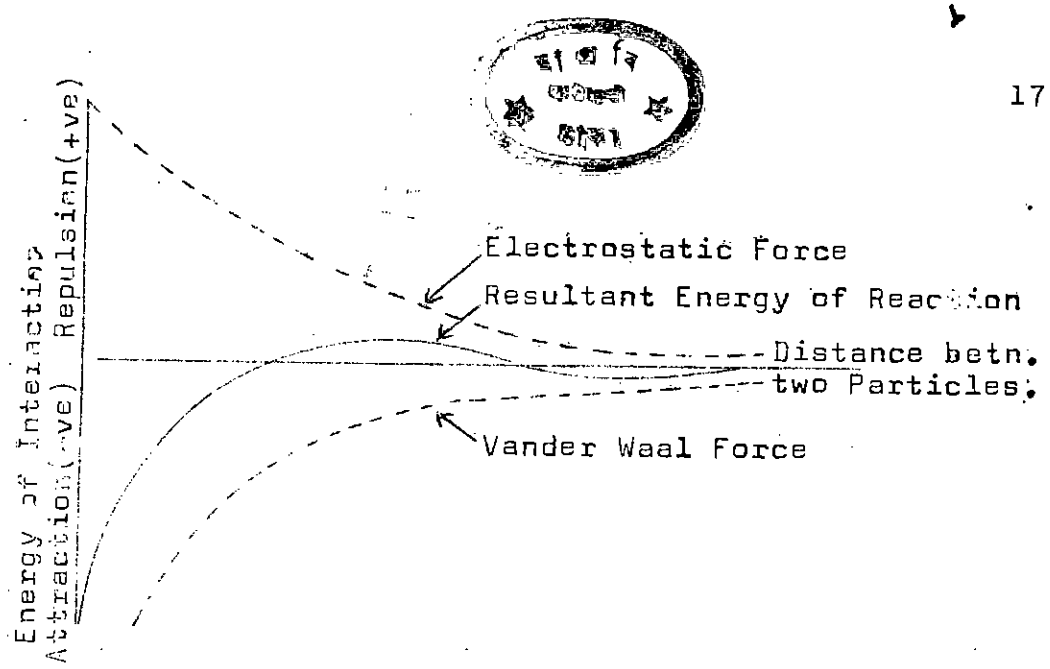

Fig. 2.1 Schematic Diagram of Potential Curves

This is because, the electrostatic forces of double layer at long distances diminishes more rapidly with increasing distances than the vander walls forces and because at the small distances, comparable with atmoic dimensions, atomic attractive forces always predominate. Mutual interaction does not occur, however, until the distance between the particles is not so small that the penitration of the diffuse part of the double layer or the solvated layer begins to take place.

The interaction, when repulsive, is responsible for the stability of the collioidal system. At intermediate distance, corresponds approximately to the thickness of the diffuse double layer, repulsive electrostatic forces may predominate. This occurs when psi-potential (potential at the plane between diffuse and non-diffuse parts of double layer), of the interacting particles is high and of the same sign and when the duffuse layer is sufficiently thick, under such condition 'energy barrier' is formed which can prevent the approach of the particles within a distance at which the attractive force

predominate. Under this condition the colloid is stable and does not coagulate.

The instability, on the other hand, is due to the Brownian motion and Vander Walls' forces of attraction. The effect of the Brownian motion is that the particles are driven closer to each other to distance at which the influence of interaction between them takes place. The instability of the colloidal system results in coagulation which occurs when the energy barrier is sufficiently reduced and the energy level of the resulting agglomerates is lower than the original agglomerates. The conditions may be attained by.

(1) The contraction of the diffuse part of the double layer. The contraction of the diffuse part of the double layer can be produced by increasing the ion-concentration of the solution.

(2) The reduction of the psi-potential of the colloidal particles. The psi-potential can be reduced by (a) changing the concentration of the potential determining ions and (b) adding ions that possess a charge opposite to that of the potential determining ions and that are able to replace those ions in the Helmholtz (inner non-solved) part of the double layer[14].

The above conditions may be attained by the addition of polyvalent cations such as Al^{+++}, Fe^{+++} or other coagulants. The addition of these coagulants will repress the double layer (contraction) and lower the stability of the particle. At a critical level of destabilization the particles begin to

coalesce, forming aggregates. A more important factor affecting the rate of agglomeration is the total exchange capacity of the turbidity particle that is the total concentration of adsorbed or exchangeable cations in the system. In water having very high exchange capacity, exceeding certain critical limits, the agglomeration following destabilization will be very rapid resulting a large floc and rapid clarification.

In most natural waters, the concentration of exchange capacity is less than the critical concentration, and as a result the rate of aggregation is slow. The aggregates that form following destabilization are too small for rapid settling. In order to affect a rapid clarification of normal waters it is necessary that a suitable agglomerating agent or binder material be present which will bind the various small aggregates into large and rapidly settling flocs. In practice, a properly adjusted single hydrolizing coagulant chemical such as aluminium or ferric salt will affect both the destabilization and mechanical binding action[13]. In alum flocculation, a portion of Al^{+++} ions is affective in destabilizing the turbidity particles and the remainder of the ions, through hydrolysis, forms insoluble hydrous oxide binder material. The dosage of alum needed for the destabilization process will equal the exchange capacity of the system and essentially all the initially adsorbed cations will be replaced by Al^{+++}. The hydrous oxide required will depend upon the concentration and particle size distribution.

The precipitate particles of ferric or aluminium-hydrous oxides that are formed by crystalization usually posses slightly positive Zeta-potential (potential at the sloping plane of particles) the velue of which firstly depend on the pH of the solution[14]. At pH range of optimum coagulation the psi-potential is low and zeta potential is high, which is an important factor in coegulation. The colloidal impurities in water have high negative charge which is the principal factor in stabilizing these impurities in solution. The initial phase of coagulation involving the hydrolysis of coagulant, crystallization, compencation of negative charge of colloidal impurities in water and consequent mutual coagulation of distabilized colloids, ends with the formation of microflocs. When the quantity of ferric or aluminum-hydroxide precipitate is small and insufficient to compensate for the high negative charge of colloidal impurities, further coagulation stops. The resultant agglomerates still possess sufficiently high charges to creat an energy barrier between the interacting partially agglomerated particles and thus to prevent the continuation of coagulation. By increasing the coagulant dose, the negative charge is gradually reduced until the critical point is reached at which the mutual coagulation of aggregates is not hindered.

The process of coagulation summerized by Steel[5] describes that coagulation proceeds in three steps as the alluminum sulphate and ferric sulphate dissolve, positive alluminum and ferric ions becomes available to neutralize the negative charge on the particles of turbidity, including colloidal clay and colour.

This is the first stage of coagulation. After the positively charged ions have neutralized, a large part of the colloidal turbidity or colour particles, the resulting flocs are still too small to be seen or to settle by gravity. Again the flocs retain certain positive charges, possibly due to adsorption of positive ions from water, in other words, the resulting positive flocs still have the property of neutralizing negative colloids, the treatment, therefore, should be a slow stirring called flocculation in order that the second step may occur during which the very small flocs may agglomerate and grow in size until they are in proper condition for rapid sedimentation. During these phases, the third action, surface adsorption of particles takes place on the large surface area provided by the floc particles. Entrapment of others including bacteria also takes place.

2.2.2 Rate of Floc Formation

Flocculation results from the velocity differences or gradients in water during gentle stirring, which causes contacts between the moving floc masses. They also cause shearing stresses along planes in water and to overcome these, power is needed. Camp[15,17,18] showed that the rate of floc formation is proportional to the value of root-mean-square (RMS) velocity gradient which is defined as

$$G = \sqrt{\frac{W}{\mu}} \qquad (2.1)$$

in which G is the root-means-square velocity gradient in the basin in ft. per sec. per ft. (Sec^{-1}), W is the mean value of the dissipation function, equal to the total power dissipation

divided by the volume of the chamber or conduit and μ is the absolute viscosity of water in pound-second per square foot. The larger the value of G, the shorter will be the time required to form floc. Also a very high value of G will result in excessive shearing forces, these may, in fact tend to shear apart the floc particles which as they grow larger, will become weaker. Yerachmiel[19] experimentally also proved the fact that for a given residence time, performance increase almost linearly with the RMS velocity gradient until maximum value is reached beyond which any further increase results in the decrease in performance.

The optimum value of G is considered between 25 to 65 Sec^{-1}. In case of rotating blades the peripherial speed should be between 0.6 to 2.5 ft. per sec. Usually, the velocity of water will be generally $\frac{1}{4}$th the blade velocity. Total paddle area should not exceed 15 to 20 percent of the cross-sectional area.

2.2.3 Rate of Sedimentation:

As the flocs form, the rate of clarification of water is affected by the sedimentation of flocs. Particles having more density than the surrounding water will settle vertically due to gravity. The particles subside at uniform rate as acceleration ceases due to frictional resistance. Two major drag forces are at play, inertia and viscosity. Newton[5] assumed that the drag force was a function only of inertia whereas Stoke emphasised the role of viscosity.

The impeling force F_i is the weight of the particles in liquid media i.e.

$$F_i = (\rho_s - \rho)\, gV \qquad (2.2)$$

where ρ_s and ρ are the densities of particles and of the liquid, g is the acceleration due to gravity, and V, volume of the particles. Equating Newton's drag force to the impelling force in Eqn. (2.2), the subsidence velocity is obtained as

$$v = \sqrt{\left(\frac{4}{3}\,\frac{g}{C_d}\,.\,\frac{\rho_s - \rho}{\rho}\,d\right)} \qquad (2.3)$$

where C_d is the Newton's coefficient of drag, d is the diameter of the particles, v is the settling velocity.

Equating Stoke's drag force with the Eqn. 2.2, the subsidence velocity obtained,

$$v = \frac{1}{18}\left(\frac{(\rho_s - \rho)}{\mu}\right) gd^2 \qquad (2.4)$$

where μ is the absolute viscosity of the medium.

It has been varified by many careful experiments that both viscous and inertia force control the velocity of suspended matter in polluted water. Upto particle diameter of 0.1 cm, (Reynolds Number; R_e = 1.0) the viscosity controls the settling velocity, and above particle diameter 0.1 to 1.0 cm (R_e=2000) trans ition zone exists and above 1.0 cm. inertia force controls the settling velocity and the Eqn. 2.3 holds good. As the particles, which produce turbidity, are smaller than 0.1 cm, Stoke's law (Eqn. 2.4) is found valid for settling velocity.

Camp[17,18] states that heavy floc particles, significant in water treatment, settle in the transition region but most of

the particles settle well within the Stroke's law. Particles with irregular shapes settle some what more slowly than spheres of equivalent volume.

The flocs formed by coagulation are mostly shaped like snow flakes. The sheet-like flocculent particles expose a large portion of their mass to absorption of water and hence lowering density, very lacy floc particles may thus approach the density of water, with almost complete loss of settling velocity. In the process of agglomeration, compaction takes place, the framework of the floc is filled in, water is expelled and density increases[1,20]. The increase in the time of flocculation increases the opportunity of contact and enhences agglomeration to such an extent that the time required for the sedimentation is reduced. Opportunity for agglomeration is greater where concentration of the flocculent particles is high, simple because there exists greater opportunity for contact among greater number of particles, consequently the influence of agglomeration on subsidence is more pronounced in watar of high suspended solids concentration than those of low concentration.

Bond[20] deduced the equation relating the velocity of particle and its concentration in the liquid.

$$V_s = V_p (1 - f_s)^{2/3}) \qquad (2.5)$$

where V_s is the settling velocity, V_p, velocity of the particles relative to the upflowing liquid, s is the concentration of the particles in the liquid f is a constant depending on particleshape. Bond observed fair agreement of the Eqn.2.5 with

experimental settling velocities of alum and lime flocs in water. He also graphically related the settling velocity of fresh and aged alum slurry in water at different temperature.

Kalinske[21] has deduced, from some settling experiments, with alum floc and calcium carbonate, the velocity-concentration relation

$$V_s = V_p - KS \qquad (2.6)$$

Another equation relating velocity and concentration

$$V_s = V_p\ (1-ms) \qquad (2.7)$$

was developed by Schaafsma[20] and obtained good experimental aggrement with alum floc.

2.2.4 Quantity of Chemical Requirements:

Optimum flocculation represents attainment of a very complex equilibrium in which many variables are involved. Experiments[1] carried at reasonable constant condition of dispersion medium show that certain relation exists between the alum dosage and colour concentration of raw water which is a measure of organic fraction of colloids. The general relation based on the experimental results and plant performance is developed.

$$y = m\log x + b \qquad (2.8)$$

in which y stands for alum dosage in grain per gal to reduce colour to 20 mg/l and x for raw water colour in mg/l, m and b are constants.

Again surface adsorption is the process by which turbidity and colour are removed by the floc particles. During the time of flocculation, the adsorbed substance (adsorbate) is removed from liquid and deposited on solid surface of coagulant floc. Which clarifies the mechanism of adsorption. The phenomenon of adsorption states[22] that the amount of material adsorbed by a given weight of the adsorbent at a given temperature depends on the concentration of the solute. The quantitative studies of adsorption is possible through Freundlich adsorption equation

$$\frac{X}{M} = KC^{\frac{1}{n}} \qquad (2.9)$$

where X is the weight of the adsorbed substance, M is the weight of the adsorbing medium, C is the concentration of adsorbate remaining in water, K and n are the constants related to the concentration unit employed, type of the adsorption medium and its temperature. The expereession indicates that the system assumes an equilibrium condition at which the concentration of the adsorbate in the adsorbing medium X/M is a function of its residual concentration in water C.

The phenomenon has been applied to the removal of gases and odour, but not yet been applied to the removal of turbidity and colour.

2.2.5 Factors Influencing Coagulation:

(1) Kind of Coagulants:

The colloids are negative in nature[5,13,14]. The addition of a polyvalent cation will coagulate water. For all waters,

some type of coagulant does not coagulate well. The selection of the particular type depends upon the efficiency to form flocs, absorb colloids, and clarify rapidly. However, the selection of the particular type is based on its specific advantages and disadvantages.

(2) Quantity of Coagulant:

Quantity of coagulant required to clarify turbid waters varies widely. There is, of course, some relation between the turbidity of raw water and the proper coagulation dosage[2]. The other factors that control coagulant dosage are temperature, time of mixing, pH., ion exchange capacity, etc.

(3) Concentration of Colour and Turbidity:

Turbidity and colour are produced by fine colloids of size varying 0.2 micron to 5 microns which remain in stable state in water. Flocculation is highly influenced by the particle size and concentration of turbidity and colour. Finely divided suspended particles are more difficult to coagulate than the larger particles, necessiating a larger quantity of coagulant for a certain turbidity. Waters having sufficient turbidity agglomerate successfully and settle well.

(4) pH:

There is at least one pH zone in any water in which good flocculation occurs in the shortest time with a given dose of coagulant. Failure to operate within the optimum zone for a

given water may be the waste of chemicals. Studies on the effect of pH on coagulation concluded that "the more dilute the water in salt contents and less the alum added, the narrower becomes the pH zone within which optimum floc formation is to be found2. Different coagulant have different zone of optimum coagulation which is not always applicable for all type of waters.

(5) Time of Mixing and Flocculation:

Time of mixing and flocculation have significant importance upon the clarification of turbid waters. A long time of mixing increases the density of the flocs by expulsion of water from it and get havier by the adsorption of suspended particles and thus increases the settling velocity. The growth of floc depends upon two factors, collision which in turn is dependent upon the physical action particularly agitation, and adhesion which is controlled by the chemical and electrical forces.

(6) Temperature:

The main influence of temperature upon coagulation is its effect upon the time required for good floc formation. Generally the colder the water the larger the time required to produce good floc with a given amount of coagulant. Since the control of temperature is very difficult, it is overcomed by the adjustment of other factors.

(7) Violence of Agitation:

The rate of floc formation increases with the agitation as velocity gradient increases with it but after a certain

limit, the flocs break and shear off if the agitation exceeds the limit. The recommended velocity is generally 1 to 1.3 ft. per sec.

(8) Presence of Neuclei:

Suspended solid particles act as a neucleous for the initial formation of flocs. Water containing small amount of colloidal turbidity is more difficult to flocculate than the water containing large amount of coarse turbidity, and the difficulty can be overcomed by returning preformed aged flocs to water containing nascent flocs.

2.2.6 Chemicals and Chemical Reactions

(1) Aluminum Sulphate:

Alum (aluminum sulphate) is the most widely used coagulant. Water contains bicarbonate as natural alkalinity in which case the chemical reaction proceeds as follows:

$$AL_2(SO_4)_3.XH_2O+3Ca(HCO_3)_2 = 2AL(OH)_3+3CaSO_4+XH_2O+6CO_2 \quad (2.18)$$

The aluminium hydroxide is the floc. In the process all aluminum added precipitates and the temporary or bicarbonate hardness caused by calcium bicarbonate is reduced and parmanent or non-carbonate hardness caused by $CaSO_4$ is increased, with the another addition of carbon dioxide.

Some water have insufficient natural alkalinity, in these cases, alkalinity in the form of lime (CaO, and $CaCO_3$) and soda ash (Na_2CO_3) is generally added. Calcium oxide dissolved in

water forms $Ca(OH)_2$ which reacts with alum.

$$Al_2(SO_4)_3.XH_2O + 3Ca(OH)_2 = 2\ Al(OH)_3 + 3CaSO_4 + XH_2O$$

$$Al_2(SO_4)_3.\ XH_2O+3Na_2CO_3+3H_2O = 2Al(OH)_3+3Na_2SO_4+3CO_2+XH_2O.$$

(2) Iron Salts:

Ferrous sulphate reacts with natural alkalinity but the reaction is very slow, addition of caustic alkalinity causes speedy reaction.

$$Fe\ SO_4 + Ca(HCO_3)_2 = Fe(HCO_3)_2 + CaSO_4$$

$$Fe(HCO_3)_2 + 2Ca(OH)_2 = Fe(OH)_2 + 2CaCO_3 + 2H_2O$$

or $$Fe\ SO_4.7H_2O + Ca(OH)_2 = Fe(OH)_2 + CaSO_4 + 7H_2O$$

Dissolved oxygen present in water oxidizes $Fe(OH)_2$ to $Fe(OH)_3$ and flocs are formed.

$$4\ Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$$

In this method less hardness in added.

Ferric sulphate may be used with natural alkalinity or added alkalinity and reactions are respectively as follows:

$$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 = 3CaSO_4 + 2Fe(OH)_3 + 6CO_2$$

$$Fe_2(SO_4)_3 + 3Ca(OH) = 3CaSO_4 + 2Fe(OH)_3$$

Ferric chloride when used as a coagulant reacts with natural as well as added alkalinity in the form of calcium hidroxide.

$$2Fe\ Cl_3 + 3Ca(HCO_3)_2 = 2Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

$$2FeCl_3 + 3Ca(OH)_2 = 2Fe(OH)_3 + 3CaCl_2$$

chlorinated copperas is a mixture of $FeCl_3$ and $Fe_2(SO_4)_3$ prepared by adding chlorine to a solution of ferrous sulphate.

$$6FeSO_4 + 3Cl_2 = 2Fe_2(SO_4)_3 + 2FeCl_3$$

This is effective in colour removing and forms tough flocs which settle well and can work in the wide range of pH.

(3) Sodium Alluminate:

Sodium alluminate has been successfully used as a coagulant for water treatment. If it is used with aluminum sulphate, the following reactions takes place.

$$3Na_2Al_2O_4 + Al_2(SO_4)_3.18H_2O = 8Al(OH)_3 + 3Na_2SO_4 + 6H_2O$$

$$2Na_2Al_2O_4 + CO_2 + 3H_2O = NaCO_3 + 2Al(OH)_3$$

Sodium aluminate alone reacts with Ca and M_g salts and added alkalinity in water to form aluminate of metal which are effective as coagulant.

$$Ca(HCO_3)_2 + Na_2Al_2O_4 = CaAl_2O_4 + Na_2CO_3 + CO_2 + H_2O$$

$$Ca(SO_4) + Na_2Al_2O_4 = CaAl_2O_4 + Na_2(SO_4)$$

$$CaCl_2 + Na_2Al_2O_4 = CaAl_2O_4 + 2Nacl$$

$$Ca(OH)_2 + Na_2Al_2O_4 = CaAl_2O_4 + 2Na(OH)$$

The reactions with magnesium salt are similar,

(4) Other Chemicals:

Others like lime and soda ash are used to produce artificial alkalinity and pH adjustment. Sodium silicate eids tc built larger flocs. Clay is used to increase the weight of flocs for better settling. Amonia alum is generally used for the treatment of water in small installation like swimming pool, ice plant, laundries etc.

2.3 CHEMICAL PROCESS OF DISINFECTION

2.3.1 Introduction:

The safety and palatability of water is often hinge upon the elimination or destruction of two groups of living organisms, (a) the pathogenic bacteria and other micro-organisms that may infect man through his use of contaminated water, and (b) the algae and related water-booms that may render water aesthetically unfit for human consumption with the creation of taste, odour, colour and other associated problems. The term strilization means killing of all organisms present in water. It is impracticable to attempt to kill all water-organisms within technical and financial limitation[12], the practicable objective is particularly to destroy pathogenic microorganisms called disinfection, and generally to eliminate organisms those capable of multiplication in water mains with the consequent development of taste, odour and objectionable forms. Hence, in waterworks practices, the term used is disinfection, means the killing of pathogenic bacteria present in water to prevent water-borne diseases.

2.3.2 Disinfectants:

(1) Chlorine:

Chlorine and its compounds, such as hypochloride of lime $Ca(OCl_2)$, and Sodium hypochloride (NaOCl) are widely used for disinfection and addition of chloride (free) or its compound in water is termed as chlorination. Chloride of lime or bleaching powder or hypochloride of lime are commercially available having 33 per cent of free available chlorine when fresh. Sodium hypochloride has 15 per cent available chlorine.

(2) Ozone:

Ozone (O_3) is sometimes, used as a disinfectant. Passage of electric spark through air will cause triatomic oxygen terme as ozone has the third atom loosely bound. It has the capability of readily splitting up into oxygen molecule and nascent oxygen. Releasing ozone in water will disinfect it and will reduce the organic matter present in it through the action of nascent oxygen.

(3) Lime:

Use of lime in softening water showed incidentally that requisite quantity of lime would also disinfect. Experiment has shown that addition of lime in polluted waters to absorb Co_2 has also reduced coloforms 99.67 per cent is 5 hrs[5].

(4) Ultraviolet Light:

Ultraviolet invisible rays are very effective in killing all types of bacteria and spores. The process of disinfection

is costlier than chlorination but produce no taste and odour. Ultravoilet rays are not effective for turbid and coloured water exceeding 15 mg/l.

(5) Heat:

Heat alone is an excellent disinfectant. But heated water cannot be supplied to the public, rather instruction can only be given to use heated water.

2.3.3 Theory:

The primary purpose of addition of chlorine to water is to destroy bacteria and other microorganism. In early period of chlorination of water, the hypothesis, generally held was that the chlorine reacts directly with water to produce nascent oxygen[11].

$$H_2O + Cl_2 = 2HCl + O$$

This nascent oxygen has certain bactericidal effect by its action on the cells. This theory has been found fallacious in as much as it has been demonstrated that the batericidal effect is not proportional to the concentration of nascent oxygen. The belief generally accepted is that the cell wall structure and the cell contents contain protein and amino groups with which the chlorine reacts. This action alters the chemical characteristics of cell contents and destroys life and may cause disinfection of cell structures[1,11]. Some recent works by Green and Stumpf[9] indicates that the primary reaction is one between chlorine and a certain engyme, essential for the becterial reproduction. It was found

that once the power of glucose oxydization by the bacterial cell is lost, the bacterial cell die and bacteria once inactivated by chlorine cannot be reactivated.

In absence of organic matter capable of oxydation or chlorination the germicidal reaction proceeds more rapidly with the increase in H^+ concentration, that is, with more undissociated hypochlorous acid. Specific reaction possibly with amine end chains which characterize protein molecule takes place. On the other hand, presence of oxydizable organic matter reduces chlorine concentration to the detriment of the germicidal reaction. The both oxidization and germicidial reactions are speeded up in more acid and retarded in alkaline water. At pH 10 disinfection reaction almost ceases.

2.3.4 Chemical Reactions:

When elementary chlorine is dessolved in water it react in the following way.

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

It is a reversible reaction free acids, HOCl, HCl further dissociates.

$$HCl \rightleftharpoons H^+ + Cl^-$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

Hypochlorous acid is a weak acid and its dissociation is controlled by the pH of water.

Chlorine compound, $Ca(OCl)_2$ or NaOCl dissociates with the formation of nypochlorous ion.

$$Ca(OCl)_2 \rightleftharpoons Ca^{++} + 2OCl^-$$

$$NaOCl \rightleftharpoons Na^+ + OCl^-$$

The above reactions are dependent on the pH of water. At lower pH (below 5.0), the chlorine present as molecular chlorine at pH 5.0 to 6.0, the chlorine exist almost entirely as hypochlorous acid and above pH 6.0, hypochlorous ions are present and predominate above pH 7.5.

2.3.5 Chlorine Demand and Residual Chlorine:

Chlorine demand is defined as "the differences between the amount of chlorine added to water and the amount of chlorire (free available and combined available) remaining at the end of a specific contact period"[11]. And the chlorine remain at the end of a specific contact period is known as chlorine residual. In the Fig. 2.2 a hypothetical time concentration curve of the chlorine demand ten minutes after the application of initial dose, the residual chlorine is measured.

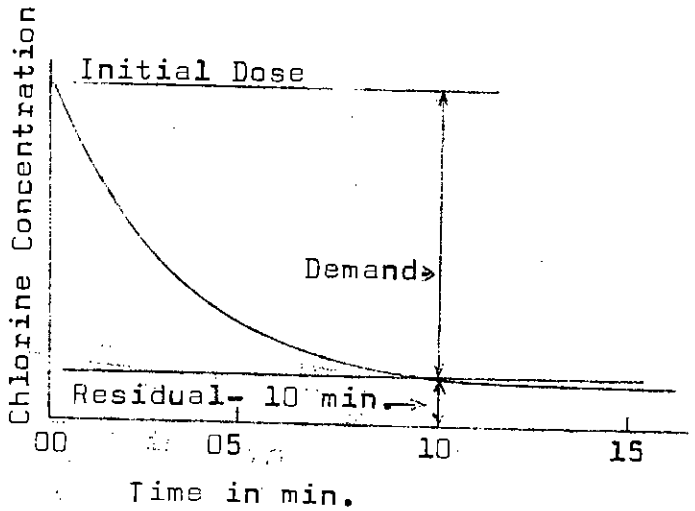

Fig. 2.2. Chlorine Demand and Chlorine Residual.

The loss indicates 10 minutes demand. As the chlorine concentration and speed of disinfection are linearly related, the ordinate of the curve could represent actual speed of disinfection rather than the concentration, then the area of this curve would represent the total disinfection.

2.3.6 Available Chlorine:

The chlorine existing in water as hypochlorous acid, hypochlorite ion and molecular chlorine is defined as free available chlorine[2]. Chlorine is very active element. When it is added in water as free chlorine, it will combine with organic and in-organic matter and oxidize some organic and inorganic compounds. Free available Cl_2 reacts with substances such as phenol and amonia to form chlorine-substitution or chlorinated products, chlorophenol, chloromines.

$$C_6H_6\ OH + Cl_2 = C_6H_5OH\ Cl + HCl$$

$$NH_3 + Cl_2 = NH_2Cl + HCl$$

$$NH_2Cl + Cl_2 = NHCl_2 + HCl$$

$$NHCl_2 + Cl_2 = NCl_3 + HCl$$

The chloramines are less active than hypochlorous acid, hence the formation chlorinated products reduces the activity considerably. Available free chlorine also reacts with organic compounds containing Nitrogen (such as protein, and amino acid) to form chlorine derivatives. The chloramine and chlorine derivatives have a lower oxidizing potential than that of free available chlorine but the chlorine combined in these forms are

still available for chemical reactions. That chlorine existing in water in chemical combination with ammonia, or organic nitrogen compounds is defined as combined available chlorine.

2.3.7 Break Point Chlorination:

The break point chlorination means the chlorination of water to the extent that chlorine combination tastes and odours have been avoided, and other tastes and odours due to other substances which can be oxidized by chlorine have been eliminated, and that the chlorine available for further disinfection is free available chlorine.

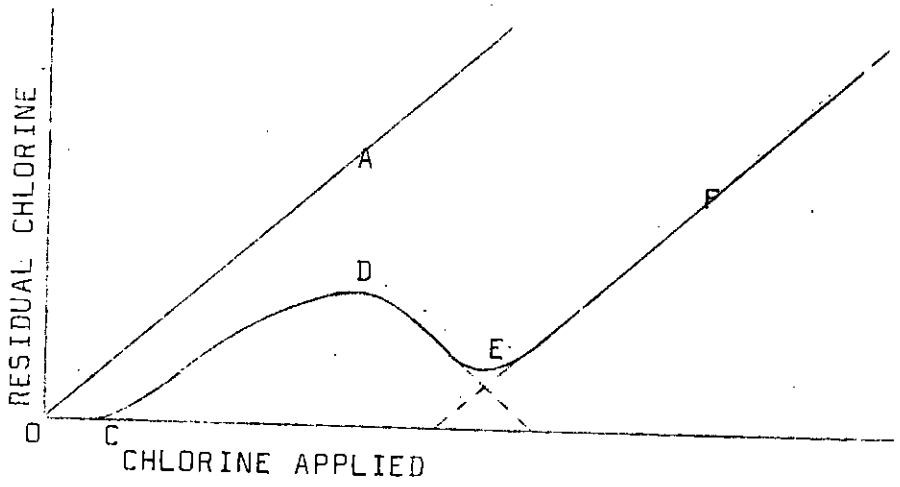

Fig. 2.3 The Chlorine Break Point.

In the Fig. 2.3 the curve CDEF is the residual chlorine curve and OA is the no demand curve. The difference of the curves is chlorine demand. Natural water may contain substances, those of phenolic or amino nature which consume chlorine, and may start at C instead of point O showing an initial demand.

With the addition of chlorine, chloramine and chlorine derivatives concentration increases showing a peak residual at D. With the further application of chlorine the reactions are completed and the end products do not react with orthotolidine to show residual chlorine, thus residual chlorine decreases with the application of more chlorine until the break point E is reached when the chlorine applied remains as free residual and the curve show an increase in residual gaining the slope of the no demand curve OA. The residual chlorine curve shows a minimum at E where the chloramine and free residual are in equal proportion. Tha chlorine for break point chlorination is to be applied slightly above the break point E.

2.3.8 Factors Affecting Disinfection:

The efficiency of disinfection depend on[2]

(1) The nature and concentration of organism in water to be destroyed.

(2) The nature and amount of disinfecting agent

(3) The characteristics of water

(4) pH and temperature of water

(5) The time of Concentration.

2.4 CONCLUSIONS

Turbidity and colour are the most important parameters for water quality prediction and its importance in the water

treatment processes is vital. Works of different investigators presented the fundamental mechanism of coagulation-sedimentation for the removal of colour and turbidity. Studies of camp[15,17,18] show the effect of agitation and velocity gradient upon floc formation. Kalinske[21] and Bond[20] investigated the influence of various parameters upon floccution and settling characteristics of alum and lime flocs. Markle[14], Yerachmiel[5] and other investigators[23,24] worked on floc formation in turbid waters. The preceding investigators considered coagulation sedimentation a prerequisite for rapid filtration, not the only process of treatment in water clarification. Hence, a quantitative relationship between the coagulant dosage and turbidity of raw water has not yet been developed. A typical correlation between coagulant requirement and colloidal colour concentration is proposed by Gehm[1] which also for general practical use awaits the accumulation of sufficient basic data.

CHAPTER 3

EXPERIMENTAL APPROACH

3.1 SAMPLING

The proper collection of samples of water for analysis is of great importance because of the danger of contamination at the time of sampling. However, sampling for ordinary chemical analysis require no other precaution than collection in a clear glass container of good quality having glass stopper. Samples for bacterial analysis must be collected in a sterilized bottle with stoper.

Samples of water collected from different sources fairly represent the body of the water from which they were collecte The sample were collected from a considerable distance away from the bank, neither from the surface nor from the bottom. While collecting water in the sampling bottle, the open bottle was plunged beneath the surface of water, having the neck downward. The bottle was then moved with proper care so that no water enters inside that had been in contact with hands. The sample collected were at once transported to the laboratory and almost all the physical and chemical properties were determined. Possible efforts were made to minimize the time between collection and analysis, so that no significant change in water qualities occur. The samples were also kept refrigerated in case of any delay in the laboratory analysis.

3.2 PARAMETERS CONSIDERED

Water treatment consist of two subsequent operations

(1) Water clarification

(2) Water disinfection

Water clarification is the removal of turbidity, colour and other suspended matter. These are not dangerous characteristics of water but objectionable from the stand-point of appearance. Aesthetically, turbid and coloured water is not acceptable to the consumers, rather it is repulsive. If the water is highly turbid, pathoganic and other microorganism some times may be encased in turbid waters[10]. The International Standard for Drinking Water Supplies (Table 1.3) limits the maximum permissible turbidity and colour to 10 mg/l and 20 mg/l respectively.

Disinfection means killing of pathogenic microorganisms which are the impurities of greatest importance in surface waters to be used for public water supplies. Most common diseases are caused by pathogenic microorganisms present in contaminated water (Table 1.1). Both present and past literature abounds with the history of waterborne epidemics around the world caused by polluted water[23,25]. In Bangladesh, water borne epidemics have their regular seasonal occurances throughout the years. To make water fit for domestic uses, removal or killing of microorganisms is highly desirable. The WHO International Standards for Drinking Water Supplies stresses on the complete removal of pathogenic microorganisms.

3.3 EXPERIMENTAL APPARATUS:

Mixing and flocculation are the important operations in the coagulation sedimentation process. Mixing and flocculation are done by stirring the sample of water with coagulants. Two methods stirring studied are (1) stirring by revolving paddles (Jar Test Apparatus), (2) Air Agitation.

(1) Jar Test Apparatus:

The apparatus consist of six metatic paddles each 4" long and $\frac{3}{4}$" wide attached to a vertical rod. A rotating velocity is transferred to the vertical rods by a horizontal shaft through gear system. The horizontal shaft is rotated by a electric motor. The speed of the motor, and consequently the speed of the paddle can be controlled by an adjustable switch. There is a speed indicator attached on the body of the apparatus (Fig. 3.1). By careful adjustment, a constant speed can be maintained throughout the time of mixing and flocculation.

(2) Aeration Apparatus:

In the laboratory, a suitable device for agitation of water by air was not available. Agitation is commonly provided by inducing air inside the water samples. The rising velocity of the air bubbles creates sufficient agitation in water for the formation of flocs. The air bubble also oxidize the impurities and can increase the dissolved oxygen concentration in water. An apparatus for this purpose has been designed and

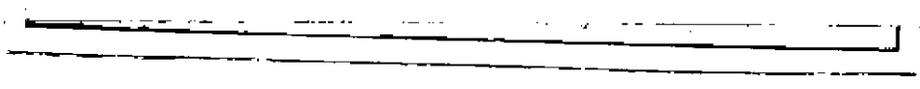

Fig.3.2 Aeration Apparatus.

fabricated in the Glass Blowing Laboratory of Bangladesh Atomic Energy Centre, Dacca. The simple apoaratus consist of a glass rod $\frac{5}{8}$" in diameter and 30" long to receive the main supply of air from an air compressor through rubber tube (Fig.3.2).

The air is then distributed to the secondary tubes, $\frac{1}{8}$" in diameter and 10" long, each branched perpendicularly from the main tube. The ends of each branch tubes has been shaped like nozzles of equal openings for the equitable distribution of air in each sample. The branch tubes can be adjusted to release air at any desirable depth in the sample by raising and lowering the supports of the main tube. The supply of air may, however, be controlled either by discharging air in the atmosphere through one or two branch tubes, or by controlling the release valve of the air compressor.

3.4 METHODOLOGY

Water sample were collected from various surface water sources in and around Dacca City and routine laboratory analysis were performed according to the Standard Method[26] to determine water quality of the sources.The quality of water is determined by parameters, grouped into three classes; physical, chemical and Bacteriological. Temperature, colour, turbidity, dissolved solids and total solids from the physical qualities, carbon dioxide, acidity, alkalinity, DO, BOD from the chemical qualities were determined. Bacterilogical quantities include all types of bacteria. Turbidity was determined with the Hellige turbidimeter (Fig. 3.3) at the time of collection and after two hours of plain sedimentation, before the coagulation

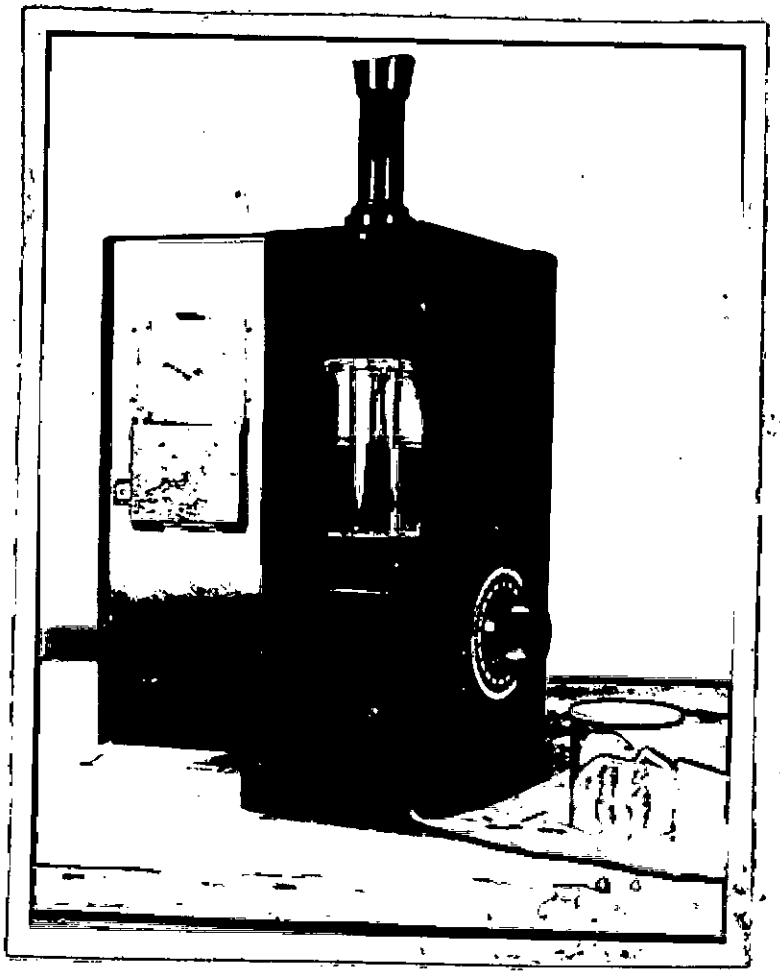

Fig.3.3 Hellige Turbidimeter.

sedimentation was started. Hellige colour comparator was used to determine the colour of raw water. The turbidimeter used for water, analysis was found to be satisfactory. A minimum concentration of 0.1 mg/l can be read precisely. Tylors slide comparator (Fig. 3.4) was used to determine concentration of chlorine in water by orthotolidine test. At the time of sampling Hellige pocket pH meter was used to know the pH of the water approximately. In the laboratory an automatic pH meter (Fig.3.5) was available to determine pH with higher degree of accurary.

The other tests for chemical qualities were performed by tritration methods. The chemicals were prepared as instructed in the Laboratory manual[27] for chemical and bacteriological Analysis of Water and Waste Water.

(1) Water Clarification:

The primary clarification of water was initiated by the removal of unstable or settleable turbid particles by plain sedimentation of two hours. The secondary clarification was madeby the process of chemical coagulation. The selection of coagulant and the method of mixing for chemical coagulation were considered of first order importance. A selective dose of 40 mg/l of the available chemicals such as alum, ferrous sulphate, soda ash and lime were mixed with water in separate jars and floc formation was initiated by gentle stirring with electrically operated paddles (Jar Test Apparatus) and by air agitation (Fig.3.1 and 3.2) and it was continued for 20 minutes. The same procedure was followed for another three samples with

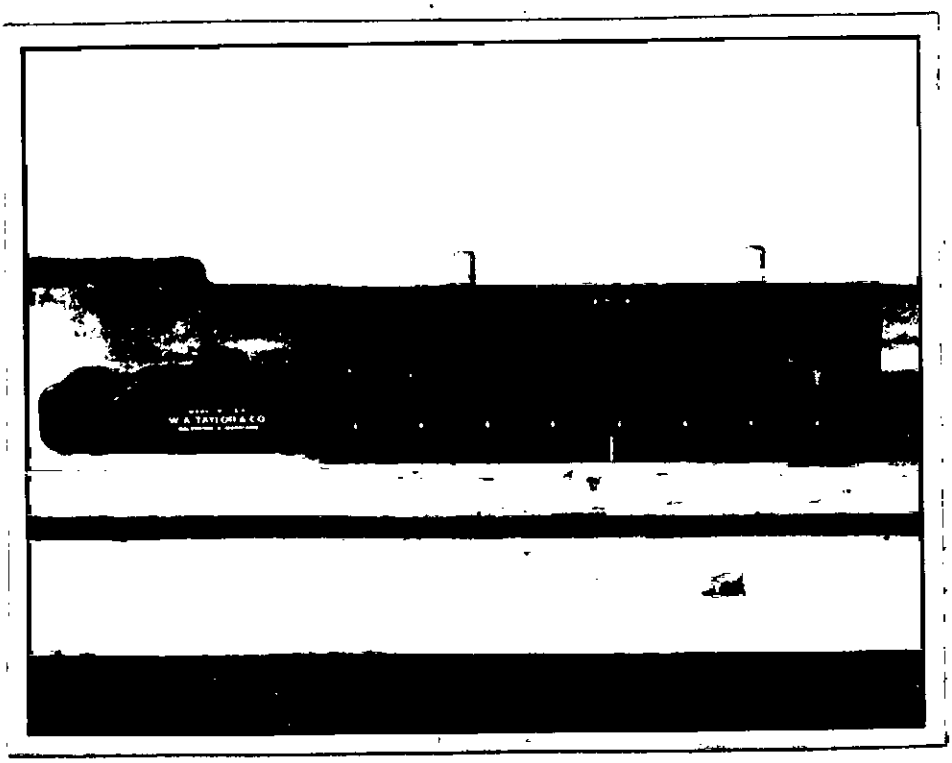

Fig.3.4 Tyler's Slide Comparator.

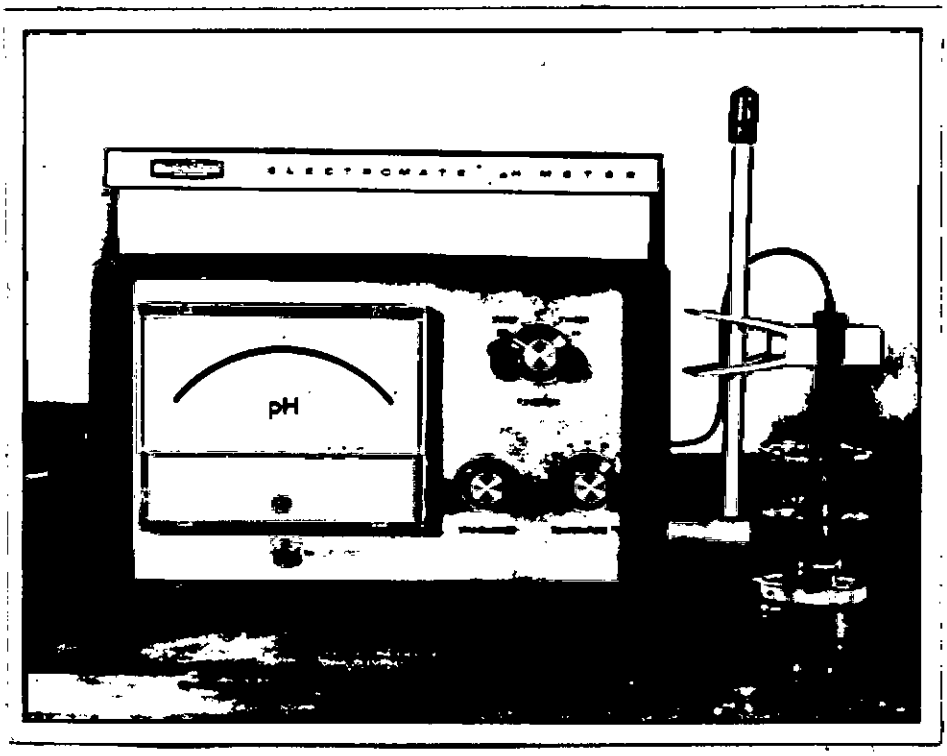

Fig.3.5 Automatic pH Meter.

25 mg/l alum [$Al_2(SO_4)_3$] in each and 15 mg/l sodium carbonate (Na_2CO_3), calcium hydroxide [$Ca(OH)_2$] , and calcium carbonate ($CaCO_3$) in the respective samples. The flocs were then allowed to settle for 24 hours and degree of clarification at different time intervals were determined with turbidimeter.

In the second stage of the teste, attempt was made to determine the optimum mixing time for the proper floc formation. For the test, a representative sample of Buriganga River water was taken in 8 jars, and jar test was started with a speed of 40 rpm after the addition of 10 mg/l of alum to each of the samples. The jars were taken out from the paddles at 3rd,5th, 10th, 15th, 20th, 25th, 30th and 35th minutes, and the flocs were allowed to settle. The turbidity of the samples in each jar were recorded at different time interval. The above experiments were repeated with the coagulant doses of 20, 30, 40 and 60 mg/l and the effect of different mixing time, on various coagulant dosage were studied.

To study the effect of turbidity and colour concentration upon the consumption of alum dosage, a total of 14 samples were collected from different sources - the Buriganga River, Dhanmondi Lake, Ramna Lake and some ponds having different concentration of turbidity and colour. The coagulation and sedimentation of the each samples were observed in the laboratory very carefully. During the experiment the variation of other factors like violence of agitation, pH, temperature, which influence coagulation were maintained within shorter range. The apparatus was operated at 40 rpm, the temperature range was 24.4°C to 26.9°C (Table 3.1)

and variations of pH of the sample from the Buriganga River were noted 7.3 to 7.6 with few exceptions having pH 8.5 and as low as 7.0 (Table 3.2). Each of the samples was mixed and flocculated for 20 minutes with coagulant dosage of 10,20,30, 40 and 60 mg/l and residual turbidity was recorded at various time interval for 24 hours. The residual colour was also recorded after the complete sedimentation of the flocs.

(2) Disinfection:

Bleaching powder was used for the purpose of disinfection of water samples. As the solution with higher concentration of chlorine is not stable[28], a solution of 40 mg/l concentration of chlorine was prepared with bleaching powder and standardized according to the Standard Method[26,27].

A series of jars were arranged in a row containing the sample to be chlorinated and to each of the jar, a calculated amount of chlorine water was added to get a different concentration of applied chlorine. Water in each of the jars was stirred gently and a time of 10 minutes were allowed for the reactions. The residual chlorine in water of each of jars was determined by orthotolidine test[26,27]. As many as 33 readings for residual chlorine were taken for a sample with a small increment of applied chlorine at each stage. At every stage of chlorinations, the presence of higher forms of plants and animals, were observed under the microscope. The higher plants and animals are more tolerant in chlorine water, hence its absence was assumed to be criterian for the complete absence of bacteria.

To study the effect of water clarification upon chlorine demand, the residual chlorine test as described earlier was performed on raw water, and water treated and clarified with 20, 40, 60 and 80 mg/l of alum. Finally the residual chlorine in a distilled water produced in the laboratory was also determined for the various dosage of applied chlorine.

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 WATER QUALITIES

The physical, chemical and bio-chemical qualities of water samples representing different surface sources are listed in Tables 3.1 and 3.2 (Appendix-B). Almost all the samples have the parameters measuring water quality within the permissible limits of International Standards for Water Source (Table 1.1). Only Ramna Lake water, at the time of collection of the year, contained excessive decomposable organic matter showing higher BOD (8.20 mg/l) which exceeds the International Standard (6.0 mg/l) for water sources. The other important observation made was that the samples collected from ponds and lakes contained more stable turbidity showing no significant reduction by plain sedimentation (Table 3.1).

4.2 COAGULANTS AND MIXING METHOD

The results of coagulation-sedimentation, and aeration sedimentation are presented in Tables 4.1a and 4.1b (appendix-B) respectively. The graphical representation of the results are shown in Fig. 4.1. The flocs formed during coagulation by mechanical mixing in jar test were much better than those formed by air agitation. The flocs formed by air agitation may be termed as micro-flocs which remain in the nascent state of formation without agglomeration to form larger flocs and observed to have poor settling characteristics. This may be due

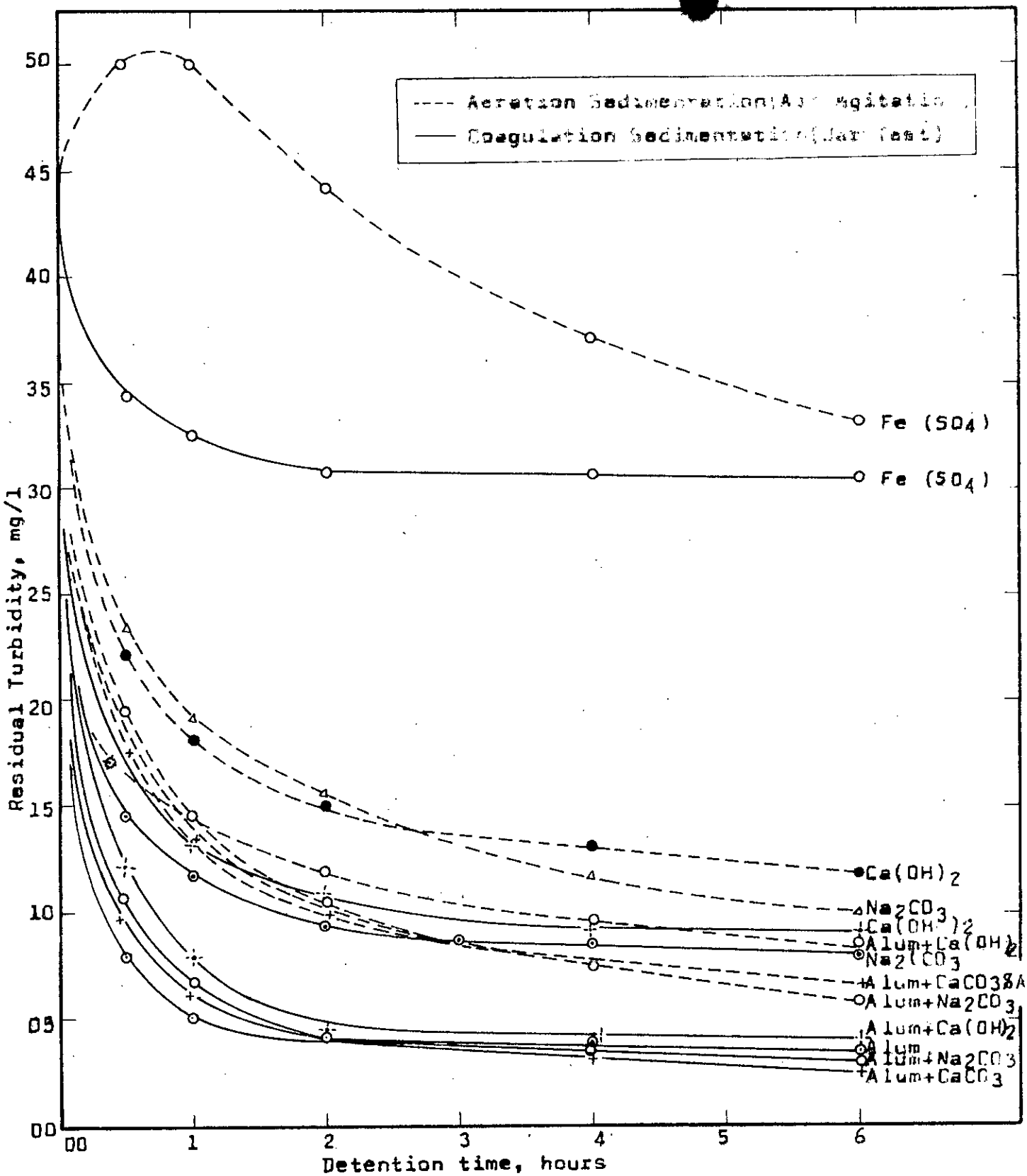

FIG.4.1 SETTLING CHARACTERISTICS OF FLOCS FORMED BY DIFFERENT COAGULANTS BY AIR AGITATION AND JAR TEST.

to the facts that the rising velocity of air bubbles in water causes violent agitation, much higher than the optimum agitation required for good floc formation. This violent agitation, which cannot be controlled by adjustments, allows no scope for the growth of larger flocs by adhesion of the smaller flocs, rather shears off the flocs to smallest elementary forms. Camp[15], for this reason, emphasised upon the miximum limit of agitation, beyond which shearing of flocs are observed. It is also noticed that certain micro-flocs formed by air agitation always remain in suspension, a part remains floating on the surface and other settles with a poor setting velocity, which lead to conclude that specific gravity of flocs formed by aeration was much less than those formed by mechanical mixing. The comparative study of the settling characteristics of the flocs formed by two methods can be observed in Fig. 4.1. Water clarification by air agitation is, therefore, a delayed process. Hence to remove the flocs formed by aeration and consequently to remove turbidity, only sedimentation is not enough and subsequent filtration, as practiced in the conventional method, is essential.

The settling characteristics of alum, $[Al_2(SO_4)_3]$ and a combination of alum and soda ash (Na_2CO_3), alum and calcium hydroxide $[Ca(OH)_2]$, alum and calcium carbonate ($CaCO_3$) were almost similar making insignificant differences throughout the observed length of the settling period (Fig. 4.1). Any of them can be recommended as a good coagulant. Ferrous sulphate was found to be completely unsuitable for coagulation, rather it imparts colour to water to such an extent that requires additional

treatment for removal. The difficulty was admitted by Steel[5], who stated that "colour may be adversely affected" when ferrous sulphate is used as a coagulant for water treatment. An increase of turbidity was observed initially (Fig.4.1) when water containing ferrous sulphate as coagulant was aerated and finally it was reduced to certain extent after 24 hours sedimentation. This may be due to the oxidation of the iron compounds by aeration, or the chemicals could contain certain oxides of iron, which in water produced excess turbidity and colour. The other chemicals like $NaCO_3$, $Ca(OH)_2$, $CaCO_3$ alone in water did not show satisfactory results.

4.3 MIXING AND FLOCCUTION TIME:

Mixing and flocculation time have significant effect upon the clarification of turbid waters. As the time of mixing increases the flocs become more dense by expelling water and more heavy by adsorption of turbid particles from water, and thus the settling velocity and the degree of clarification is improved. Table 4.2 (Appendix-B) shows the effect of mixing time and coagulant dosage upon the rate of clarification of turbid waters. Tables 4.3a and Table 4.3b (Appendix-B) show the percentage turbidity removal in 24 hrs and 2 hrs detention time respectively of a sample of water, for various dosage of alum and flocculation time. As much as 95.6% of turbidity can be removed by only alum coagulation. Fig. 4.3a and Fig. 4.3b are the graphical representations of Tables 4.3a and 4.3b, which indicate that the curves gradually becomes horizontal, that is,

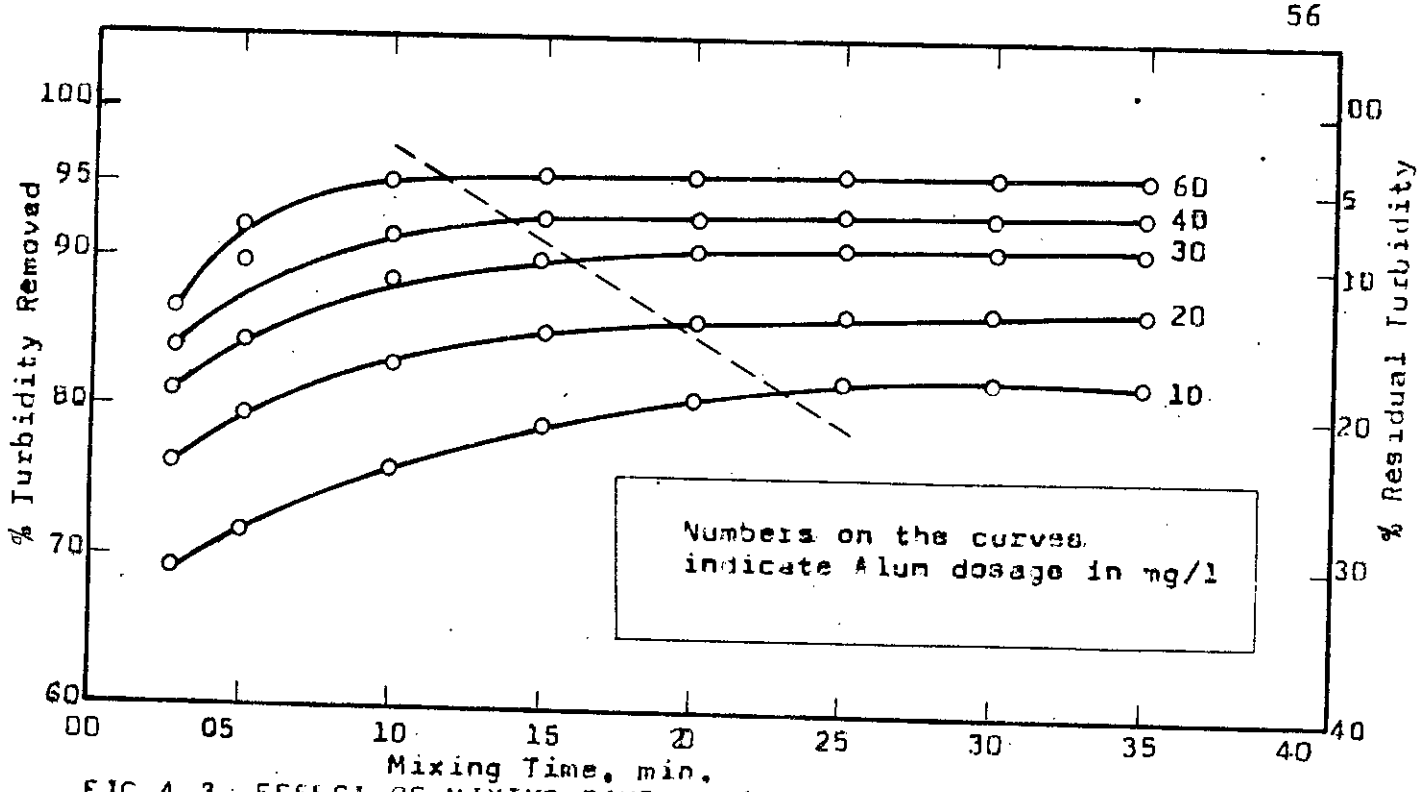

FIG.4.3a EFFECT OF MIXING TIME ON % TURBIDITY REMOVAL IN 24 HOURS. DETENTION TIME.

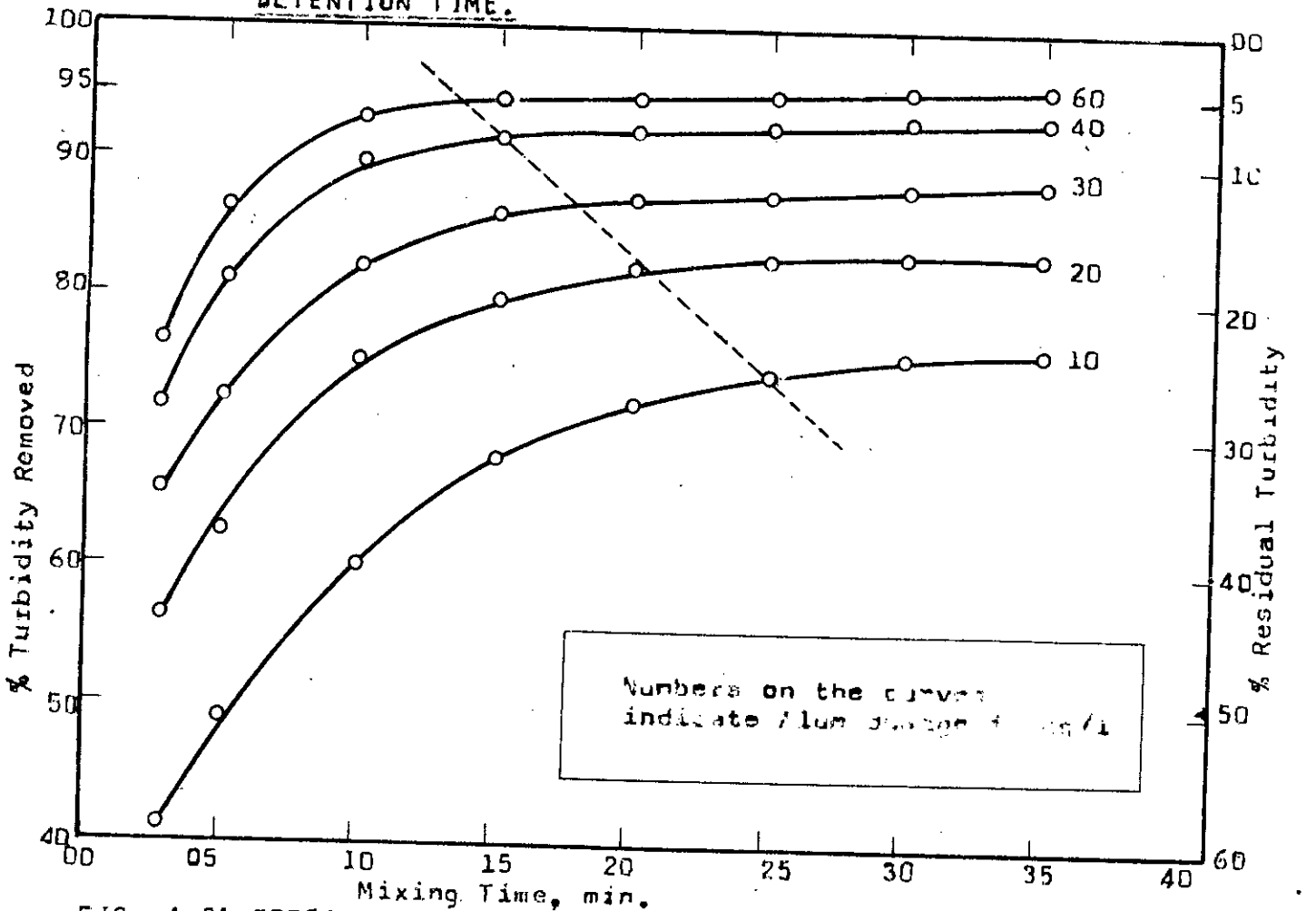

FIG. 4.3b EFFECT OF MIXING TIME ON % TURBIDITY REMOVAL IN 2 HOURS DETENTION TIME.

after a certain mixing and flocculation time, the removal of turbidity was not effective. The degree of clarification for any mixing time is dependent upon the alum dosage and detention time. The fact can be explained in the light of the attainment of the equilibrium condition in the phenomenon of adsorption, which states that for a sample of water, at a perticular temperature, the concentration of adsorbate in the adsorbing medium is a function of its residual concentration in water, when it reaches an equilibrium condition[1,2], i.e., more the adsorbing substance (adsorbent) the less is the residual concentration of turbid particles in water.

The optimum time of mixing i.e. the time at which the curves (Figs. 4.3a and 4.3b) becomes horizontal, depends largely upon alum dosage and to certain extent, on the detention time allowed. An exact demarkation of the optimum mixing time is difficult; a broken line is drawn through the mixing time of optimum coagulation, the graphical representation of which is shown in Fig. 4.2 (Appendix-B). It shows that the time of mixing required for optimum coagulation increases with the decrease of coagulant dosage. It was for the reason, that at lower quantity of alum dosage, the flocs formed were less, and the probability of random collision between the turbidity producing particles and alum flocs were lowered. As a result, it took more time to reach an equilibrium condition at which the flocs were saturated and could take no turbid particles from water. However, a mixing time of 15 to 25 minutes can be considered sufficient for the attainment of optimum coagulation.

4.4 DETENTION TIME

The effect of coagulation on pH, colour, and turbidity of different samples of water were studied and tabulated in Table 4.4 to 4.17 (Appendix-B) and graphical representation were made in Figs. 4.4 to 4.17 (Appendix-B). Turbidity removal for various dosage of coagulants and specified sedimentation time of 1 hr., 2 hrs, 4 hrs, and 24 hrs were taken from Fig. 4.4 to 4.17 and presented in Tables 4.18 to 4.31.(Appendix-B). Graphically, the three variable, residual turbidity, coagulant dosage and detention time of Tables 4.18 to 4.31 are shown in Fig.4.18 to 4.31 (Appendix-B), which show that the curves representing clarification in 2 hrs, 4 hrs, 8 hrs. and 24 hrs detention time are closely spaced. This indicates that the efficiency in turbidity removal for detention time above 2 hrs is not significant. On the other hand, the increase in detention time, for example, from 2 hrs to 4 hrs will reduce the total capacity (daily rate) of a plant to half without noticeable improvement of water quality.

4.5 COAGULANT DOSAGE

The coagulant dosage required for water treatment for the removal of turbidity and colour depends upon the degree of clarification desired and detention time. International Standard for miximum allowable turbidity are 10 and 5 mg/l as recommended by the USPHS and the WHO respectively. The coagulant dosage required to reduce turbidity to permissible concentration can be directly read in Figs. 4.18 to 4.31 (Appendix-B). The coagulant

dosage required to reduce turbidity to 5 mg/l and 10 mg/l at different detention time are presented in Tables 4.32 and 4.33 (Appendix-B) respectively. The coagulant dosages are plotted against raw water turbidity in Fig. 4.32a and 4.33a, and it is observed that the points in the graphs for water of the same source lies on a smooth curve. This lead to the conclusion that there exists certain relationship between the turbidity of raw water collected from same source and coagulant dosage required for the recommended degree of clarification. The points obtained for other water samples collected from Ramna Lake, Dhanmondi Lake, and various ponds do not lie on the same curve, but other correlation may be obtained with the samples collected from each of the sources which need extensive studies. It is evident that the turbidity producing particles of each of the water body, stangnant or running, may not be the same and its removal may not demand equal quantity of coagulants.

The correlation between turbidity of raw water and coagulant dosage is observed to maintain a linear relationship in semi-log scales, having turbidity in the log scale (Fig.4.32b and 4.33b). The mathematical expressions to correlate the variables (Fig. 4.32b) for the reduction of turbidity to the limiting concentration of 5 mg/l are as follows:

$$\underline{a} = 29.5 \log_{10} \underline{t} - 22.40 \text{ (for detention time of 24 hrs.)} \quad (4.1)$$

$$\underline{a} = 33.2 \log_{10} \underline{t} - 26.05 \text{ (" " " 8 hrs.)} \quad (4.2)$$

$$\underline{a} = 35.8 \log_{10} \underline{t} - 27.05 \text{ (" " " 4 hrs.)} \quad (4.3)$$

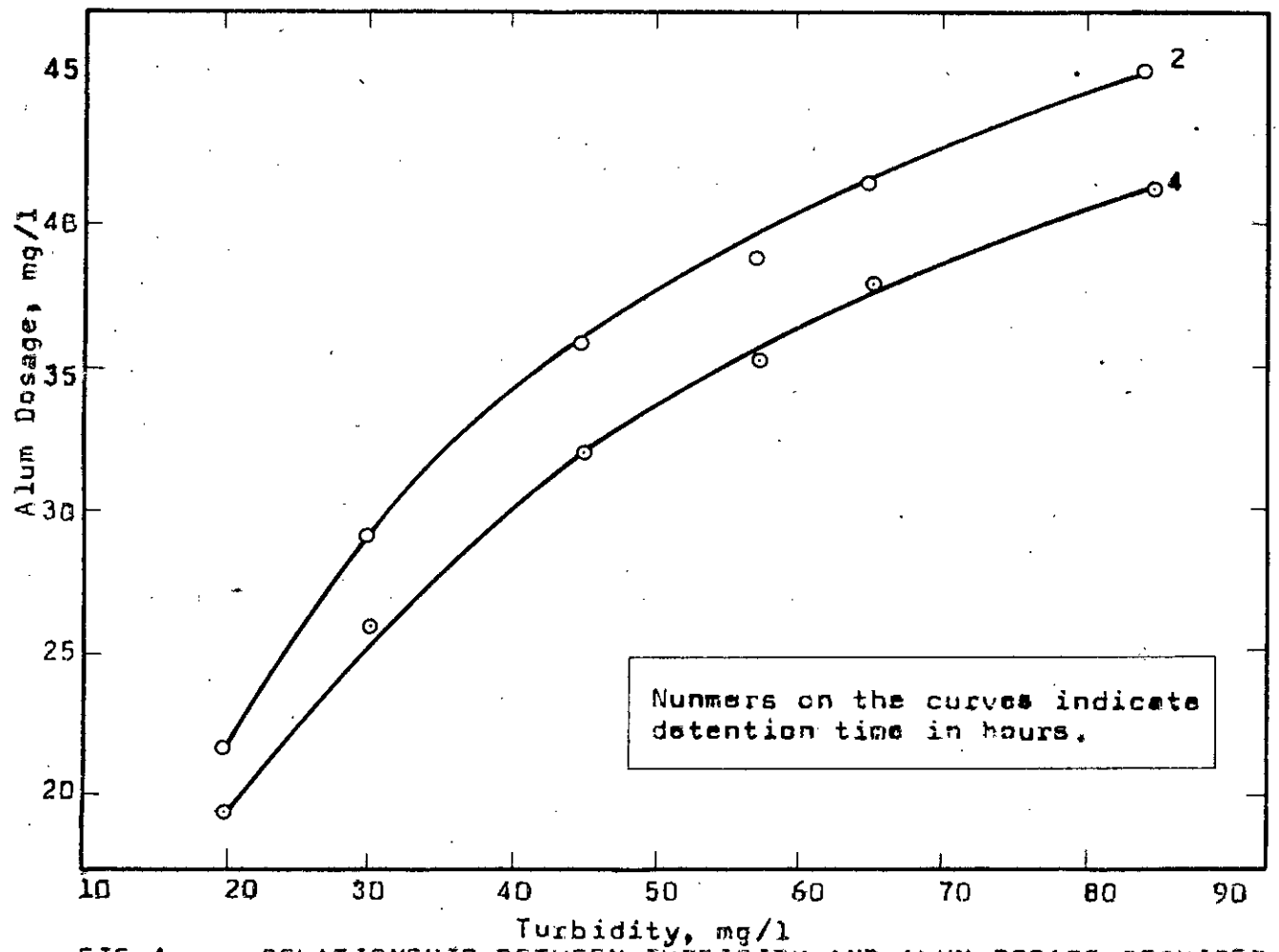

FIG.4.32a RELATIONSHIP BETWEEN TURBIDITY AND ALUM DOSAGE REQUIRED TO REDUCE TURBIDITY OF BURIGANGA RIVER WATER TO 5 mg/l

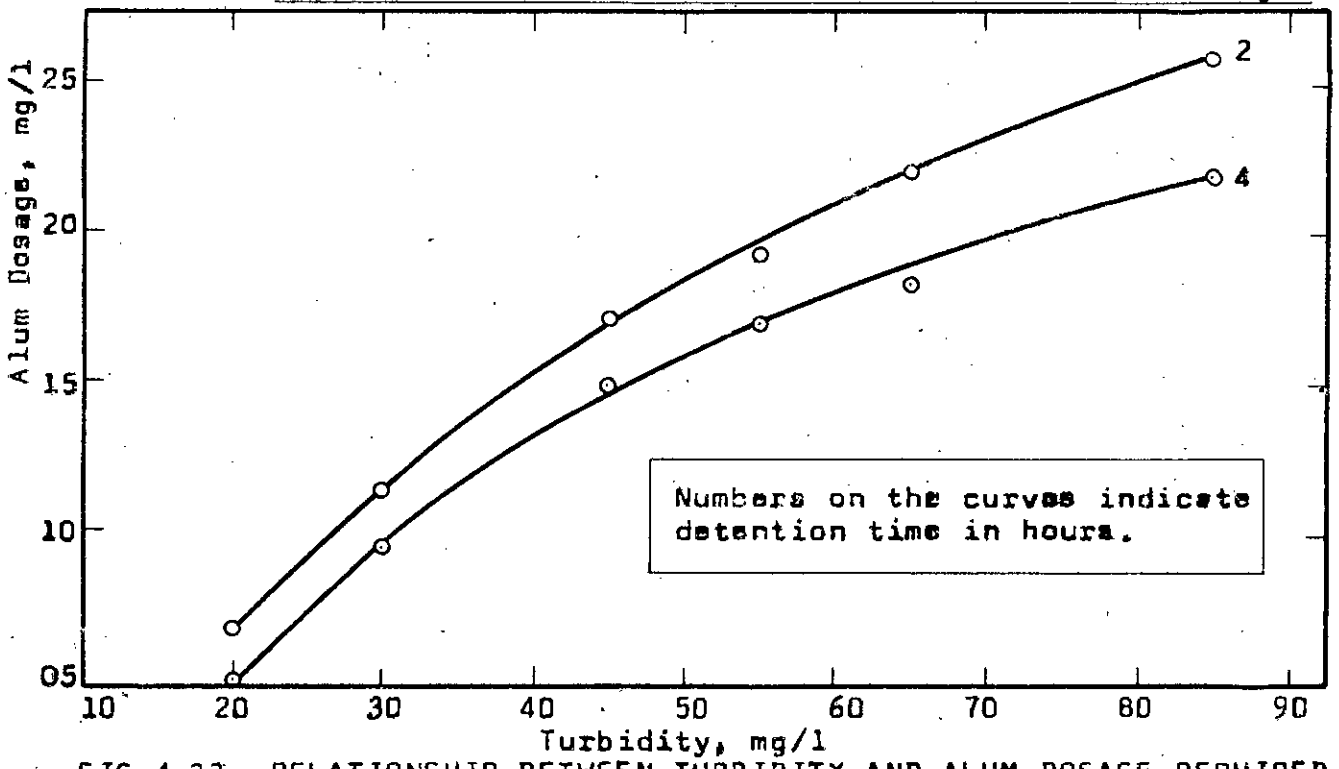

FIG.4.33a RELATIONSHIP BETWEEN TURBIDITY AND ALUM DOSAGE REQUIRED TO REDUCE TURBIDITY OF BURIGANGA RIVER WATER TO 10 mg/l

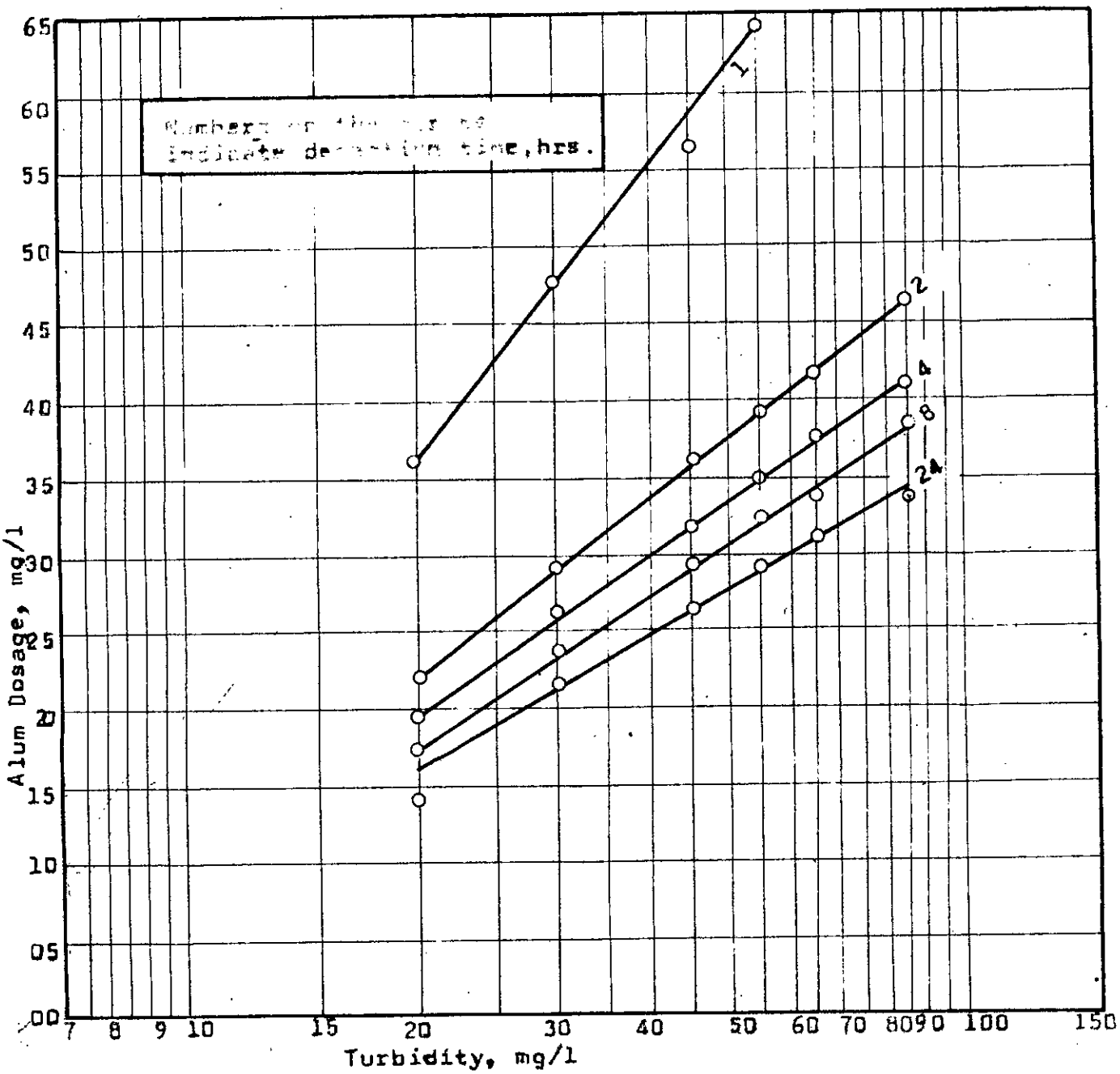

FIG.4.32b RELATIONSHIP BETWEEN TURBIDITY AND ALUM DOSAGE REQUIRED TO REDUCE TURBIDITY TO 5 mg/l.

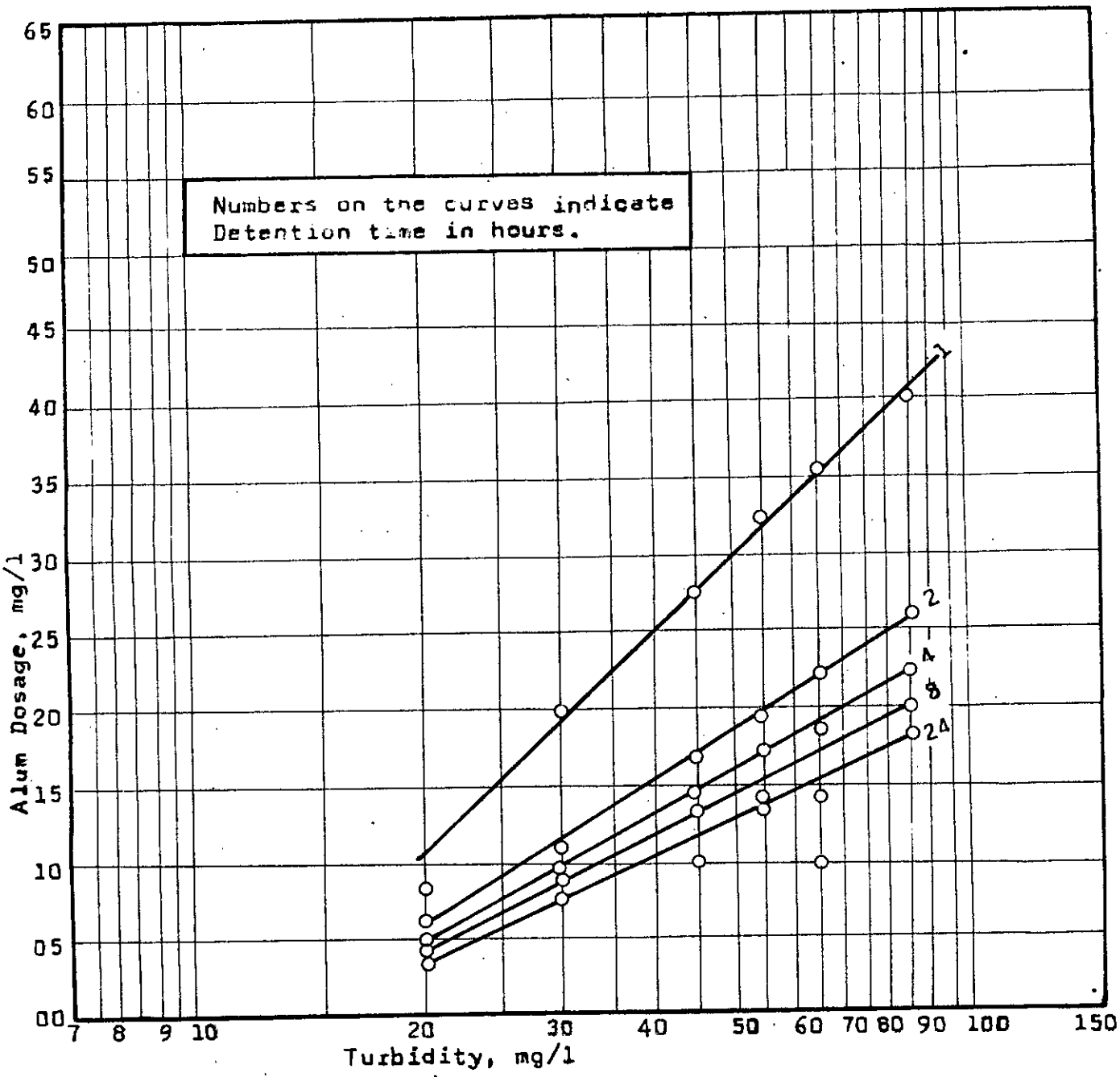

FIG.4.33b RELATIONSHIP BETWEEN TURBIDITY AND ALUM DOSAGE REQUIRED TO REDUCE TURBIDITY TO 10 mg/l

$\underline{a}$ = 39.0 $\log_{10}$ $\underline{t}$ - 28.85 (for detention time of 2 hrs). (4.4)

$\underline{a}$ = 63.33 $\log_{10}$ $\underline{t}$ - 46.45 (" " " " 1 hrs.) (4.5)

where $\underline{a}$ and $\underline{t}$ represent alum dosage (mg/l) and turbidity (mg/l) respectively.

Other equations for the requirements of 10 mg/l residual turbidity as represented in Fig. 4.33b are calculated out as:

$\underline{a}$ = 24.1 $\log_{10}$ $\underline{t}$ - 28.36 (for detention time 24 hrs) (4.6)

$\underline{a}$ = 25.5 $\log_{10}$ $\underline{t}$ - 28.95 (" " " 8 ") (4.7)

$\underline{a}$ = 27.4 $\log_{10}$ $\underline{t}$ - 30.80 (" " " 4 ") (4.8)

$\underline{a}$ = 31.6 $\log_{10}$ $\underline{t}$ - 35.10 (" " " 2 ") (4.9)

$\underline{a}$ = 48.1 $\log_{10}$ $\underline{t}$ - 52.04 (" " " 1 ") (4.10)

The lines are gradually divergent at higher turbidity and meet at a point in the region of lower turbidity approximately 5,-1.8 in Fig. 4.32b and at 10,-3.4 in Fig. 4.33b, those points correspond to 5 mg/l and 10 mg/l raw water turbidity in the scale. The graphs also show that a raw water turbidity of 6 mg/l and 13 mg/l requires no coagulant to reduce them to 5 and 10 mg/l respectively. It indicates that only stirring is sufficient to break the stability and reduce raw water turbidity to a certain extent without any coagulant.

Similar correlations were found to exist between the raw water colour and coagulant dosage. The reduction of colour by various dosage of coagulant are plotted in Fig. 4.34a for Buriganga River water, from Tables 4.4 to 4.17 (Appendix-B).

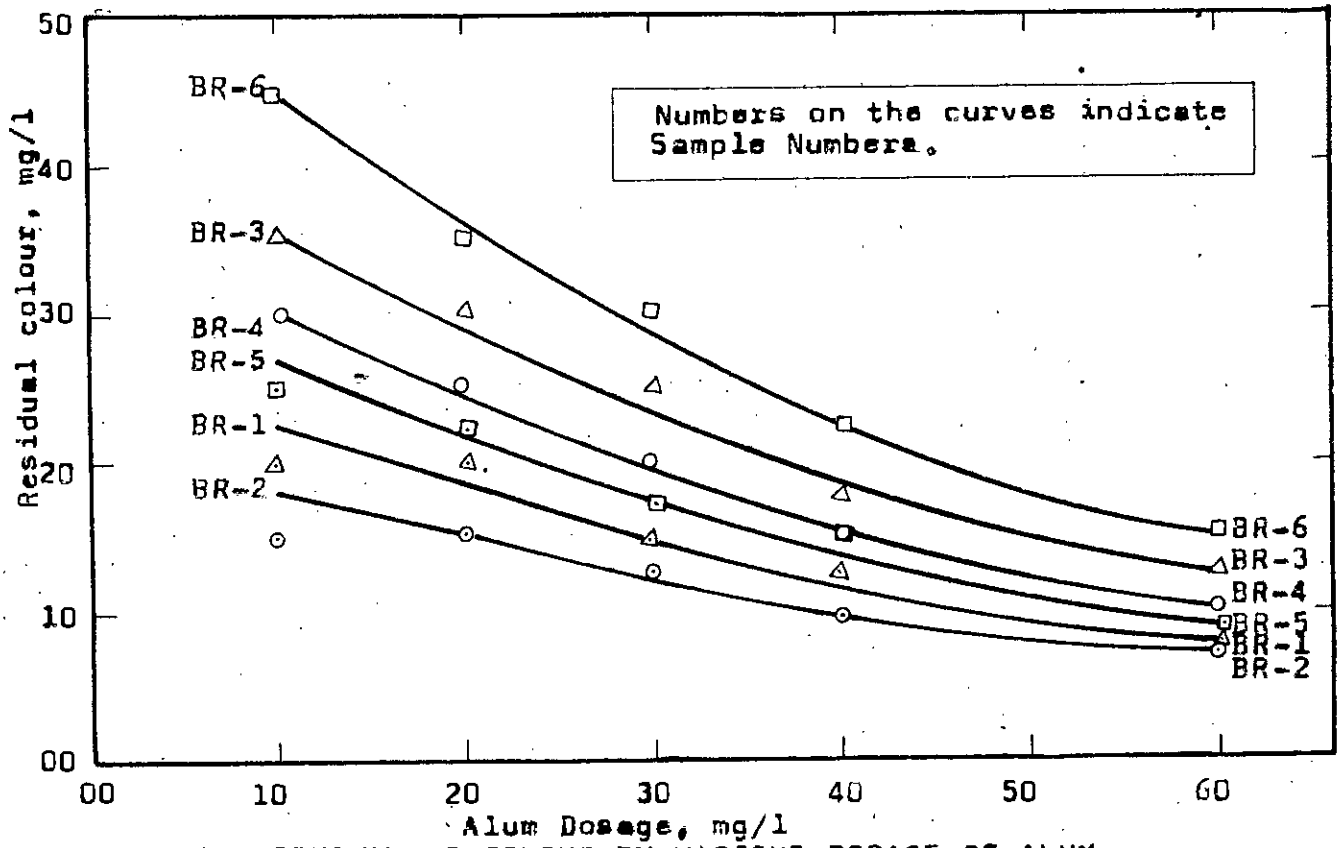

FIG.4.34a REMOVAL OF COLOUR BY VARIOUS DOSAGE OF ALUM.

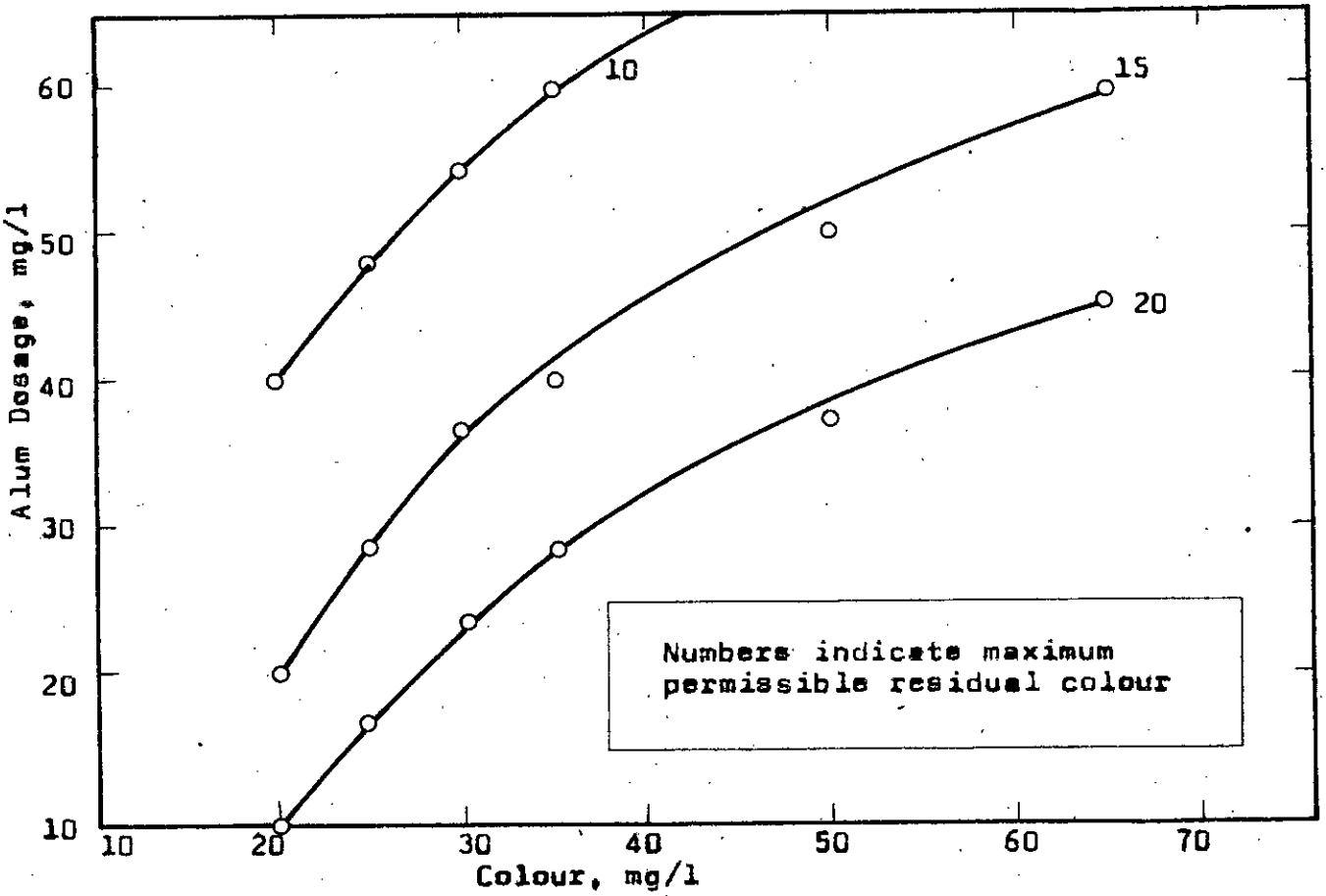

FIG.4.34b RELATIONSHIP BETWEEN COLOUR AND ALUM DOSAGE REQUIRED TO REDUCE COLOUR TO THE MAXIMUM PERMISSIBLE CONCENTRATION.

From Fig. 4.34a the coagulant required to reduce colour to 20, 15, and 10 mg/l are tabulated in Table 4.34 (Appendix-B). The above mentioned maximum permissible colour of 20, 15, and 10 mg/l for drinking water are recommended by the USPHS, the WHO and the EUROPEAN (WHO) respectively. The Table 4.34 is represented by graphs in Fig. 4.34b in ordinary scale and in Fig. 4.34c in semi-log scale. The mathematical experessions relating the coagulant dosage and colour of raw water for the removal of colour to the recommended residual concentration of 20, 15 and 10 mg/l are given below:

$$a = 63.75 \log_{10} c - 71.00 \quad \text{(for residual colour of 20 ppm)} \qquad (4.11)$$

$$a = 76.25 \log_{10} c - 78.80 \quad (\text{" " " " " 15 "}) \qquad (4.12)$$

$$a = 81.25 \log_{10} c - 65.50 \quad (\text{" " " " " 10 "}) \qquad (4.13)$$

where c stands for raw water colour in mg/l.

It is noticed that the corresponding curves in Fig. 4.34c indicate that 12 mg/l of coagulant is required even for 20,15 and 10 mg/l of raw water colour, which mean that upto 12 mg/l of coagulant, there is no effect upon the removal of colour, which can be termed as initial demand.

H.W. Gehm[1] critically analysed the results of jar tests and data available from numbers of treatment plants and correlated the variables; raw water colour and alum dosage required to reduce it to 20 mg/l. The relationships are shown by browken lines in Fig. 3.34c. It is observed that the curves relating colour and alum dosage of Buriganga River water have steeper slope, but the nature of the curves are same with those obtained by Gehm.

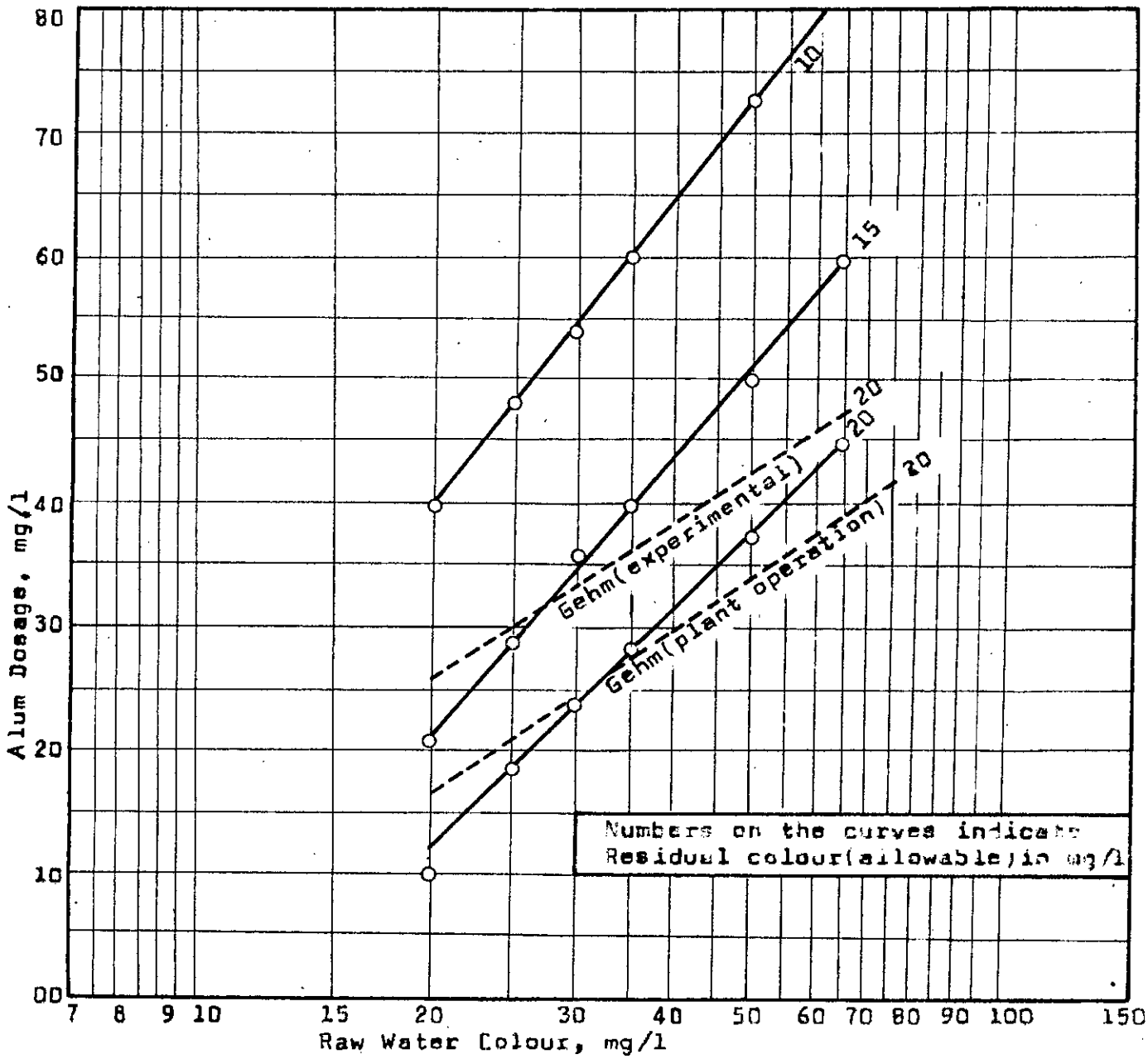

FIG. 4.34c RELATIONSHIP BETWEEN COLOUR AND ALUM REQUIRED TO REDUCE IT TO MAXIMUM PERMISSIBLE CONCENTRATION.

A gradual decrease of pH in water was observed with the increase of alum dosage. This was due to the presence of CO_2 which was produced by the chemical reaction of alum with natural alkalinity (Eqn. 2.10) in water. Moreover, alum itself is acidic in nature. The pH of natural water was found to vary from 7.0 to 8.5. The reduction of pH by 60 mg/l of alum was 0.5, in average showing a maximum reduction as much as 0.9. Alum coagulation may lower the pH of water below 7.0 which is undesirable in drinking water. To avoid this, artificial alkalinity in the form of soda ash or lime may be added which do not affect the flocculation adversely rather helps in good floc formation (Fig. 4.1).

4.6 CHLORINATION

To study the effect of coagulation upon the disinfection by chlorination, some samples with different degrees of clarification by alum coagulation were chlorinated. The chlorine applied and the residual chlorine for each sample were determined and the results are arranged in Table 4.35(Appendix-B). At each stage of chlorination, the microseepic examination of the sample was made. It was noticed that there was a complete basence of microorganisms, slightly earlier than the break point chlorination was reached. The samples of water coagulated with higher coagulant dosage was also found to be almost free from living microorganisms. However, break point chlorination was found sufficient for the complete removal of microorganisms.

In the process of chlorination, the break point chlorination occured at different dosage of chlorine application to water. The maximum chlorine was required for raw water and minimum for water treated with highest dosage of alum (Figs. 4.35a to 4.35e in Appendix-B). Even in distilled water a slight amount (0.05 mg/l) of chlorine demand was observed. Ideally, the residual chlorine curve for distilled water should concide with no demand curve A (Fig. 4.35f Appendix-B). The chlorine applied and the chlorine demand for break point chlorination was related to the coagulant dosage with which water was treated by curves in Fig. 4.36. The curves show the rate at which the use of chlorine for disinfection can be reduced with the increase of alum dosage for the treatment of surface waters.

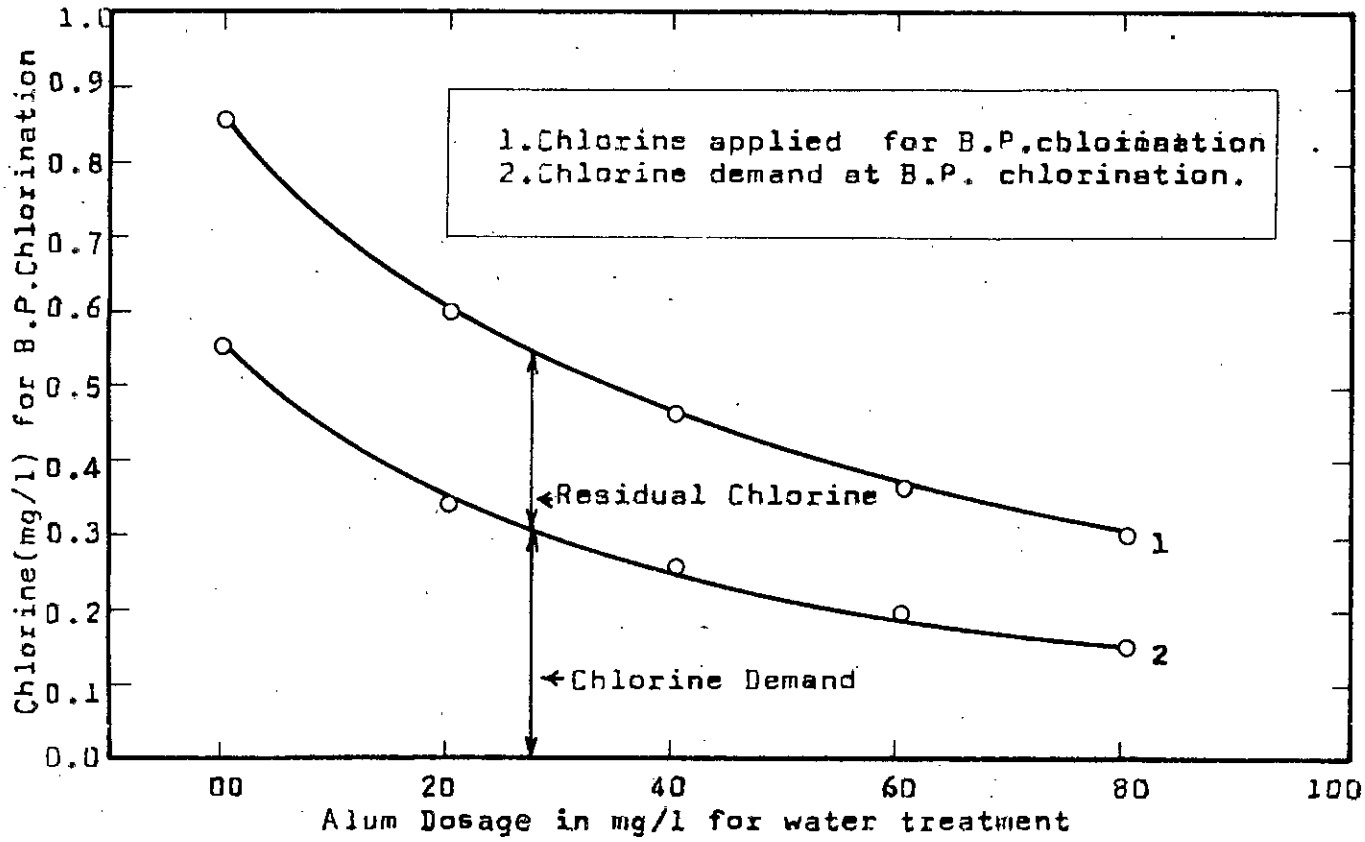

FIG.4.36 RELATIONSHIP BETWEEN CHLORINE AND ALUM DOSAGE IN POST CHLORINATION.(ALUM USED FOR WATER CLARIFICATION.)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

After careful interpretations and critical examinations of the experimental results the following conclusions are drawn:

(1) Only alum coagulation is found to be satisfactory for the clarification of surface waters. Soda-ash and lime can be used in combination with alum to impart necessary alkalinity and for the adjustment of pH which is reduced by alum coagulation to a certain extent.

(2) Mixing by paddles for floc formation is found more suitable than air agitation. Microflocs formed by air agitation have delayed settling characteristics, the removal of which demand subsequent operation like filtration. Mixing and flocculation time decrease with the increase of coagulant dosage. A mixing and flocculation time of 15 to 20 minutes is found to be satisfactory. Detention time of 2 hrs is found optimum for the sedimentation of flocs.

(3) Colour and turbidity present in surface waters are important factors influencing the alum requirement for the coagulation sedimentation process of water clarification. The dosage of alum required for the

desired degree of clarification is correlated to the concentrations of colour and turbidity and represented by the general equation,

$$y = k_1 \log_{10} x - k_2 \qquad (5.1)$$

in which y represents the dosage of alum in mg/l, x represents turbidity or colour in mg/l, k_1 and k_2, stand for constants. The equation is found to be valid for water collected from single source.

(4) Significant reduction of chlorine demand and chlorine requirement are observed for break point chlorination of water clarified by alum coagulation. The chlorine requirement decreases with the increase of the quantity of alum used for coagulatic and the variables can be graphically correlated.

5.2 RECOMMENDATION FOR FURTHER STUDIES

The correlations derived in the investigation between the alum dosage and turbidity, alum dosage and colour were found valid for single source only. These do not represent the generalized picture of multiple sources. Moreover maximum available turbidity and colour of the Buriganga River water during the period of study were 95 mg/l and 70 mg/l respectively. After two hours plain sedimentation these were reduced respectively to 85 mg/l and 65 mg/l. A higher turbidity may occur in the other seasons of the year and the validity of the

relationships developed require further study with higher concentrations of turbidity and colour. Effect of pH, temperature, alkalinity and other related water quality parameters on the coagulation sedimentation may be studied further to justify the validity of the relationships when the water quality of the river changes significantly.

The gradual effect of chlorination on microorganisms was not studied. In the process of disinfection by bleaching powder the absence of higher plants and animals in the microscopic view was considered a criterian for the absence of all type of small plants like bacteria. This may not be always true. Hence, the death rate of the microorganisms with the increase of chlorine concentration in surface waters requires continuous total plate counts and coliform counts, and extensive study of this nature is recommended.

APPENDIX - A

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APPENDIX - B

EXPERIMENTAL RESULTS

TABLE 3.1 WATER QUALITY (Physical)

Sample No.	L o c a t i o n	Date of Collection	Temperature		Turbidity(mg/l)		Colour (mg/l)	Solid Contents(mg/l)		
			°C	°F	Initial	2hrs.detn.		D.S.	S.S.	T.S.
BR-1	Buriganga River	17.10.73	26.6	80.0	40	30	25	200	150	350
BR-2	Buriganga River	29.03.73	27.2	81.0	26	20	20	220	100	320
BR-3	Buriganga River	13.04.73	25.5	78.0	87	65	50	240	240	480
BR-4	Buriganga River	04.04.73	25.3	77.5	67	52	35	270	220	490
BR-5	Buriganga River	10.04.73	24.4	76.0	58	45	30	320	115	435
BR-6	Buriganga River	12.04.74	27.2	81.0	97	85	65	300	230	530
DL-1	Dhanmondi Lake	12.10.73	26.9	80.5	58	34	30	200	100	300
DL-2	Dhanmondi Lake	30.03.74	23.6	74.5	24	20	55	300	110	410
SP-1	Stagnant Pond	15.10.73	24.4	76.0	38	32	35	280	150	430
SP-2	Stagnant Pond	16.10.73	26.6	80.0	25	25	30	260	120	380
SP-3	Stagnant Pond	28.03.74	25.0	77.0	22	20	25	300	100	400
SP-4	Stagnant Pond	18.10.74	25.5	78.0	48	44	30	270	200	470
RL-1	Ramna Lake	31.03.73	26.1	79.0	48	45	50	280	180	460
RL-2	Ramna Lake	22.03.74	25.0	77.0	95	95	100	300	150	450

TABLE 3.2 WATER QUALITY (Chemical and Bio-chemical)

Sample No.	Alkalinity(mg/l)		Acidity (mg/l	Carbon dioxide(mg/l)	pH	Dissolved Oxygen(mg/l)	BOD (mg/
	Phenop.	Total					
BR-1	00	48	10	6	7.4	7.50	0.80
BR-2	00	50	10	5	7.3	6.50	1.20
BR-3	00	170	15	9	7.6	6.50	1.40
BR-4	00	120	12	7	7.8	6.20	0.60
BR-5	00	210	13	10	7.5	6.40	1.40
BR-6	00	170	12	9	7.6	7.80	2.00
DL-1	00	168	22	16	7.0	6.00	[illegible]
DL-2	00	152	12	8	7.5	5.90	3.10
SP-1	00	46	12	7	7.80	6.20	3.60
SP-2	00	76	10	8	7.6	6.40	4.20
SP-3	00	160	18	12	7.1	5.80	3.20
SP-4	00	116	30	12	7.4	5.40	2.80
RL-1	05	150	10	2.5	8 1	4.20	5.80
RL-2	16	175	00	00	8.5	3.80	0.20

TABLE 4.1a FLOCCULATION SEDIMENTATION OF BURIGANGA RIVER WATER BY STIRRING IN THE JAR TEST APPARATUS.

Jar No.		1	2	3	4	5		6		7	
Coagulant		Alum	Na_2CO_3	$FeSO_4$	$Ca(OH)_2$	Alum	Na_2CO_3	Alum	$CaCO_3$	Alum	$Ca(OH)_2$
Dosage (mg/l)		40	40	40	40	25	15	25	15	25	15
Turbidity (mg/l) after Detention Time (hrs.) of	½	8.0	14.5	34.5	17.0	10.5		9.5		12.0	
	1	5.0	11.5	32.5	13.0	6.5		6.0		8.0	
	2	4.0	9.0	31.0	11.0	4.0		4.0		4.5	
	4	3.8	8.2	31.0	9.0	3.5		3.2		4.1	
	6	3.5	7.8	30.5	9.0	3.2		2.7		4.0	
	20	3.0	7.0	30.0	9.0	2.8		2.5		3.3	
	24	3.0	7.0	30.0	9.0	2.5		2.5		2.0	
pH		7.7	8.2	7.3	8.3	7.9		7.9		8.0	
Colour		15.0	20.0	120.0	20.0	15.0		12.5		12.5	

TABLE 4.1b FLOCCULATION SEDIMENTATION OF BURIGANGA RIVER WATER BY AIR AGITATION.

Jar No.		1	2	3	4	5		6		7	
Coagulant		Alum	Na_2CO_3	$FeSO_4$	$Ca(OH)_2$	Alum	Na_2CO_3	Alum	$CaCO_3$	Alum	$Ca(OH)_2$
Dosage (mg/l)		40	40	40	40	25	15	15	25	25	15
Turbidity (mg/l) after Detention Time (hrs.) of	½	17.5	23.5	50.0	22.0	19.0		18.5		17.0	
	1	13.0	19.0	50.0	18.0	14.5		14.0		14.5	
	2	10.0	15.5	44.0	15.0	10.8		10.5		12.0	
	4	7.7	12.0	37.0	13.0	7.5		7.8		9.5	
	6	6.5	10.0	33.0	12.0	6.0		6.5		8.5	
	20	6.0	8.0	31.0	11.0	5.5		6.2		7.0	
	24	6.0	8.0	31.0	11.0	5.0		6.0		6.5	
pH		8.1	8.6	8.0	8.6	8.1		8.2		8.2	
Colour		20.0	20.0	200.0	20.0	15.0		15.0		15.0	

TABLE 4.2 EFFECT OF MIXING TIME AND ALUM DOSAGE ON THE FLOCCULATION AND RATE OF SEDIMENTATION.

Alum Dosage (mg/l)	Mixing Time(min)	3	5	10	15	20	25	30	35
10	Turbidity(mg/l) after Deten. Time(hrs.)of ½	36.0	32.5	26.0	23.0	21.8	21.0	20.0	19.0
	1	29.5	26.5	21.0	18.0	17.0	15.8	15.0	14.5
	2	26.5	23.0	18.0	14.0	12.5	11.5	11.0	10.8
	4	22.0	19.8	14.3	12.0	11.0	10.8	10.0	9.6
	8	17.0	15.9	13.8	11.5	10.8	9.8	9.0	8.5
	24	14.0	13.0	10.5	9.5	8.0	8.0	8.0	7.8
20	Turbidity(mg/l) after Deten. Time(hrs.)of ½	30.0	25.0	18.0	16.5	15.5	15.0	14.5	14.0
	1	23.0	20.0	14.0	12.5	11.8	11.0	10.5	10.0
	2	19.5	17.0	11.0	9.0	8.0	7.8	7.6	7.5
	4	15.0	13.8	9.0	8.5	8.2	8.0	7.5	7.0
	8	13.2	11.0	8.2	7.5	7.4	7.3	6.8	6.
	24	10.5	9.2	7.5	6.5	6.4	6.3	6.2	6.0
30	Turbidity(mg/l) after Deten. Time(hrs.)of ½	25.0	20.0	14.2	12.5	11.2	10.8	10.5	10.0
	1	19.5	16.0	10.8	9.0	8.3	8.0	7.5	7.0
	2	15.5	12.4	7.5	6.2	5.8	5.5	5.3	5.0
	4	12.0	9.5	6.5	5.2	5.0	5.0	4.3	4.2
	8	10.0	7.6	5.8	5.0	5.0	4.5	4.0	4.0
	24	8.5	7.0	5.0	4.5	4.0	4.0	3.8	3.8
40	Turbidity(mg/l) after Deten. Time(hrs.)of ½	19.5	16.0	11.0	9.0	8.0	7.5	6.8	6.5
	1	15.5	11.0	7.5	6.2	5.6	5.5	5.0	4.5
	2	13.0	8.5	4.5	4.0	3.5	3.0	3.0	3.0
	4	10.5	6.8	4.0	3.3	3.2	3.2	3.2	3.2
	8	8.5	6.0	3.8	3.2	3.2	3.1	3.0	3.0
	24	7.0	4.5	3.5	3.0	3.0	3.0	2.8	2.8
	Turbidity(mg/l) after Deten. Time(hrs.)of ½	17.0	12.0	8.0	7.5	6.3	5.5	5.2	5.0
	1	13.0	9.5	6.0	4.5	4.0	3.5	3.4	3.2
	2	10.5	6.0	3.0	2.5	2.5	2.2	2.0	2.0
	4	7.0	5.0	3.0	2.2	2.2	2.1	2.0	2.0
	8	6.2	4.2	3.0	2.2	2.1	2.0	2.1	2.0
	24	6.0	3.5	2.2	2.1	2.0	2.0	2.0	2.0

TABLE 4.3a PERCENTAGE TURBIDITY REMOVED IN 24 HOURS DETENTION TIME FOR VARIOUS ALUM DOSAGE AND FLOCCULATION TIME.

Alum Dosage (mg/l)	Flocculation Time(min.)	3	5	10	15	20	25	30	35
	Initial Turbidity	45	45	45	45	45	45	45	45
10	Residual Turbidity	14.0	13.0	10.5	9.5	8.5	8.0	8.0	7.8
	%Residual Turbidity	31.2	29.0	23.4	21.2	18.9	17.7	17.7	17.3
	%Turbidity Removed	69.8	71.0	76.6	78.9	81.1	82.3	82.3	82.7
20	Residual Turbidity	10.5	9.2	7.5	6.5	6.4	6.2	6.2	6.0
	%Residual Turbidity	23.4	20.4	16.7	14.4	14.2	13.8	13.8	13.3
	%Turbidity Removed	76.6	79.6	83.3	85.5	85.8	86.2	86.2	87.7
30	Residual Turbidity	8.5	7.0	5.0	4.5	4.0	4.0	3.8	3.8
	%Residual Turbidity	18.9	15.5	11.1	10.0	8.9	8.9	8.5	8.5
	%Turbidity Removed	81.1	84.5	88.9	90.0	91.1	91.1	91.5	91.5
40	Residual Turbidity	7.0	4.5	3.5	3.0	3.0	3.0	2.8	2.5
	%Residual Turbidity	15.5	10.0	7.8	6.7	6.7	6.7	6.2	6.2
	%Turbidity Removed	84.5	90.0	92.2	93.3	93.3	93.3	93.8	93.8
60	Residual Turbidity	6.0	3.6	2.2	2.1	2.0	2.0	2.0	2.0
	%Residual Turbidity	13.3	7.8	4.9	4.7	4.4	4.4	4.4	4.4
	%Turbidity Removed	86.7	92.2	95.1	95.3	95.6	95.6	95.6	95.6

TABLE 4.3b PERCENTAGE TURBIDITY REMOVED IN 2 HOURS DETENTION TIME FOR VARIOUS ALUM DOSAGE AND FLOCCULATION TIME.

Alum Dosage (mg/l)	Flocculation Time(min)	3	5	10	15	20	25	30	35
	Initial Turbidity	45	45	45	45	45	45	45	45
10	Residual Turbidity	26.5	23.0	18.0	14.0	12.5	11.5	11.0	10.8
	%Residual Turbidity	59.0	51.0	40.0	31.2	27.8	25.6	24.5	24.0
	%Turbidity Removed	41.0	49.0	60.0	68.8	72.2	74.4	75.5	76.0
20	Residual Turbidity	19.5	17.0	11.0	9.0	8.0	7.8	7.6	7.5
	%Residual Rurbidity	43.2	37.8	24.5	20.0	17.8	17.3	16.9	16.7
	%Turbidity Removed	56.8	62.2	75.7	80.0	82.2	82.7	83.1	83.3
30	Residual Turbidity	15.5	12.4	7.5	6.2	5.8	5.5	5.3	5.0
	%Residual Turbidity	34.4	27.6	16.7	13.8	12.9	12.2	11.8	11.1
	%Turbidity Removed	65.6	72.4	83.3	86.2	87.1	87.8	88.2	88.9
40	Residual Turbidity	13.0	8.5	4.5	4.0	3.5	3.0	3.0	3.0
	%Residual Turbidity	28.8	18.9	10.0	8.9	7.8	6.7	6.7	6.7
	%Turbidity Removed	71.2	81.1	90.0	91.1	92.2	93.3	93.3	93.3
60	Residual Turbidity	10.5	6.0	3.0	2.5	2.5	2.2	2.0	2.0
	%Residual Turbidity	23.4	13.3	6.7	5.5	5.5	4.9	4.4	4.4
	%Turbidity Removed	76.6	86.7	93.3	94.5	94.5	95.1	95.6	95.6

TABLE 4.4 RATE OF CLARIFICATION OF SAMPLE NO. BR-1 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)			10	20	30	40	60
Turbidity(mg/l)after Detention Time(hrs.)of	$\frac{1}{4}$		24.0	21.0	18.0	15.0	11.5
	$\frac{1}{2}$		17.0	14.0	12.5	10.0	8.0
	$1\frac{3}{4}$		11.0	7.0	5.0	3.8	3.2
	3		10.0	6.3	4.3	3.8	3.1
	6		10.0	6.0	4.3	3.6	3.0
	8		9.5	5.8	4.2	3.5	3.0
	25		9.3	5.5	4.0	3.1	3.0
pH			7.2	7.0	6.9	6.7	6.5
Colour			20	20	15	12.5	7.0

TABLE 4.5 RATE OF CLARIFICATION OF SAMPLE NO. BR-2 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		5	10	20	30	40	60
Turbidity(mg/l)after Detention Time(hrs.)of	$\frac{1}{4}$	16.5	11.5	10.0	9.0	8.3	7.5
	$\frac{1}{2}$	15.0	9.0	7.0	6.5	6.0	4.5
	$1\frac{1}{2}$	13.0	7.3	5.5	5.0	4.6	3.2
	3	11.5	7.3	5.2	4.3	4.2	2.5
	6	9.0	7.3	4.5	4.0	3.6	2.3
	8	8.5	7.3	4.5	4.0	3.2	2.3
	23	7.8	7.3	4.0	3.6	3.0	2.0
pH		7.5	7.5	7.4	7.3	7.1	7.0
Colour		20	15	13.	12.5	10.0	7.5

TABLE 4.6 RATE OF CLARIFICATION OF SAMPLE NO. BR-3 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)			10	20	30	40	60
Turbidity(mg/l)after Detention Time(hrs.)of	$\frac{1}{4}$		42.0	27.0	22.0	18.0	15.0
	$\frac{1}{2}$		33.0	23.0	17.0	13.0	10.0
	1		21.5	16.0	12.0	9.0	6.5
	$2\frac{1}{2}$		13.5	11.0	7.0	4.5	3.0
	4		12.0	9.5	6.1	4.3	2.6
	8		10.5	8.5	6.0	3.5	2.5
	22		9.0	8.4	5.5	3.2	2.2
pH			7.8	7.6	7.5	7.4	7.2
Colour			35	30	25	17.5	12.5

TABLE 4.7 RATE OF CLARIFICATION OF SAMPLE NO. BR-4 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)			10	20	30	40	60
Turbidity(mg/l)after Detention Time(hrs.)of	$\frac{1}{2}$		33.0	26.0	20.0	14.0	10.0
	1		23.0	16.5	12.5	8.0	5.5
	2		14.5	9.5	6.0	5.1	3.5
	3		13.0	8.3	5.5	4.0	3.0
	6		11.5	8.5	5.2	3.6	3.0
	8		11.0	8.0	5.0	3.0	2.5
	25		11.0	8.0	5.0	3.0	2.5
pH			7.8	7.6	7.5	7.3	6.9
Colour			30	25	20	15	10

TABLE 4.8 RATE OF CLARIFICATION OF SAMPLE NO. BR-5 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	¼	30.0	22.5	18.5	13.5	11.5	
	½	23.0	16.5	12.5	9.0	7.5	
	1	18.0	12.5	9.0	6.2	4.5	
	2	14.0	9.0	6.2	4.0	2.5	
	4	12.0	8.5	5.2	3.3	2.2	
	8	10.5	7.5	5.0	3.2	2.2	
	24	9.5	6.5	4.5	3.0	2.1	
pH		8.0	8.0	7.8	7.7	7.5	
Colour		25.0	22.5	17.5	15.0	7.5	

TABLE 4.9 RATE OF CLARIFICATION OF SAMPLE NO.BR-6 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	½	35.0	23.4	18.5	14.5	11.5	
	1	27.0	17.0	12.5	9.0	7.0	
	2	20.5	13.0	8.0	5.5	4.5	
	4	17.0	11.3	7.0	4.5	4.0	
	8	15.5	10.0	6.5	4.5	3.5	
	12	15.0	10.0	6.3	4.5	3.2	
	24	14.0	9.5	6.2	4.0	3.0	
pH		7.9	7.6	7.5	7.3	7.1	
Colour		45.0	35.0	30.0	22.5	15.0	

TABLE 4.10 RATE OF CLARIFICATION OF SAMPLE NO. DL-1 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	$\frac{1}{4}$	19.0	16.5	12.5	11.0	9.0	
	$\frac{1}{2}$	14.0	12.0	9.0	7.0	6.0	
	1	11.0	10.0	6.5	4.5	3.5	
	3	9.5	7.5	4.5	3.5	2.5	
	6	9.0	7.0	4.2	3.0	2.1	
	8	8.0	6.0	3.6	2.5	2.0	
	20	8.0	6.0	3.6	2.5	2.0	
pH		7.9	7.7	7.5	7.4	7.3	
Colour		25.0	25.0	20.0	15.0	10.0	

TABLE 4.11 RATE OF CLARIFICATION OF SAMPLE NO.DL-2 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	$\frac{1}{4}$	13.0	11.5	9.5	8.5	7.5	
	$\frac{1}{2}$	11.0	9.0	7.0	6.5	5.5	
	$1\frac{1}{2}$	9.5	7.0	6.0	5.0	4.6	
	3	8.5	6.5	5.0	4.5	4.0	
	4	8.2	6.0	4.5	4.0	3.5	
	8	8.0	5.5	4.0	3.8	3.5	
	23	8.0	5.0	4.0	3.8	3.2	
pH		7.6	7.4	7.3	7.2	7.1	
Colour		35.0	30.0	25.0	20.0	15.0	

TABLE 4.12 RATE OF CLARIFICATION OF SAMPLE NO.SP-1 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	¼	27.5	24.5	22.5	20.0	16.5	
	½	23.0	20.0	18.0	15.0	11.0	
	1	18.5	14.5	12.5	9.5	6.5	
	2	13.5	8.5	6.5	4.5	3.5	
	4	11.0	6.5	5.0	4.0	2.5	
	8	9.0	4.9	4.3	4.0	2.5	
	20	7.5	5.5	4.5	4.0	2.5	
pH		7.8	7.6	7.3	7.1	7.0	
Colour		25.0	25.0	20.0	15.0	12.5	

TABLE 4.13 RATE OF CLARIFICATION OF SAMPLE NO. SP-2 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		5	10	20	30	40	60
Turbidity(mg/l)after Detention Time(hrs.)of	½	17.5	13.5	9.0	8.5	7.0	5.0
	1	14.0	11.0	7.0	6.0	4.5	3.0
	3	12.5	9.5	6.0	5.2	3.5	2.4
	5	12.0	9.0	6.0	5.0	3.4	2.2
	8	11.5	8.5	5.8	4.8	3.4	2.0
	20	11.0	8.5	5.5	4.8	3.4	2.0
	24	11.0	8.4	5.5	4.8	3.4	2.0
pH		7.3	7.4	7.1	6.8	6.7	6.5
Colour		25.0	25.0	20.0	20.0	15.0	10.0

TABLE 4.14 RATE OF CLARIFICATION OF SAMPLE NO.SP-3 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	½	16.0	15.0	14.0	12.5	11.5	
	1	12.5	11.5	10.0	9.0	8.0	
	2	9.0	8.0	5.5	4.6	3.6	
	4	6.0	5.5	4.3	3.8	3.0	
	8	5.8	4.5	4.0	3.5	2.5	
	20	5.5	4.5	4.0	3.5	2.5	
pH		7.5	7.4	7.4	7.3	7.0	
Colour		20.0	20.0	15.0	10.0	7.5	

TABLE 4.15 RATE OF CLARIFICATION OF SAMPLE NO. SP-4 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	¼	34.0	20.0	25.5	22.5	21.0	
	½	27.0	24.0	21.0	17.5	16.0	
	1½	17.5	13.0	12.5	9.7	8.0	
	4	13.5	11.0	9.0	6.5	5.0	
	6	12.0	10.2	8.0	6.0	4.8	
	8	11.8	10.0	7.5	5.6	4.6	
	22	11.5	9.2	7.0	5.5	4.5	
pH		8.0	8.0	8.0	8.0	8.0	
Colour		25.0	20.0	15.0	15.0	7.5	

TABLE 4.16 RATE OF CLARIFICATION OF SAMPLE NO. RL-1 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	
Turbidity(mg/l)after Detention Time(hrs.)of	¼	33.0	30.0	27.5	22.5	15.0	
	½	27.0	24.0	21.0	15.0	10.0	
	1	20.5	17.5	14.0	10.0	7.5	
	2	16.0	12.5	9.0	6.0	4.0	
	4	13.5	10.5	7.5	5.0	3.5	
	8	12.8	10.0	7.1	4.8	3.5	
	24	12.0	9.8	7.0	4.6	3.5	
pH		7.9	7.8	7.5	7.4	7.2	
Colour		40.0	35.0	30.0	25.0	20.0	

TABLE 4.17 RATE OF CLARIFICATION OF SAMPLE NO.RL-2 BY COAGULATION SEDIMENTATION WITH VARIOUS ALUM DOSAGE.

Jar No.		1	2	3	4	5	6
Alum Dosage (mg/l)		10	20	30	40	60	80
Turbidity(mg/l)after Detention Time(hrs.)of	½	65.0	60.0	55.0	38.0	40.0	33.0
	1¼	48.0	44.0	42.0	34.0	28.0	20.0
	4	31.0	27.0	24.0	19.0	13.0	11.0
	6	26.0	24.0	20.0	15.0	12.0	10.0
	9	25.0	23.0	20.0	14.0	11.0	10.0
	20	23.0	22.0	18.0	14.0	10.0	10.0
	24	23.0	22.0	17.0	14.0	10.0	10.0
pH		8.2	8.0	7.8	7.7	7.7	7.6
Colour		75.0	60.0	50.0	45.0	45.0	40.0

TABLE 4.18 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-1.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity (mg/l) after Detention time of	1 hr.	13.5	10.0	8.0	6.6	5.0
	2 hrs.	10.5	6.5	4.8	3.8	3.5
	4 hrs.	9.8	6.2	4.5	3.7	3.2
	8 hrs.	9.5	5.8	4.2	3.3	3.1
	24 hrs.	9.3	5.5	4.0	3.1	3.0

TABLE 4.19 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-2.

Coagulant Dosage (mg/l)		5	10	20	30	40	60
Turbidity (mg/l) after Detention time of	1 hr.	13.7	7.8	6.0	5.5	4.8	3.7
	2 hrs.	12.0	7.3	5.3	4.8	4.5	2.7
	4 hrs.	10.0	7.3	4.8	4.2	4.0	2.5
	8 hrs.	8.5	7.3	4.5	4.0	3.2	2.3
	24 hrs.	7.8	7.3	4.0	3.6	3.0	2.0

TABLE 4.20 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-2.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	21.5	16.0	12.0	9.0	6.5
	2 hrs.	15.0	11.3	7.5	5.0	3.5
	4 hrs.	12.0	9.5	6.1	4.3	2.6
	8 hrs.	10.5	8.5	6.0	3.6	2.6
	24 hrs.	9.0	8.4	5.5	3.2	2.2

TABLE 4.21 EFFECT OF COATULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-4.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	23.0	16.5	12.5	8.0	5.5
	2 hrs.	14.5	9.5	6.0	4.5	3.5
	4 hrs.	12.0	8.6	5.5	4.5	3.2
	8 hrs.	11.5	8.5	5.2	3.6	3.0
	24 hrs.	11.0	8.0	5.0	3.0	2.5

TABLE 4.22 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-5.

Coagulant Dosage(mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	18.0	12.5	9.0	6.2	4.5
	2 hrs.	14.0	9.0	6.2	4.0	2.5
	4 hrs.	12.0	8.5	5.2	3.3	2.2
	8 hrs.	11.5	7.5	5.0	3.2	2.2
	24 hrs.	9.5	6.5	4.5	3.0	2.1

TABLE 4.23 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. DR-6.

Coagulant Dosage(mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	27.0	17.0	12.5	9.0	7.0
	2 hrs.	20.5	13.0	8.0	5.5	4.5
	4 hrs.	17.0	11.0	7.0	5.1	4.0
	24 hrs.	14.0	9.5	6.2	4.0	3.0

TABLE 4.24 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. DL-1.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	11.0	10.0	6.5	4.5	3.5
	2 hrs.	9.5	8.0	5.0	3.6	2.5
	4 hrs.	9.0	7.3	4.2	3.4	2.3
	8 hrs.	8.5	6.3	3.6	3.0	2.1
	24 hrs.	8.0	5.5	3.5	2.5	2.0

TABLE 4.25 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. DL-2.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	9.5	8.0	6.02	5.2	4.2
	2 hrs.	8.8	6.6	5.5	4.7	3.8
	4 hrs.	8.2	6.0	4.5	4.0	3.5
	8 hrs.	8.0	5.5	4.0	3.8	3.5
	24 hrs.	8.0	5.0	4.0	3.8	3.2

TABLE 4.26 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. SP-1.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Dention time of	1 hr.	18.5	14.5	12.5	9 5	6.5
	2 hrs.	13.5	8.5	6.5	4.5	3.6
	4 hrs.	11.0	6.5	5.0	4.0	2.5
	8 hrs.	9.0	5.9	4.8	4 0	2.5
	24 hrs.	7.5	5.5	4.5	4.o	2.5

TABLE 4.27 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. SP-2.

Coagulant Dosage (mg/l)		5	10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	14.0	11.0	7.0	6.0	4.5	3.0
	2 hrs.	12.6	9.5	6.1	5.2	3.7	2.4
	4 hrs.	12.3	9.0	6.0	5.0	3.5	2.2
	8 hrs.	11.5	8.5	5.9	4.8	3.4	2.0
	24 hrs.	11.0	8.5	5.8	4.8	3.4	2.0

TABLE 4.28 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. SP-3.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	12.5	11.5	10.0	9.0	8.0
	2 hrs.	9.0	8.0	5.5	4.6	3.6
	4 hrs.	6.0	5.5	4.3	3.8	3.0
	8 hrs.	5.8	5.0	4.0	3.5	2.5
	24 hrs.	5.5	4.5	4.0	3.5	2.5

TABLE 4.29 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.SP-4.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	22.7	18.7	15.0	12.5	10.8
	2 hrs.	17.5	14.0	11.3	8.5	6.5
	4 hrs.	13.5	11.0	9.0	6.5	5.0
	8 hrs.	11.8	10.0	7.5	5.6	4.6
	24 hrs.	11.5	9.2	7.0	5.5	4.5

TABLE 4.30 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. RL-1.

Coagulant Dosage (mg/l)		10	20	30	40	60
Turbidity(mg/l)after Detention time of	1 hr.	20.5	17.5	14.0	10.0	7.5
	2 hrs.	16.0	12.5	9.0	6.0	4.0
	4 hrs.	13.5	10.5	7.5	5.0	3.5
	8 hrs.	12.5	10.0	7.1	4.8	3.5
	24 hrs.	12.0	9.8	7.0	4.6	3.5

TABLE 4.31 EFFECT OF COAGULANT DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. RL-2.

Coagulant Dosage (mg/l)		10	20	30	40	60	80
Turbidity(mg/l)after Detention time of	1 hr.	56.0	50.0	46.0	35.0	33.0	24.5
	2 hrs.	43.0	39.0	36.0	32.0	19.0	13.5
	4 hrs.	31.0	27.0	24.0	19.0	12.5	11.0
	8 hrs.	25.0	23.0	20.0	14.0	11.0	10.0
	24 hrs.	23.0	22.0	17.0	14.0	10.0	10.0

TABLE 4.32 COAGULANT REQUIRED TO REDUCE TURBIDITY TO THE MAXIMUM PERMISSIBLE CONCENTRATION OF 5 mg/l.

Sample No.	Turbidity(mg/l) at		Coagulant required to reduce turbidity to 5 mg/l after a detention time of				
	Collection	2hrs detn.	1 hrs.	2 hrs.	4 hrs.	8 hrs.	24 hrs.
BR-1	40	30	48.0	29.0	26.0	24.0	22.0
BR-2	26	20	36.0	22.0	19.5	17.0	14.0
BR-3	87	65	---	41.5	38.0	33.0	31.0
BR-4	67	55	64.0	38.5	35.0	32.5	29.5
BR-5	58	45	56.0	36.0	32.0	29.5	26.5
BR-6	97	85	---	46.0	41.0	38.0	34.0
DL-1	58	34	38.0	30.0	27.0	24.0	20.0
DL-2	24	20	46.0	38.0	30.0	26.0	23.0
SP-1	38	32	---	38.0	30.0	26.0	23.0
SP-2	25	25	35.0	30.0	27.0	25.0	23.0
SP-3	22	20	---	32.0	24.0	18.0	13.0
SP-4	48	44	---	---	60.0	49.0	44.0
RL-1	48	45	---	46.0	41.0	39.0	37.0
RL-2	95	95	---	---	---	---	---

TABLE 4.33 COAGULANT REQUIRED TO REDUCE TO THE MAXIMUM PERMISSIBLE CONCENTRATION OF 10 mg/l IN DIFFERENT DETENTION TIME

Sample No.	Turbidity(mg/l) at		Coagulant required to reduce turbidity to 10 mg/l after a detention time of				
	time of Collection	2 hrs detn. Time	1 hr.	2 hrs.	4 hrs.	8 hrs.	24 hrs.
BR-1	40	30	20.0	11.0	9.5	9.0	7.5
BR-2	26	20	8.0	7.0	5.0	4.0	3.0
BR-3	87	65	36.0	22.0	18.0	14.0	10.0
BR-4	67	55	33.0	19.0	17.0	14.0	13.0
BR-5	58	45	27.5	17.0	15.0	13.0	10.0
BR-6	97	85	40.0	26.0	22.0	20.0	18.0
BL-1	58	34	15.0	9.0	7.0	6.0	4.0
DL-2	24	20	9.0	7.0	6.0	5.0	4.0
SP-1	38	32	37.0	17.0	12.0	8.0	4.0
SP-2	25	25	12.0	9.0	8.0	7.0	6.0
SP-3	22	20	30.0	9.0	---	---	---
SP-4	48	44	---	33.0	23.0	18.0	15.0
RL-1	48	45	40.0	27.0	22.0	20.0	18.0
RL-2	95	95	---	---	---	66.0	60.0

TABLE 4.34 COAGULANT REQUIRED TO REDUCE COLOUR TO THE MAXIMUM PERMISSIBLE CONCENTRATIONS.

Sample No.	Initial colour (mg/l)	Coagulant required to reduce colour to		
		20 mg/l	15 mg/l	10 mg/l
BR-1	25.0	17.0	29.0	48.0
BR-2	20.0	10.0	20.0	40.0
BR-3	50.0	37.0	50.0	72.0
BR-4	35.0	29.0	40.0	60.0
BR-5	30.0	24.0	36.0	54.0
BR-6	65.0	45.0	60.0	---
DL-1	30.0	27.0	40.0	60.0
DL-2	55.0	40.0	60.0	---
SP-1	35.0	27.0	38.0	---
SP-2	30.0	25.0	40.0	60.0
SP-3	25.0	15.0	30.0	40.0
SP-4	30.0	20.0	35.0	50.0
RL-1	50.0	60.0	---	---
RL-2	100.0	---	---	---

TABLE 4.35 RESIDUAL CHLORINE FOR RAN WATER, TREATED WATER, AND DISTILED WATER.

Chlorine Solution added(cc)	Chlorine applied (mg/l)	RESIDUAL CHLORINE (mg/l)					
		Raw water	Water treated with alum dosage of				Distilled water
			20 mg/l	40 mg/l	60 mg/l	80 mg/l	
1.0	0.08	0.00	0.00	0.00	0.00	0.02	0.02
1.5	0.12	0.00	0.00	0.00	0.02	0.02	0.05
2.0	0.16	0.00	0.00	0.02	0.05	0.05	0.10
2.5	0.20	0.02	0.05	0.05	0.10	0.10	0.10
3.0	0.24	0.05	0.10	0.10	0.15	0.15	
3.5	0.28	0.10	0.12	0.15	0.15	0.15	0.20
4.0	0.32	0.12	0.15	0.20	0.15	0.17	0.25
4.5	0.36	0.15	0.20	0.22	0.17	0.20	
5.0	0.40	0.17	0.25	0.25	0.20	0.2[illegible]	0.30
5.5	0.44	0.22	0.27	0.22	0.22	0.27	0.35
6.0	0.48	0.25	0.30	0.22	0.25	0.30	
6.5	0.52	0.25	0.27	0.25	0.30	0.35	0.42
7.0	0.56	0.30	0.25	0.30	0.35	0.40	0.50
7.5	0.60	0.32	0.28	0.35	0.40	0.45	
8.0	0.64	0.35	0.30	0.40	0.45	0.50	0.55
8.5	0.68	0.35	0.35	0.45	0.50	0.52	0.60
9.0	0.72	0.33	0.40	0.45	0.50	0.55	
9.5	0.75	0.30	0.45	0.50	0.55	0.60	0.67
10.0	0.80	0.30	0.50	0.55	0.60	0.65	0.75
10.5	0.84	0.30	0.52	0.60	0.65	0.70	
11.0	0.88	0.32	0.60	0.65	0.70	0.75	0.80
11.5	0.92	0.35	0.60	0.67	0.72	0.77	0.85
12.0	0.96	0.40	0.68	0.70	0.75	0.80	
12.5	1.00	0.45	0.70	0.75	0.80	0.85	0.95
14.5	1.16	0.57	0.85	0.90	1.00	1.00	1.10
16.5	1.32	0.75	1.00	1.05	1.20	1.20	
18.5	1.48	0.95	1.25	1.30	1.40	1.30	1.40
20.5	1.64	1.10	1.40	1.50	1.50	1.50	1.50
22.5	1.80	1.20	1.50	1.60	1.70	1.75	
24.5	1.96	1.50	1.70	1.75	1.75	1.90	1.90
33.0	2.64	2.00	2.40	2.50	2.50	2.50	2.50
35.0	2.80	2.25	2.80	2.75	2.75	2.80	
37.0	2.96	2.50	2.80	2.80	2.75	2.75	2.90

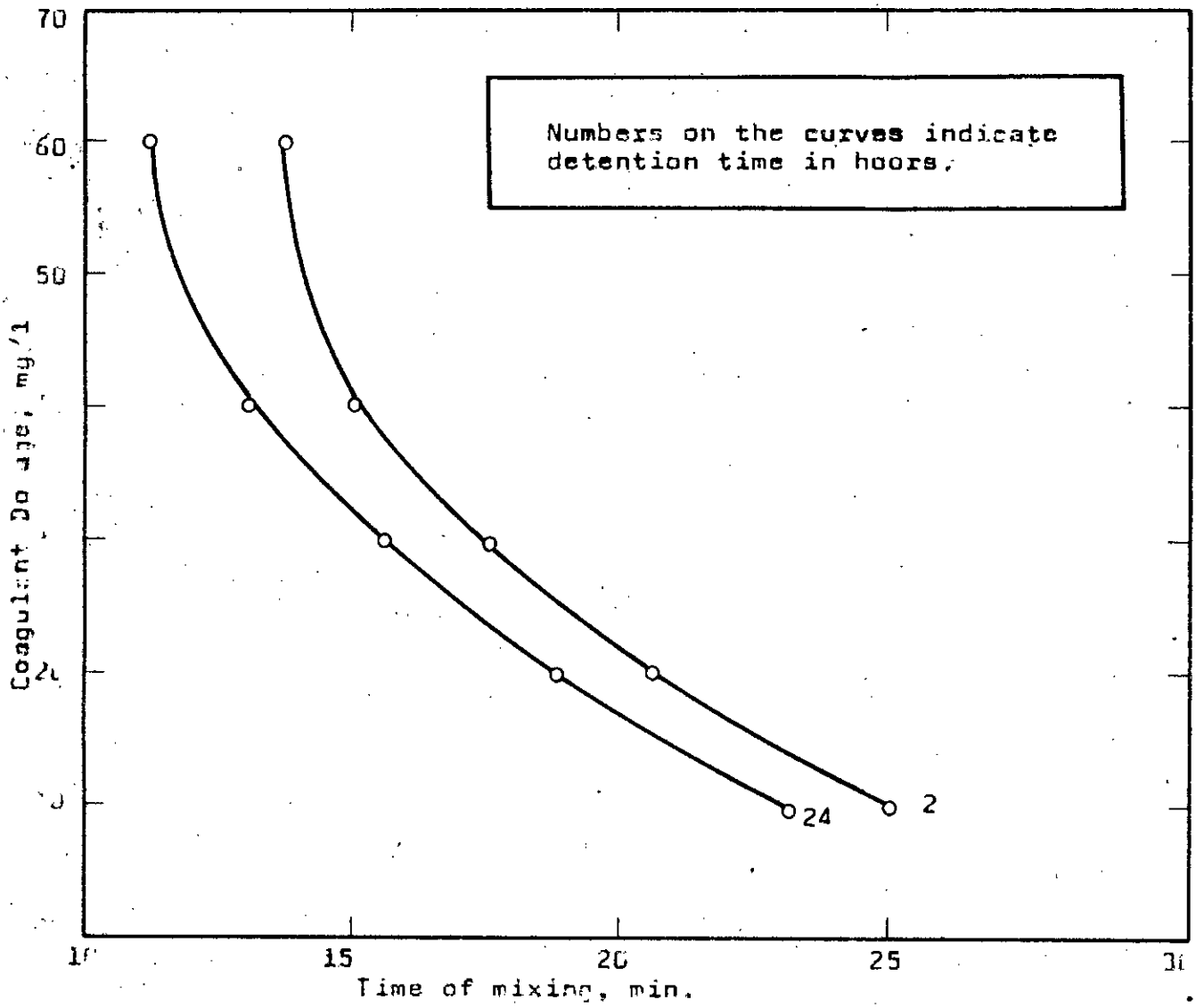


FIG.4.2 RELATIONSHIP BETWEEN COAGULANT DOSE AND MIXING TIME.

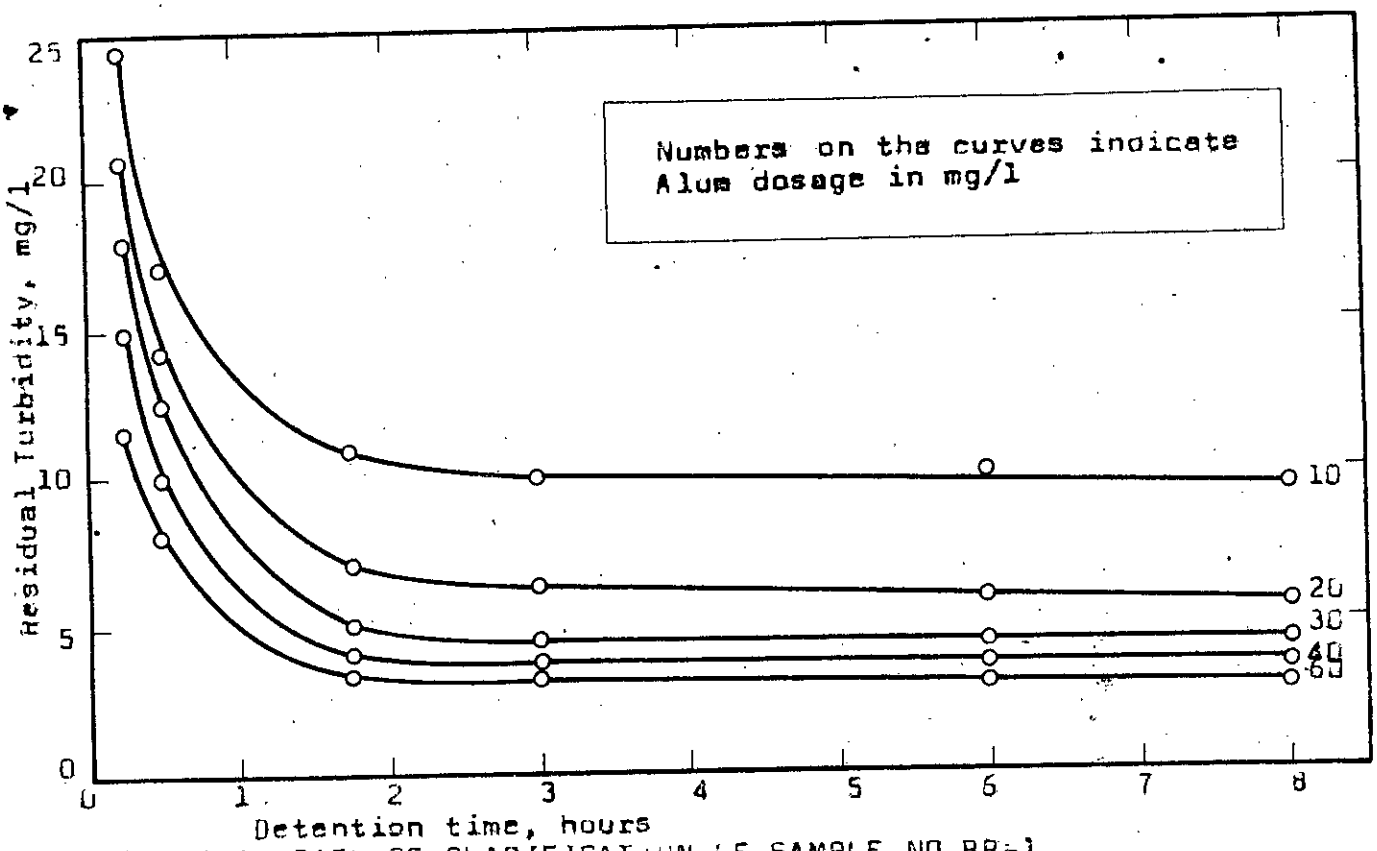


FIG. 4.4, RATE OF CLARIFICATION OF SAMPLE NO.BR-1

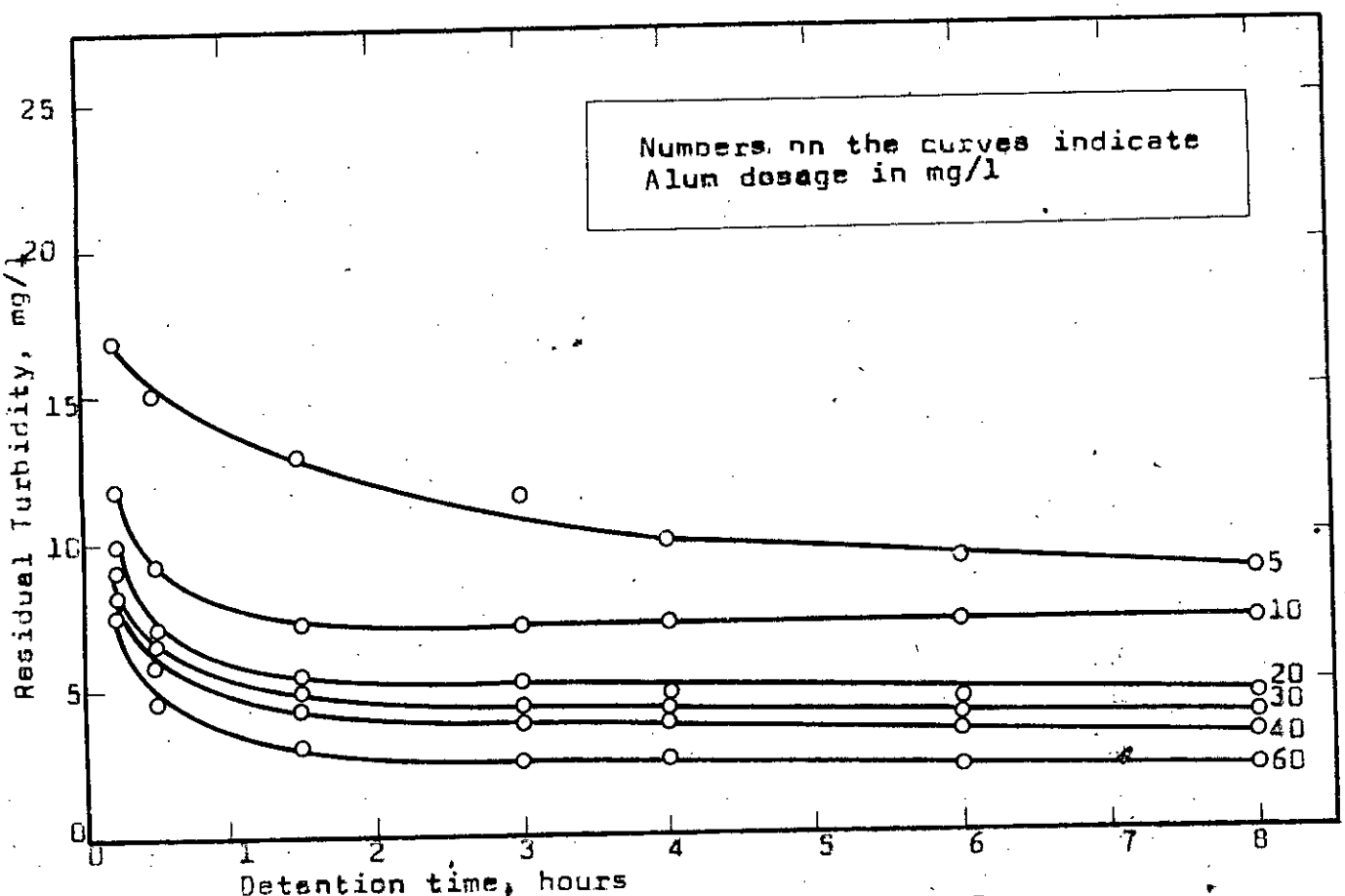


FIG.4.5 RATE OF CLARIFICATION OF SAMPLE NO. BR-2

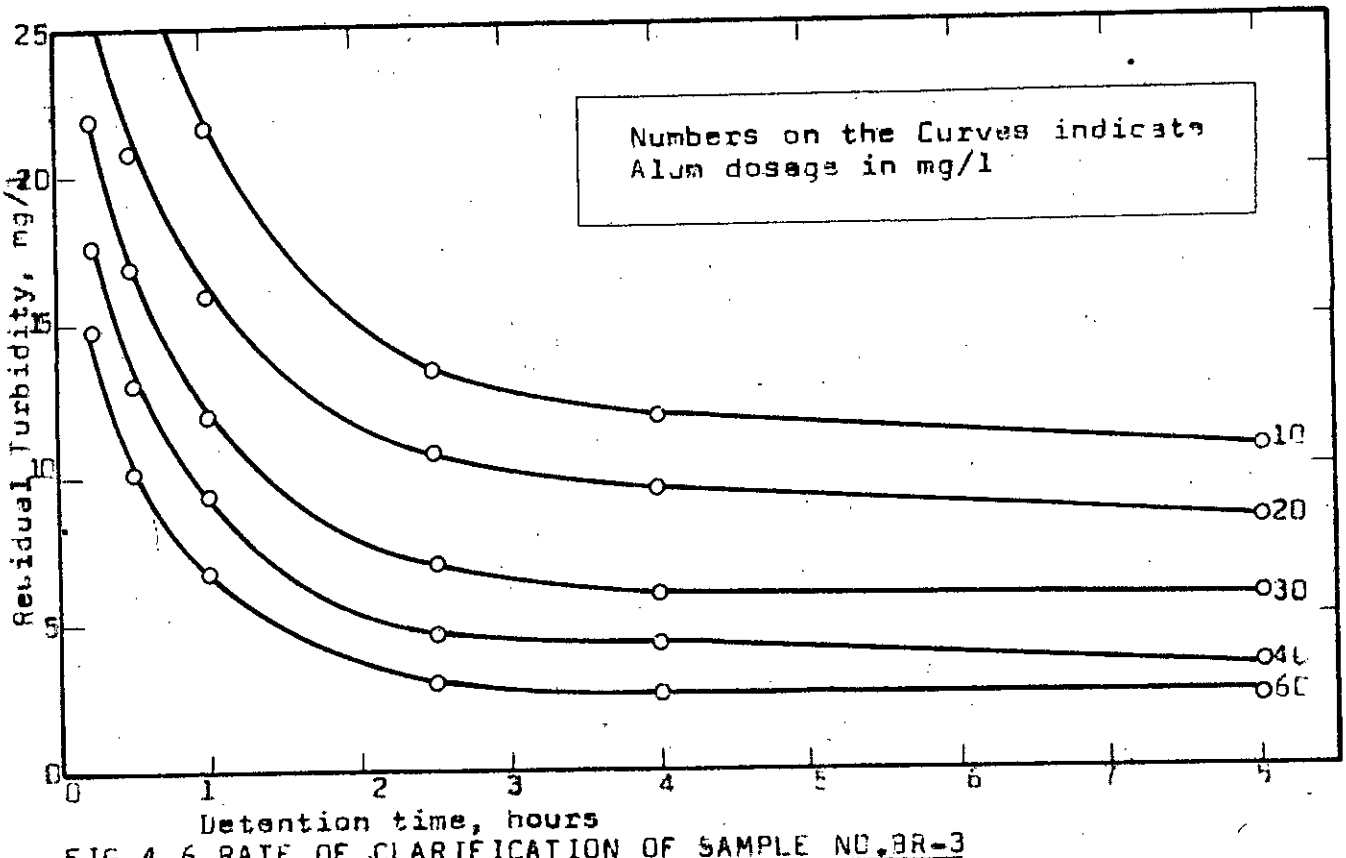


FIG.4.6 RATE OF CLARIFICATION OF SAMPLE NO.BR-3

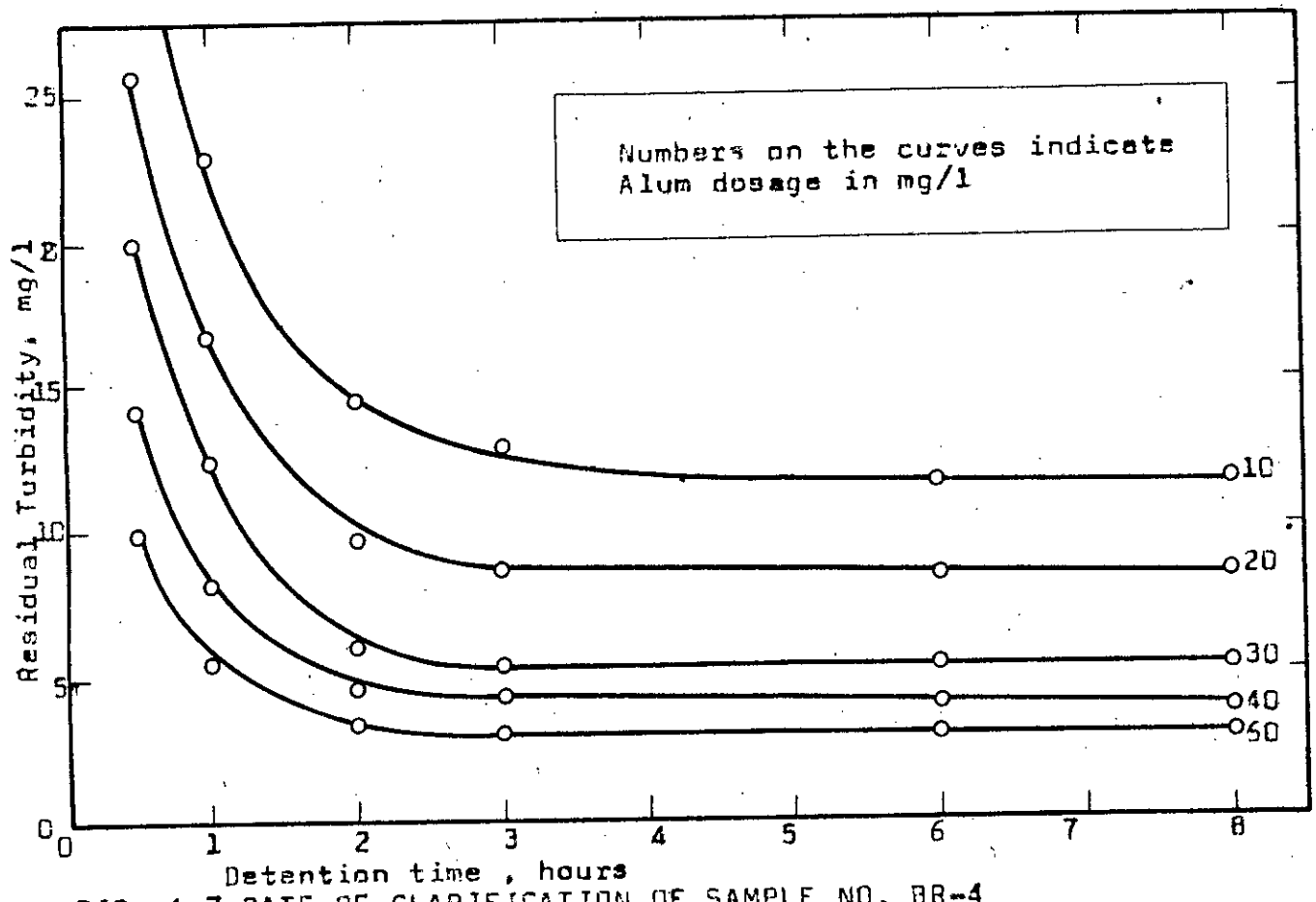


FIG. 4.7 RATE OF CLARIFICATION OF SAMPLE NO. BR-4

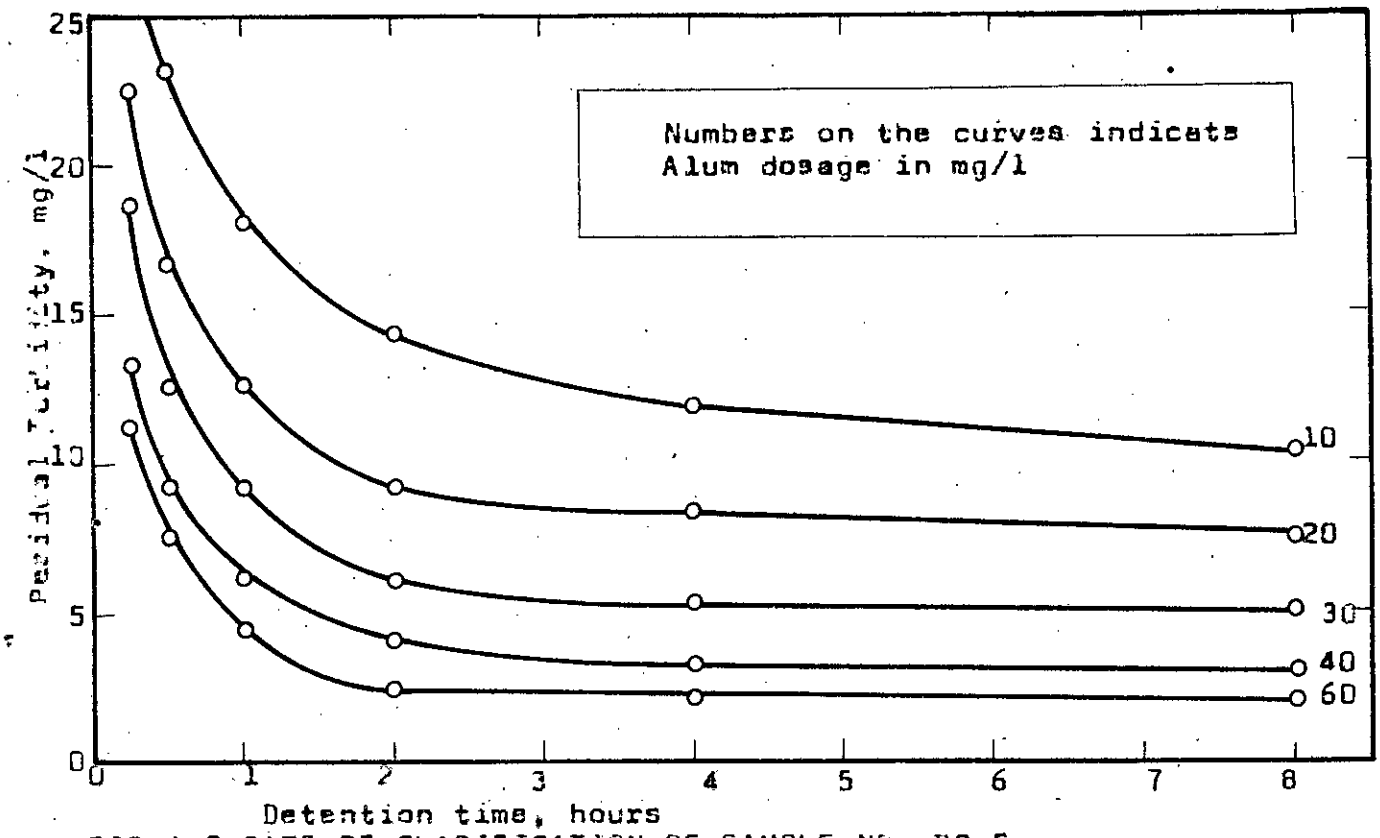


FIG.4.8 RATE OF CLARIFICATION OF SAMPLE NO. BR-5

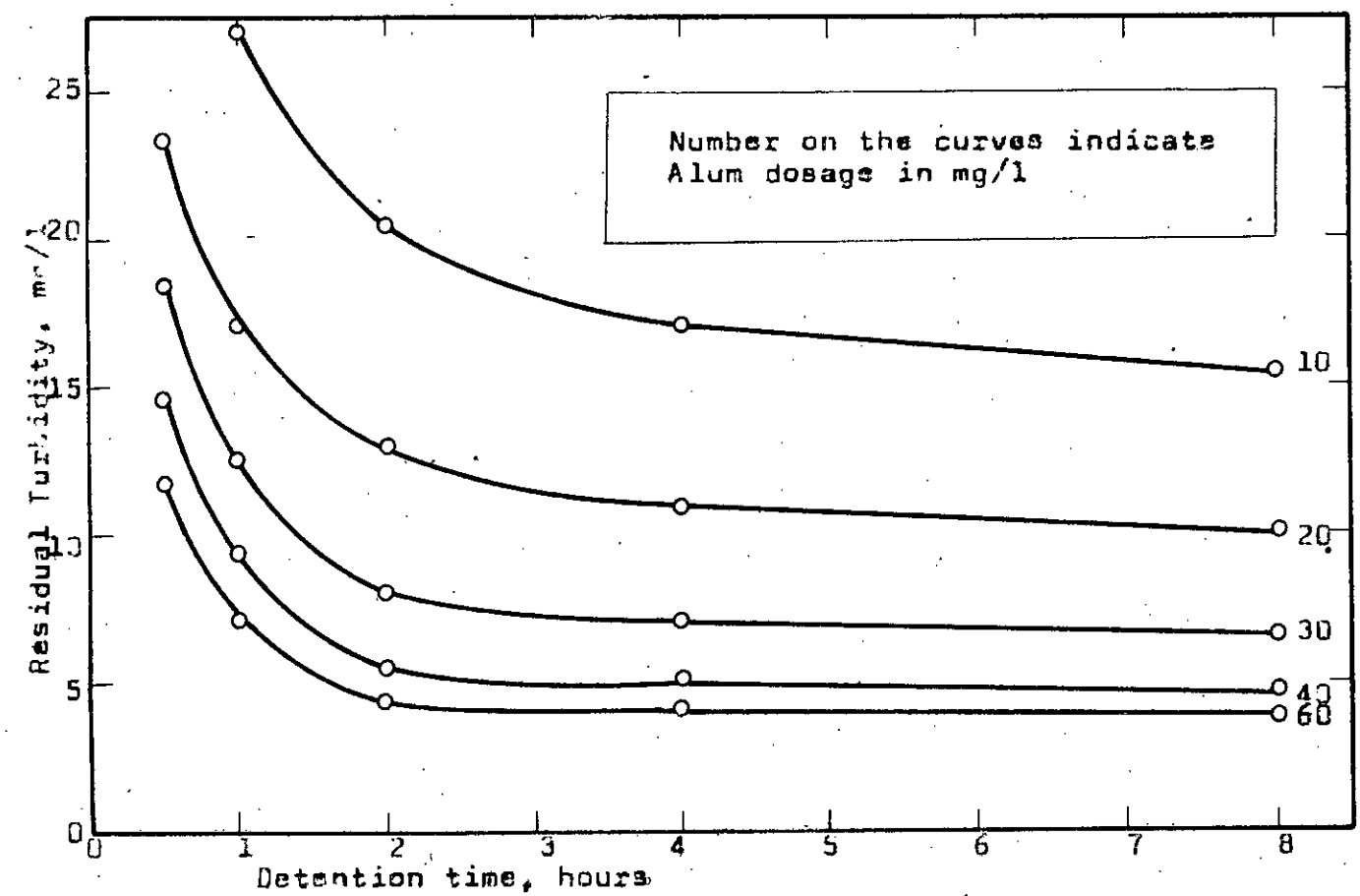


FIG.4.9 RATE OF CLARIFICATION OF SAMPLE NO.BR-6

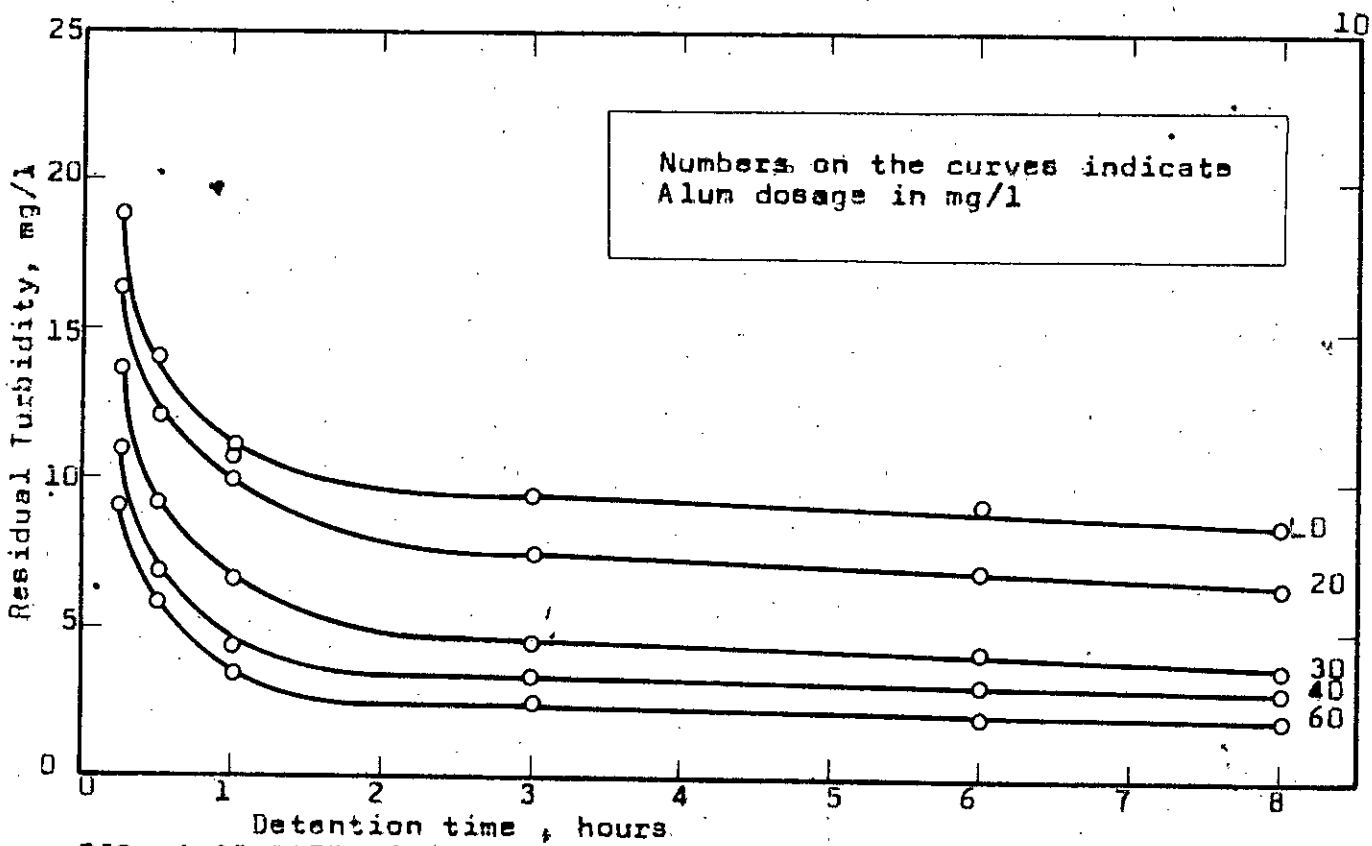


FIG. 4.10 RATE OF CLARIFICATION OF SAMPLE NO. DL-1

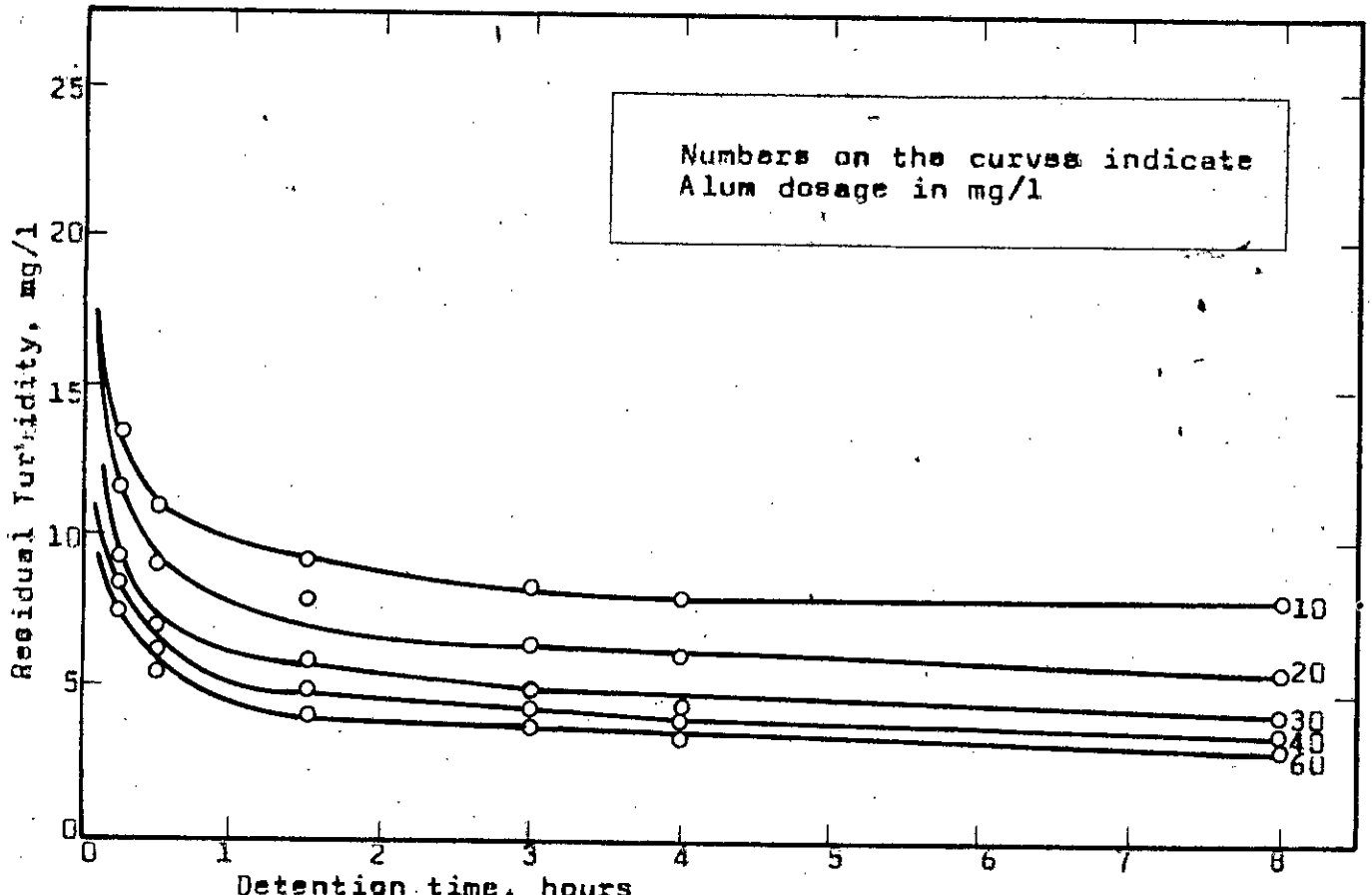


FIG.4.11 RATE OF CLARIFICATION OF SAMPLE NO DL-2

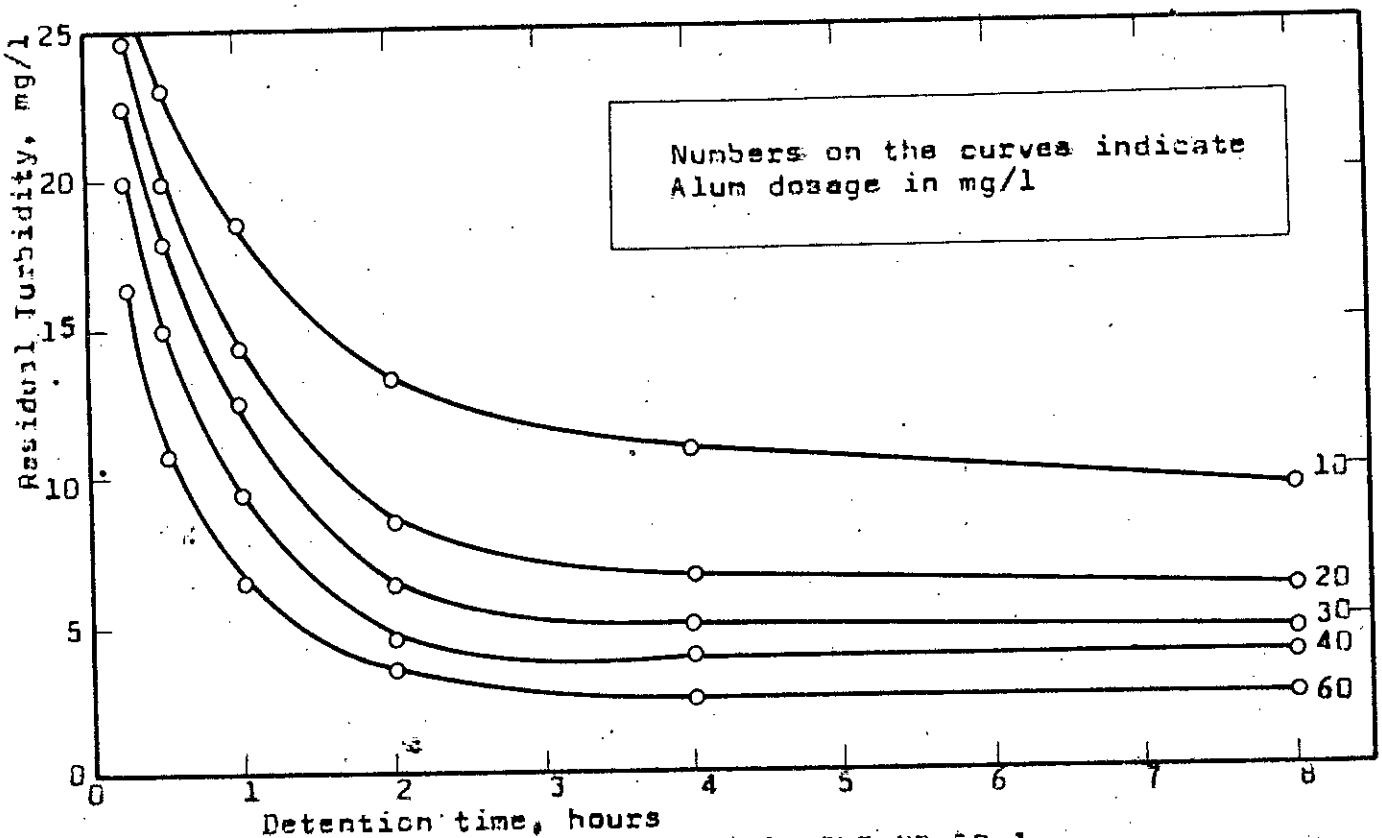


FIG. 4.12 RATE OF CLARIFICATION OF SAMPLE NO.SP-1

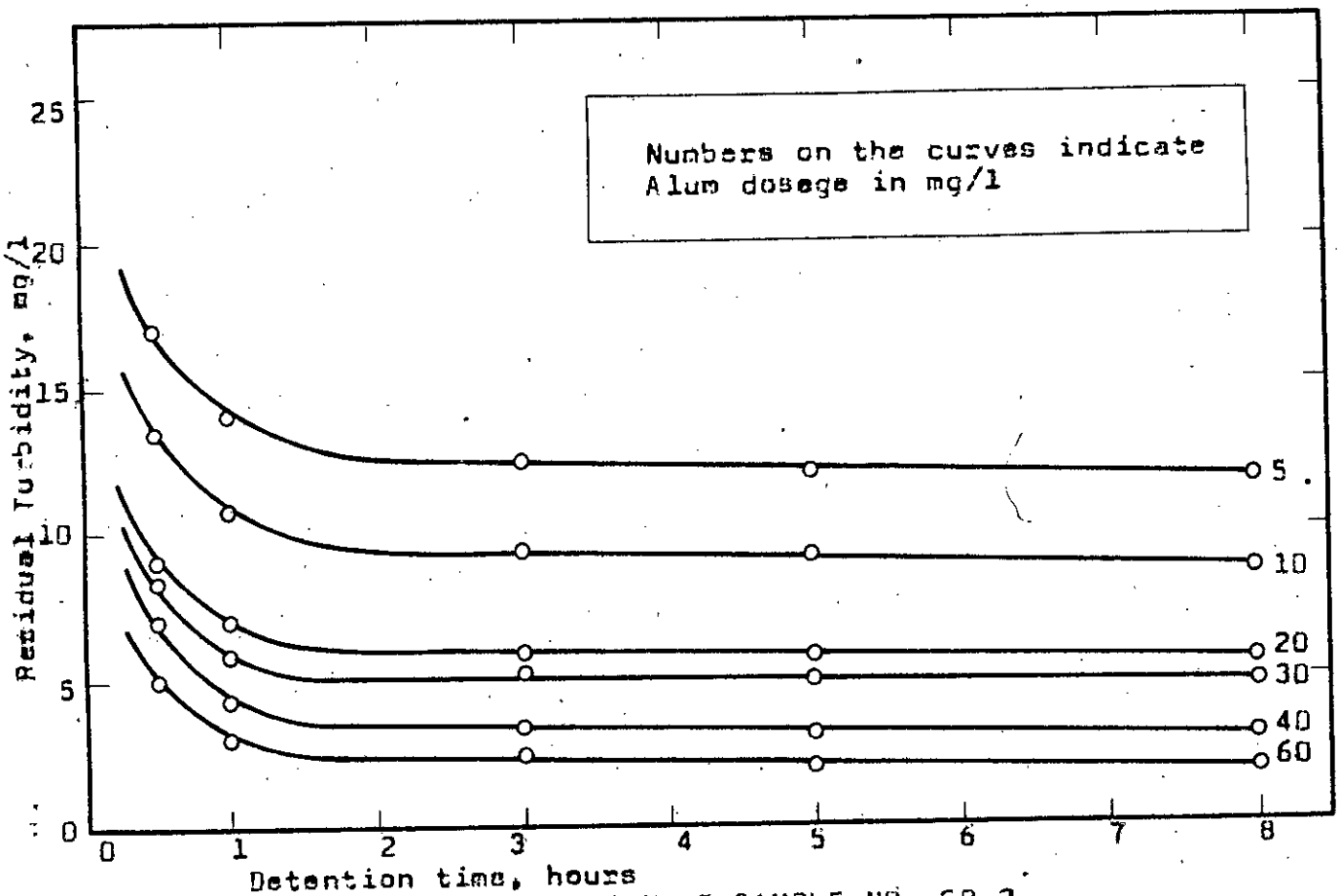


FIG. 4.13 RATE OF CLARIFICATION OF SAMPLE NO. SP-2

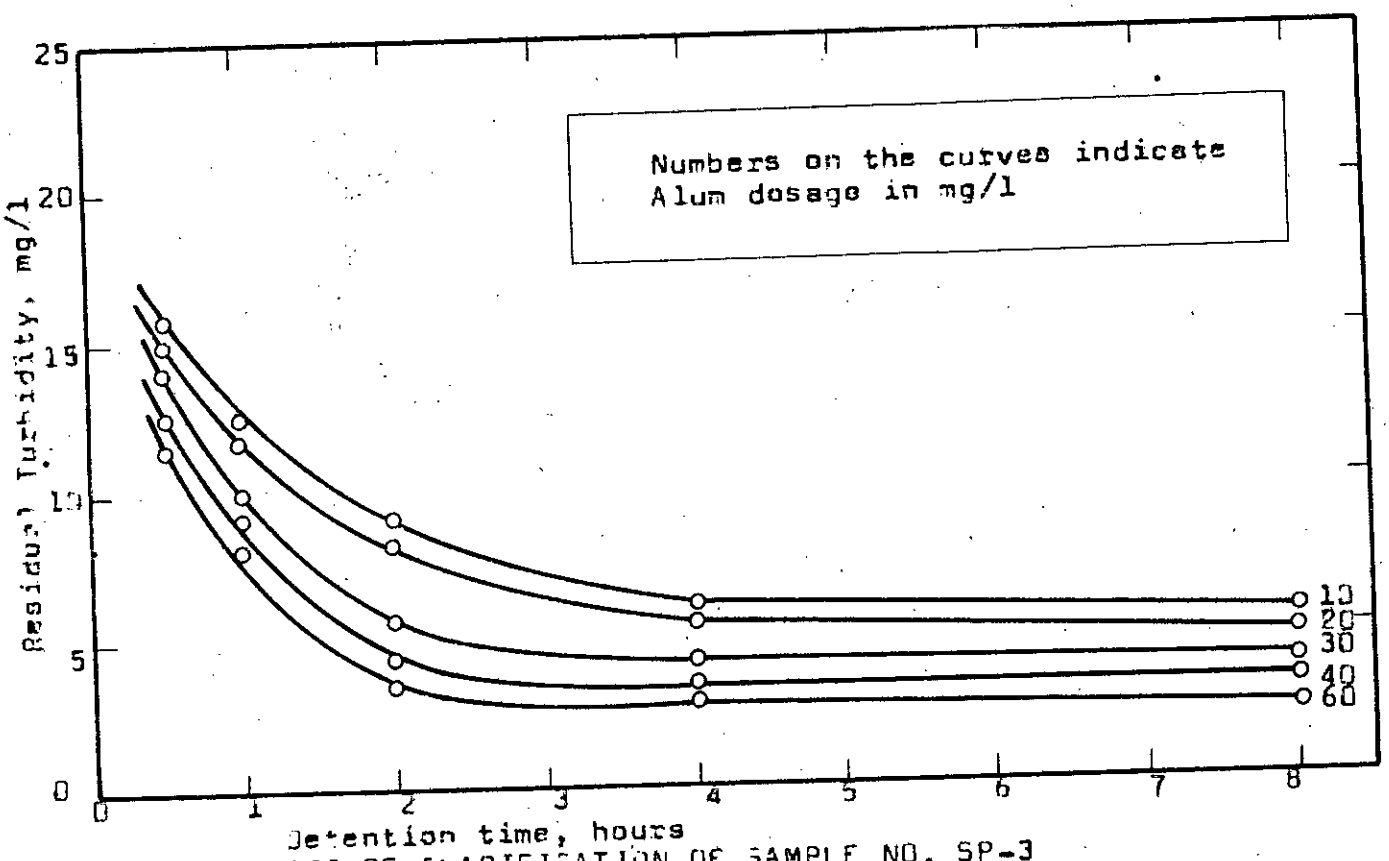


FIG.4.14 RATE OF CLARIFICATION OF SAMPLE NO. SP-3

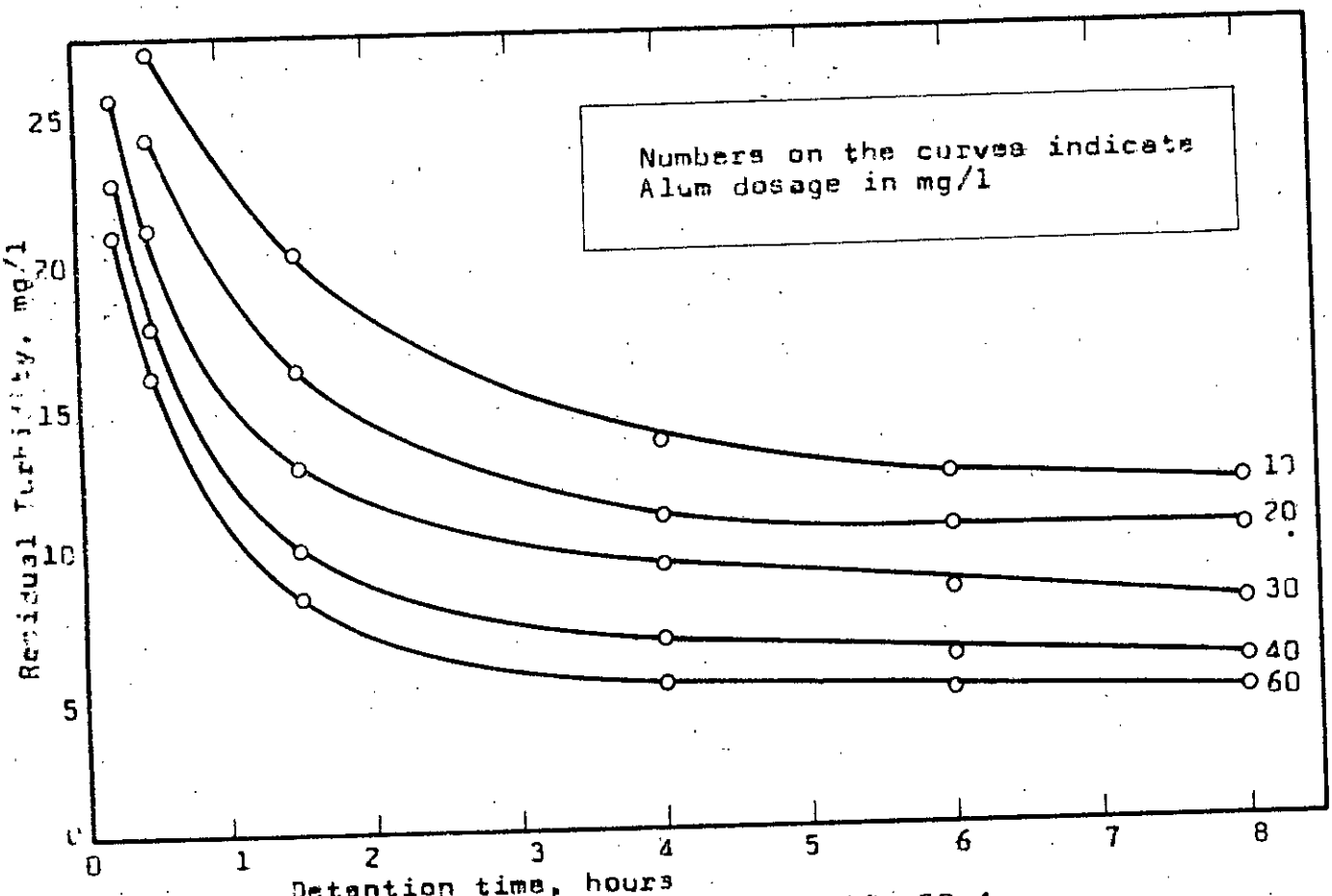


FIG.4.15 RATE OF CLARIFICATION OF SAMPLE NO. SP-4

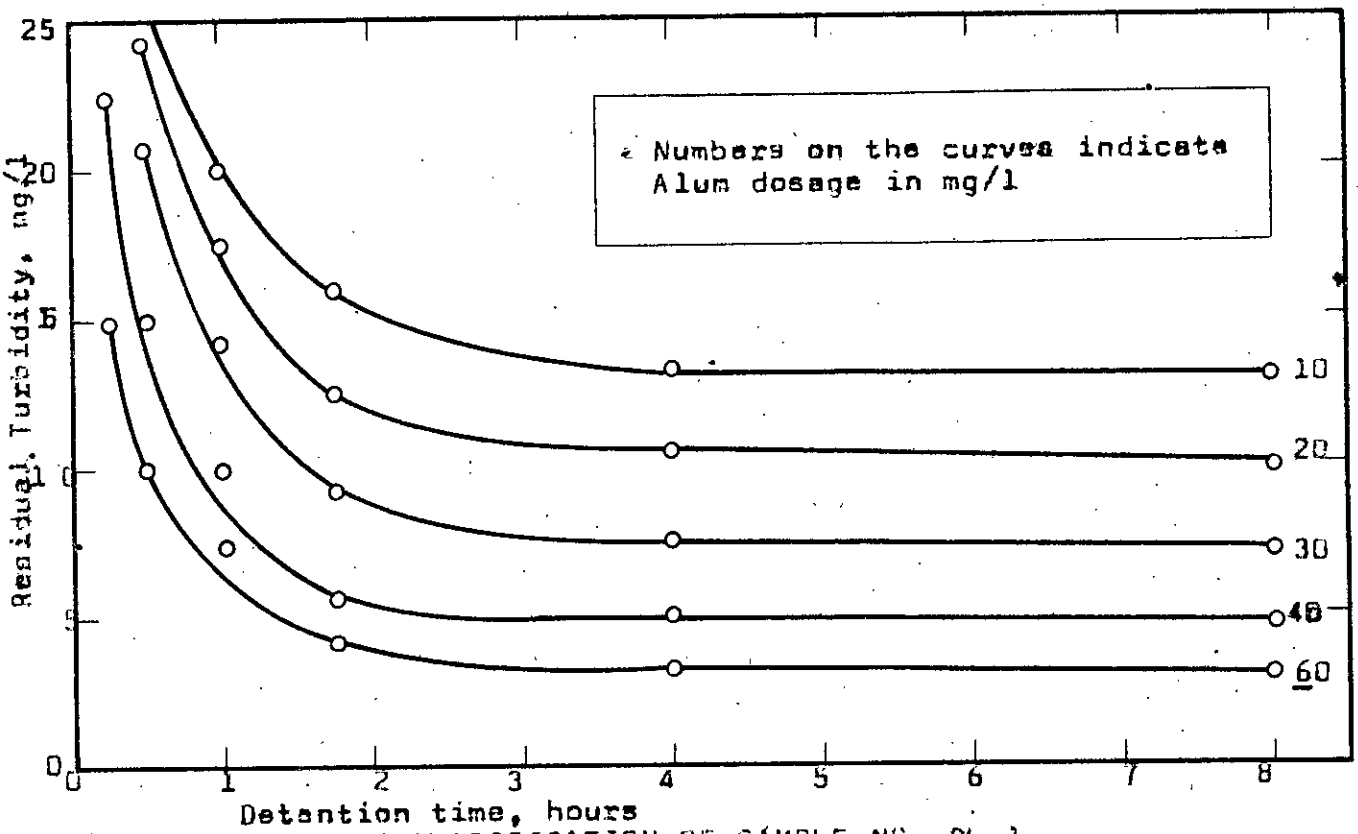


FIG. 4.16 RATE OF CLARIFICATION OF SAMPLE NO. RL-1

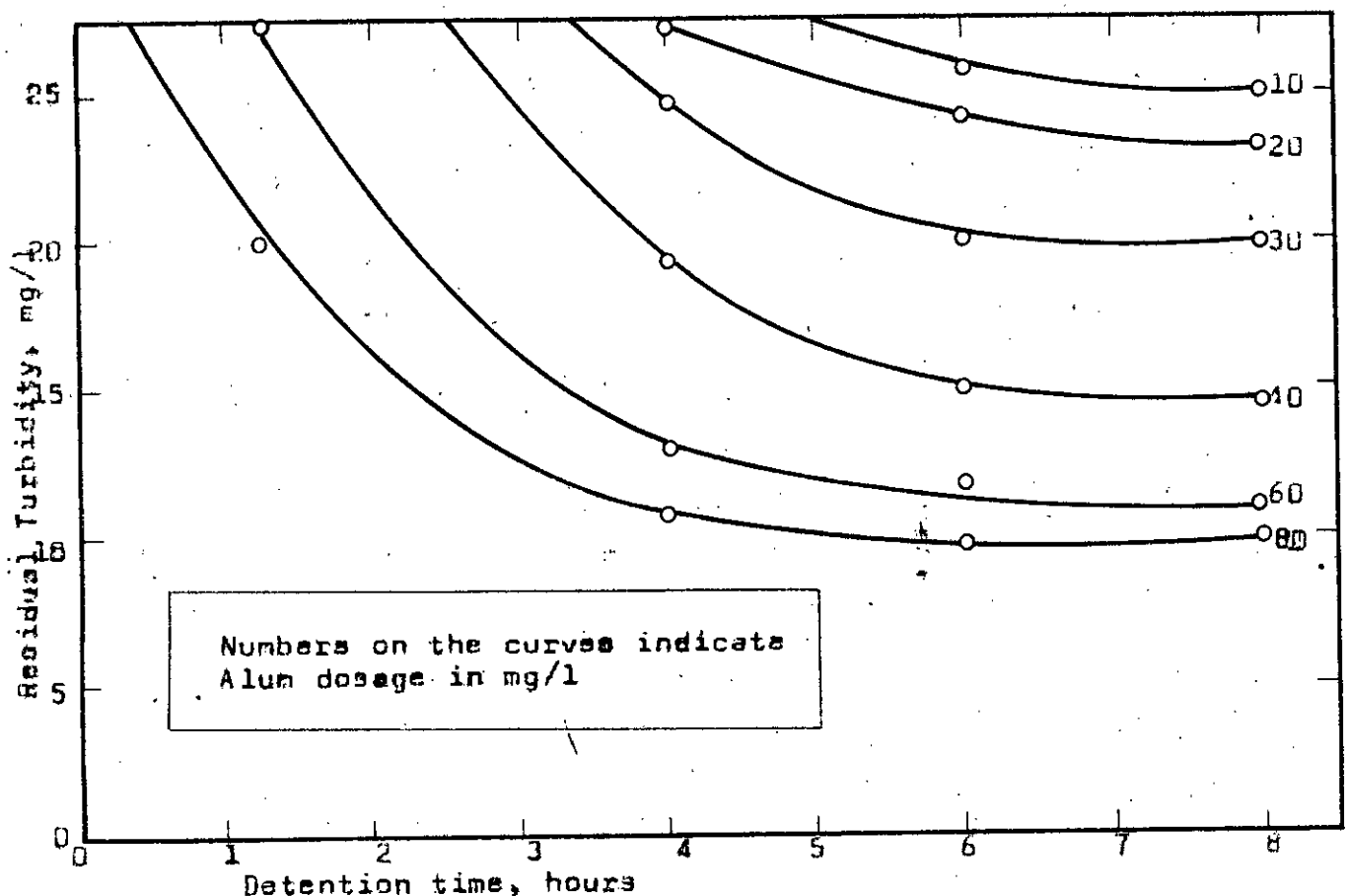


FIG. 4.17 RATE OF CLARIFICATION OF SAMPLE NO.RL-2

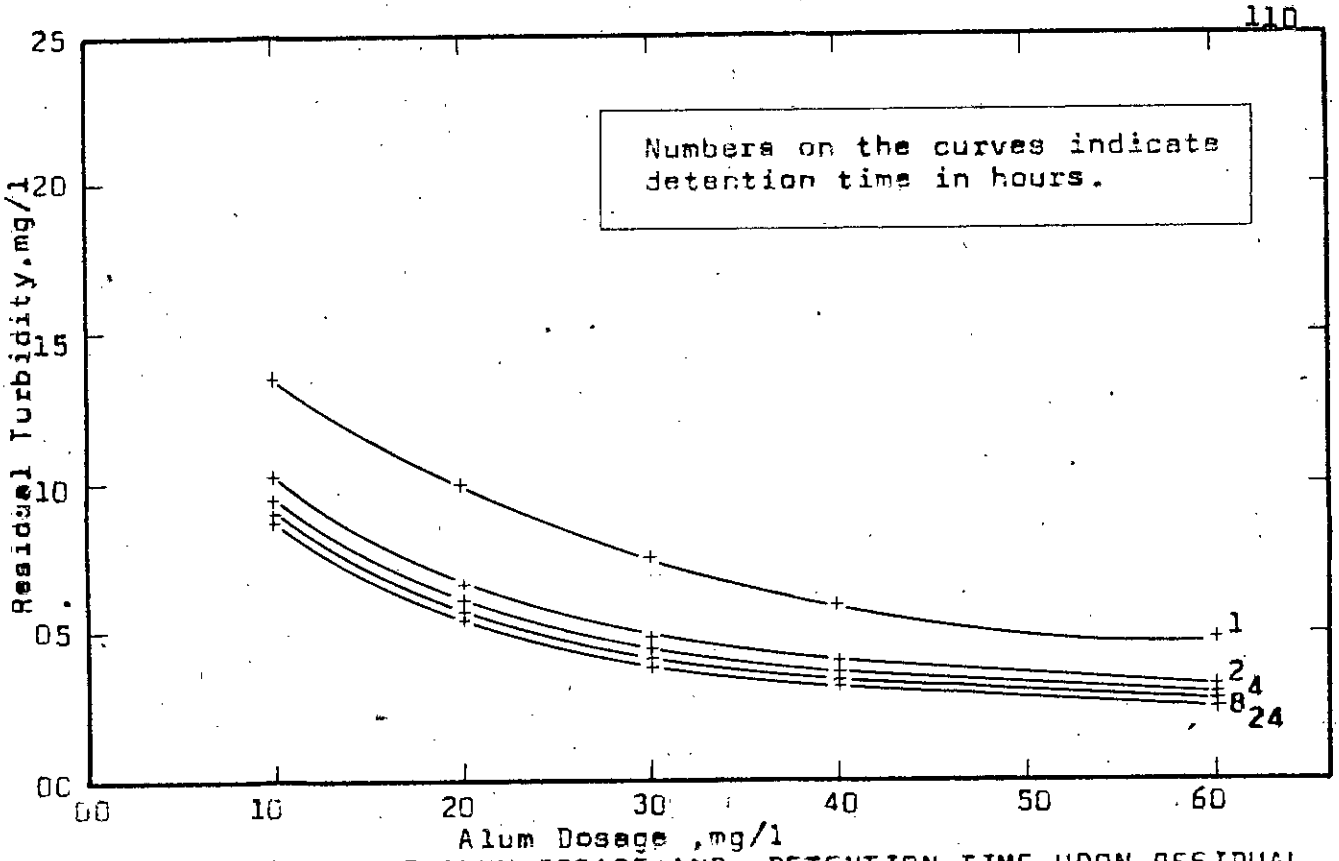


FIG.4.18 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.BR-1

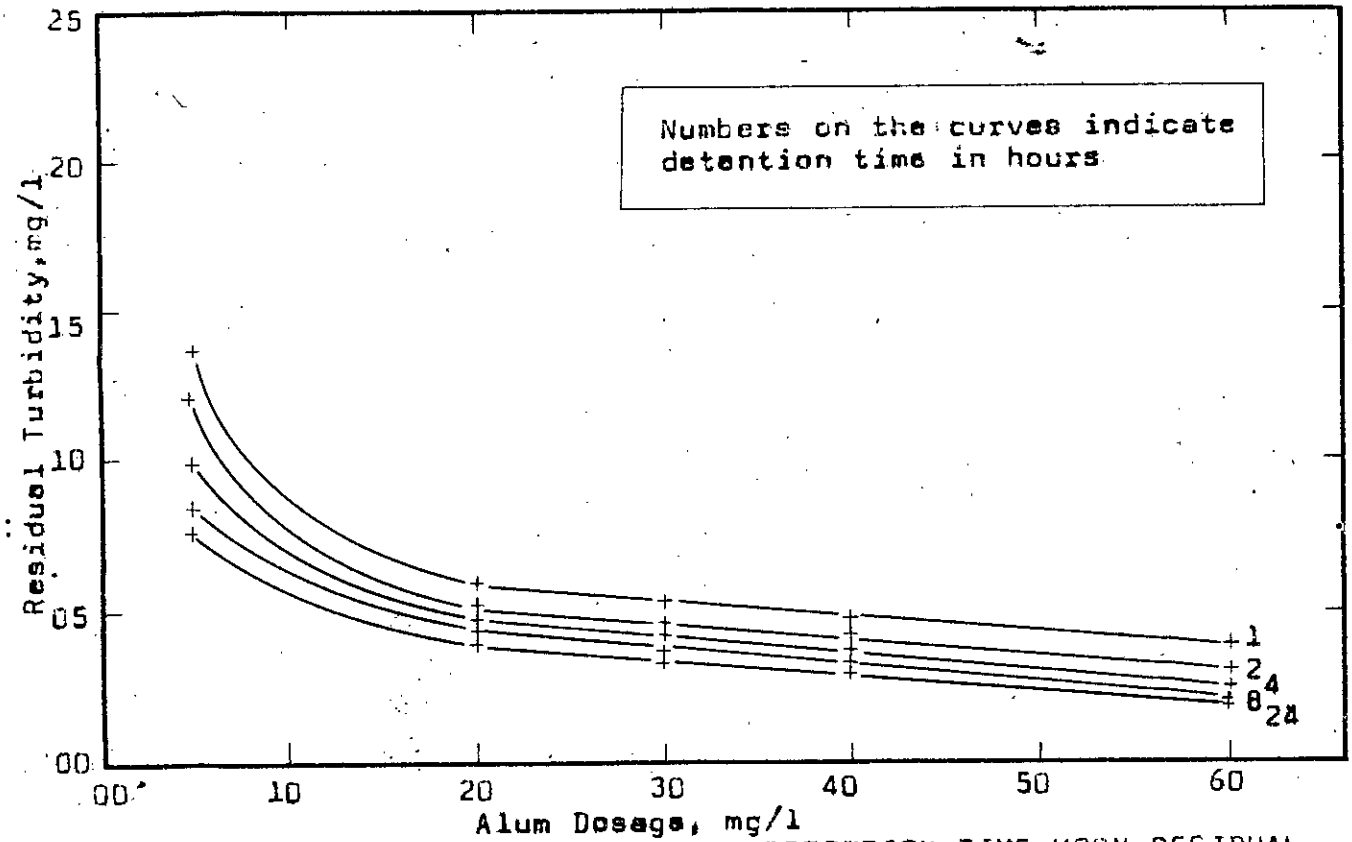


FIG.4.19 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.BR-2

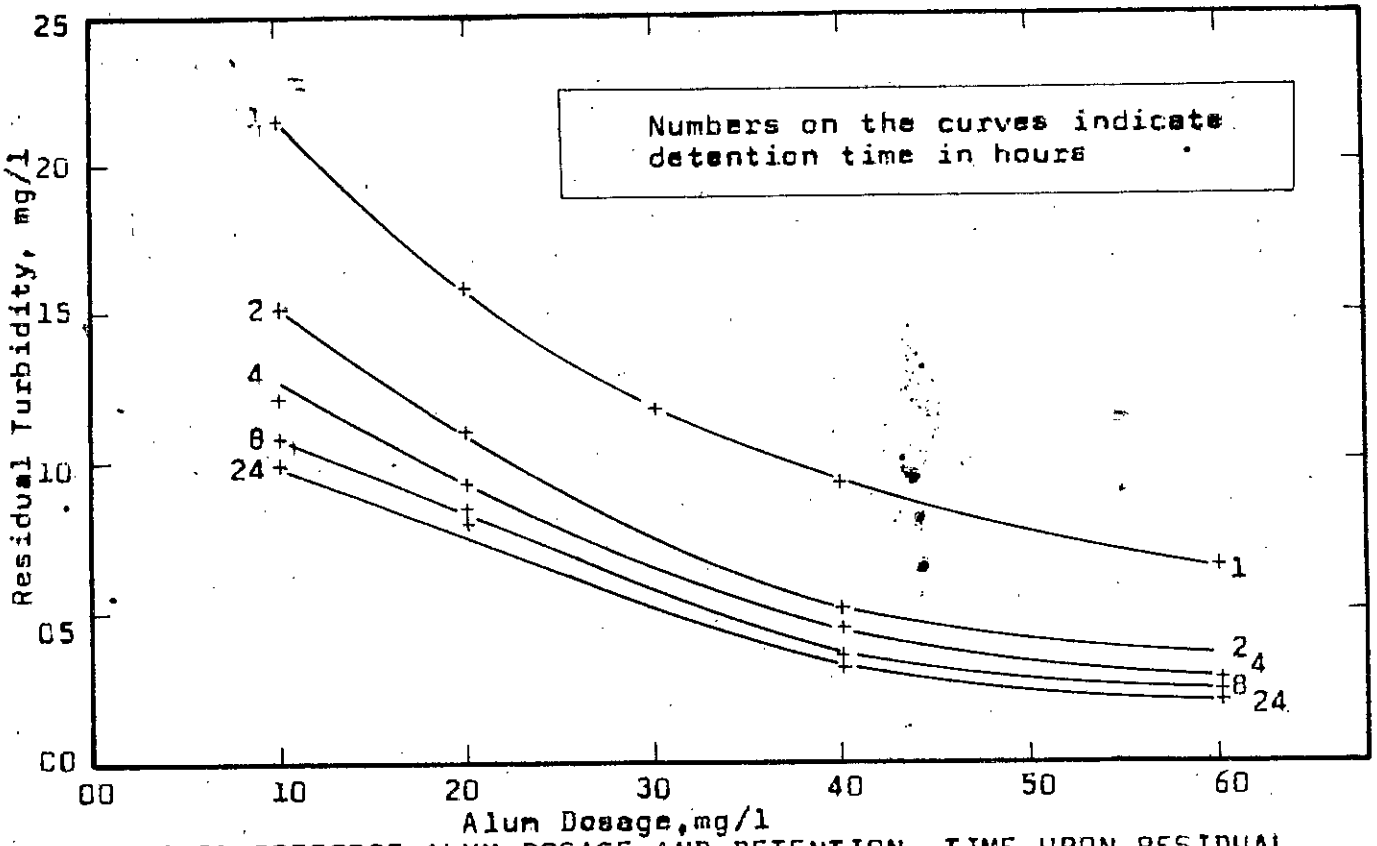


FIG.4.20 EFFECTOF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.BR-3

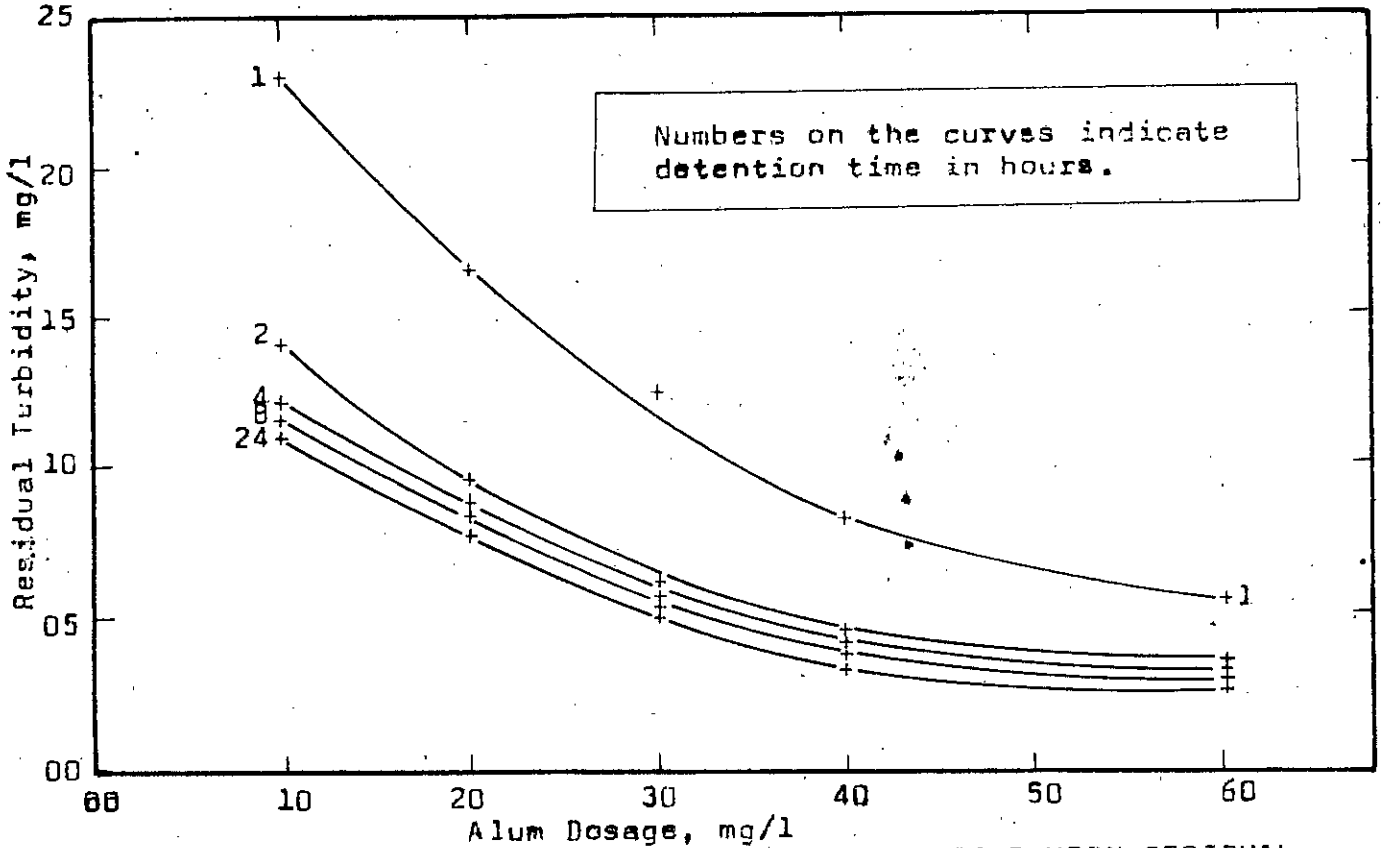


FIG.4.21 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-4

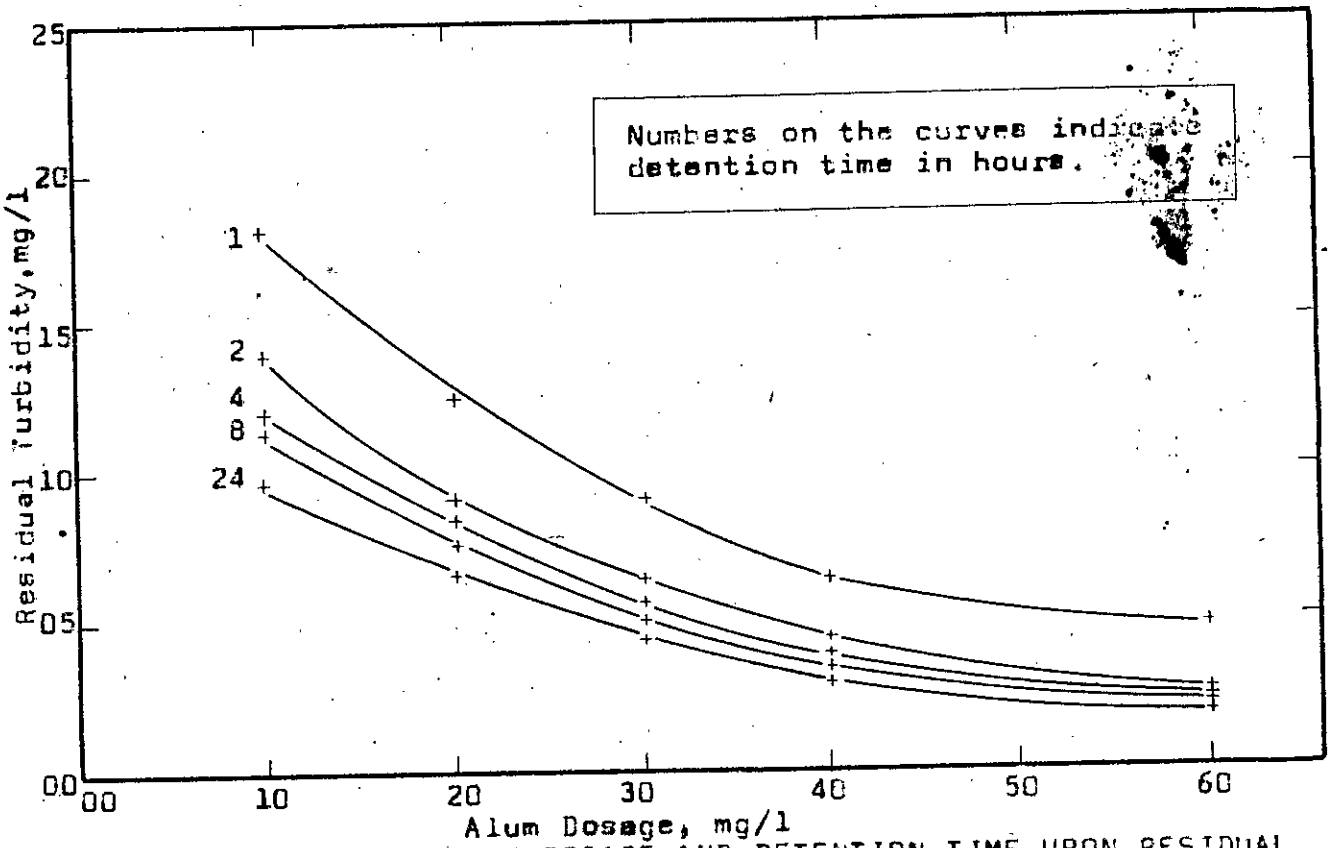


FIG.4.22 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. BR-5

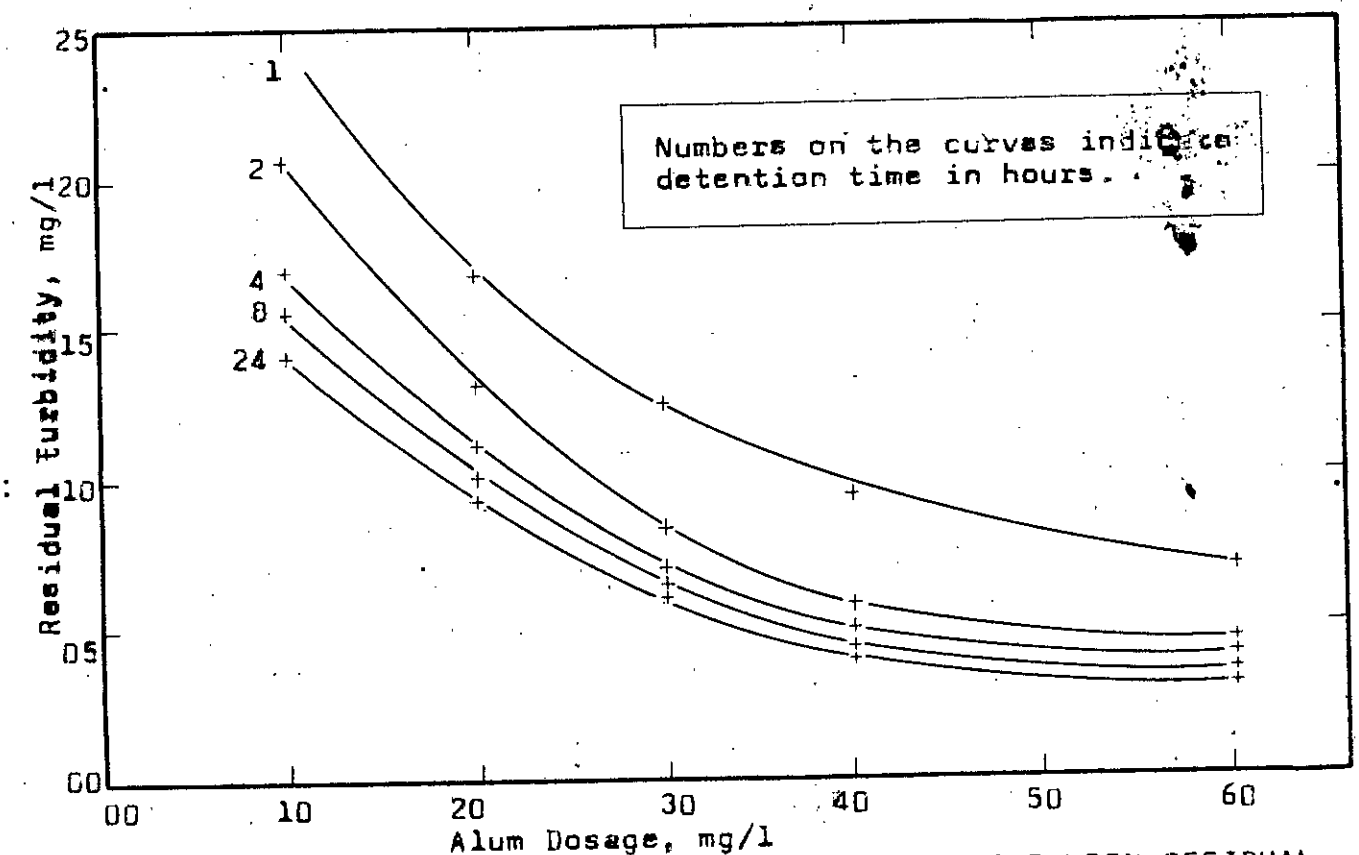


FIG.4.23 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.BR-6

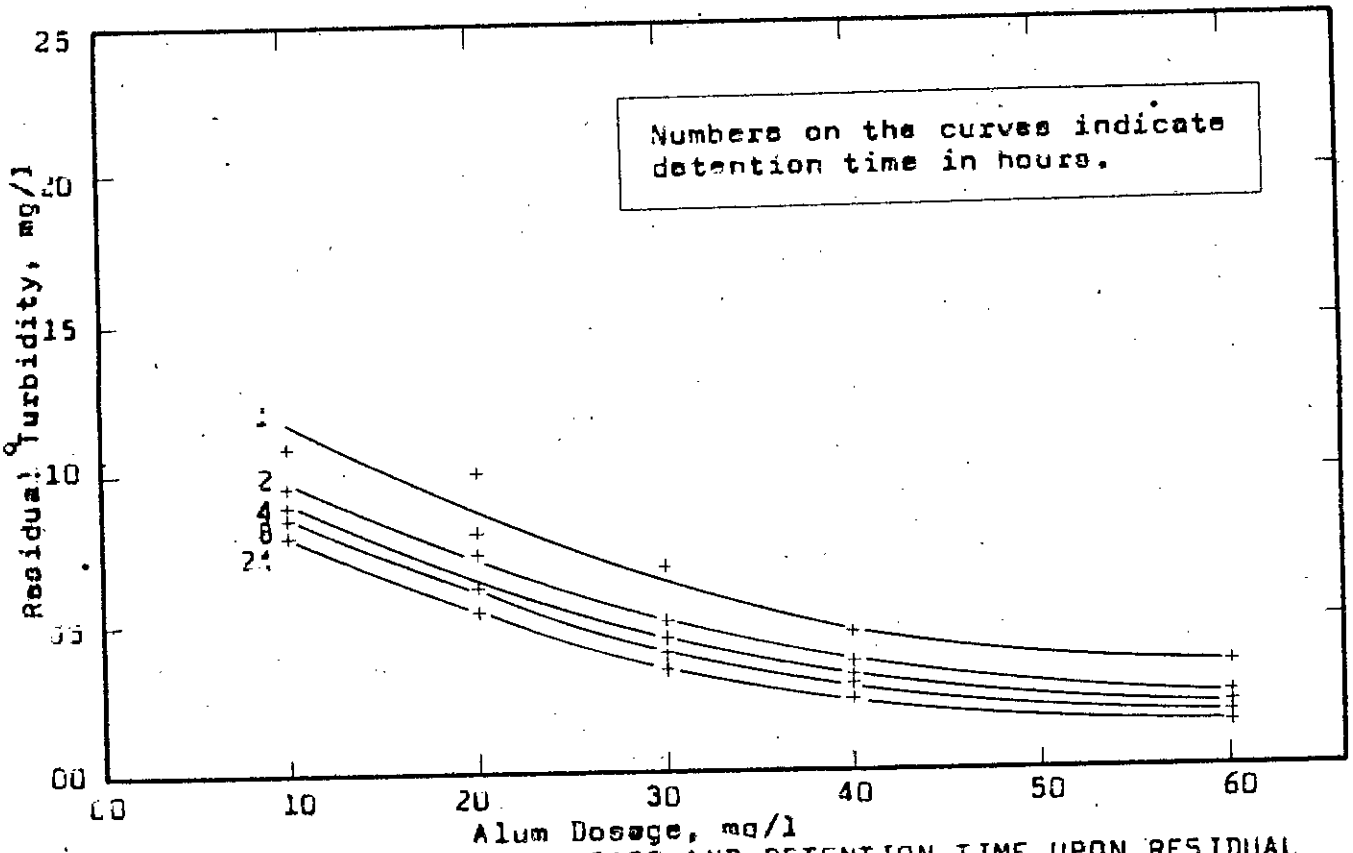


FIG.4.24 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.DL-1

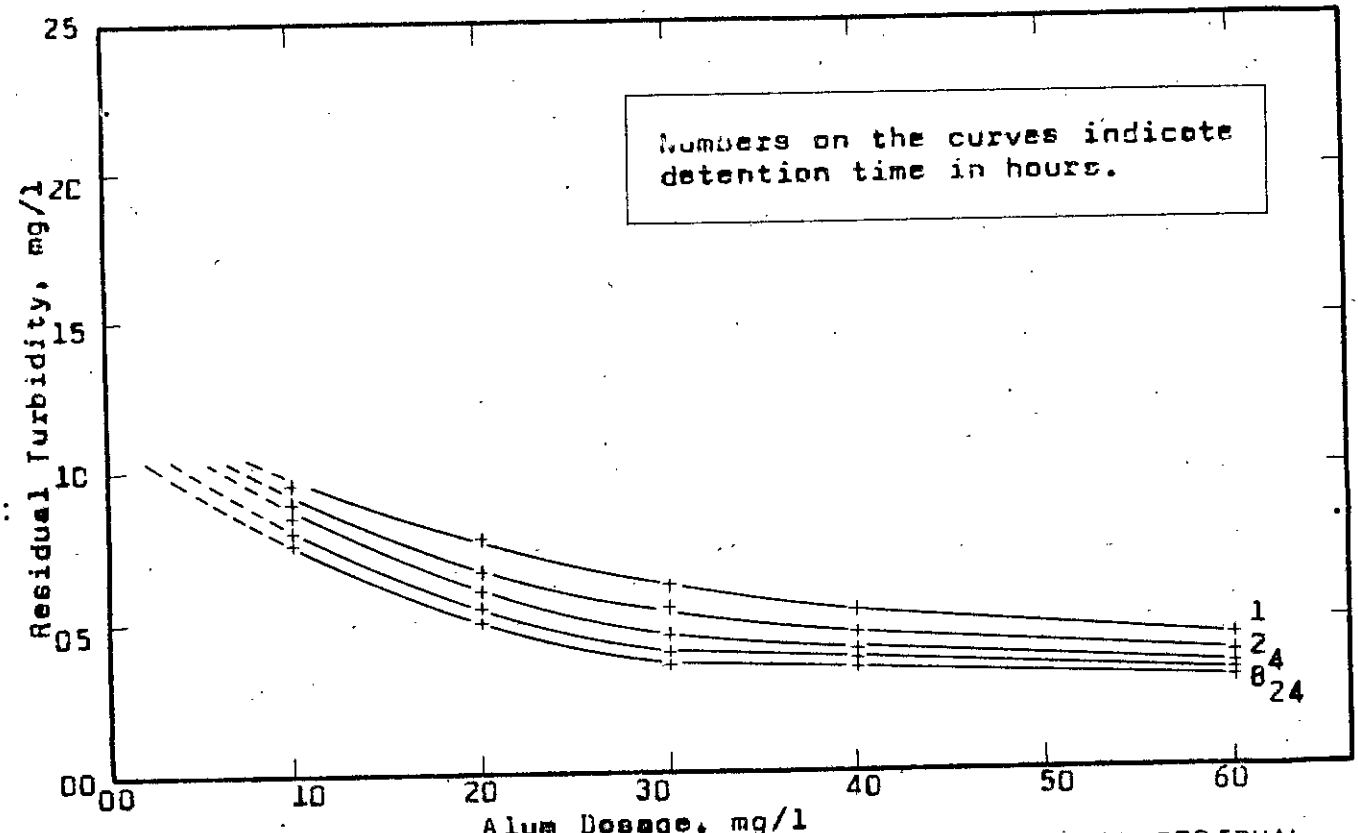


FIG.4.25 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.DL-2

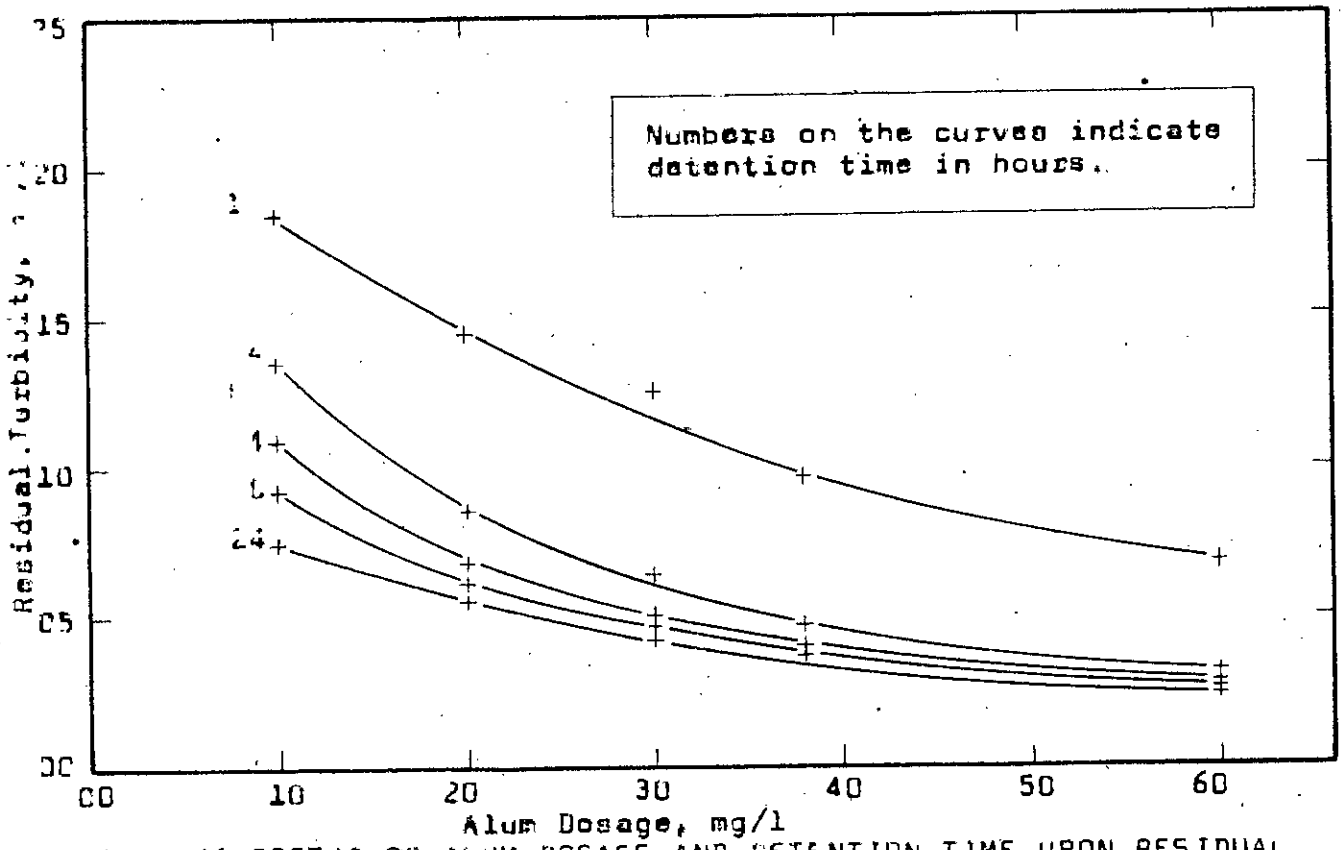


FIG. 1.26 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.SP-1

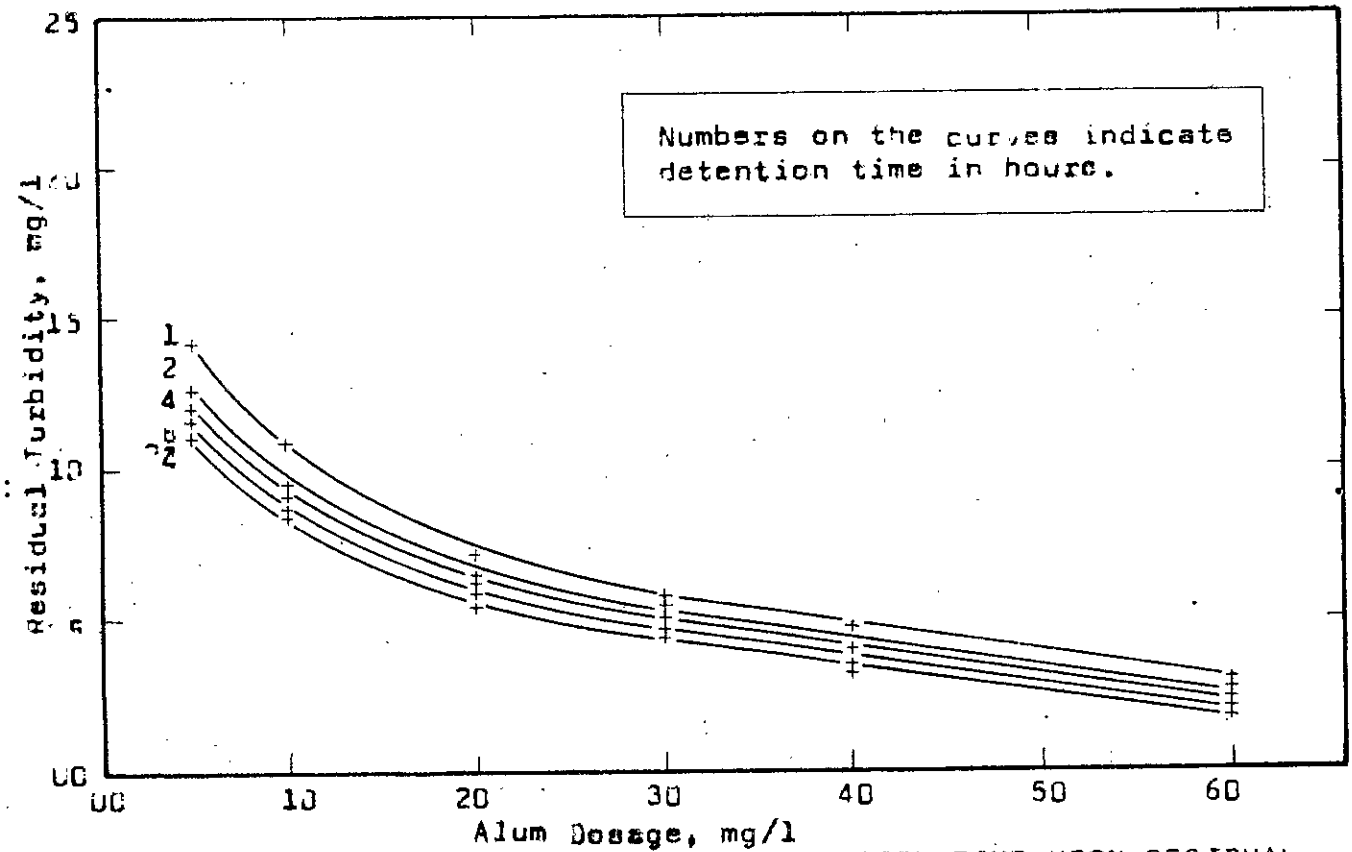


FIG. 1.27 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. SP-2

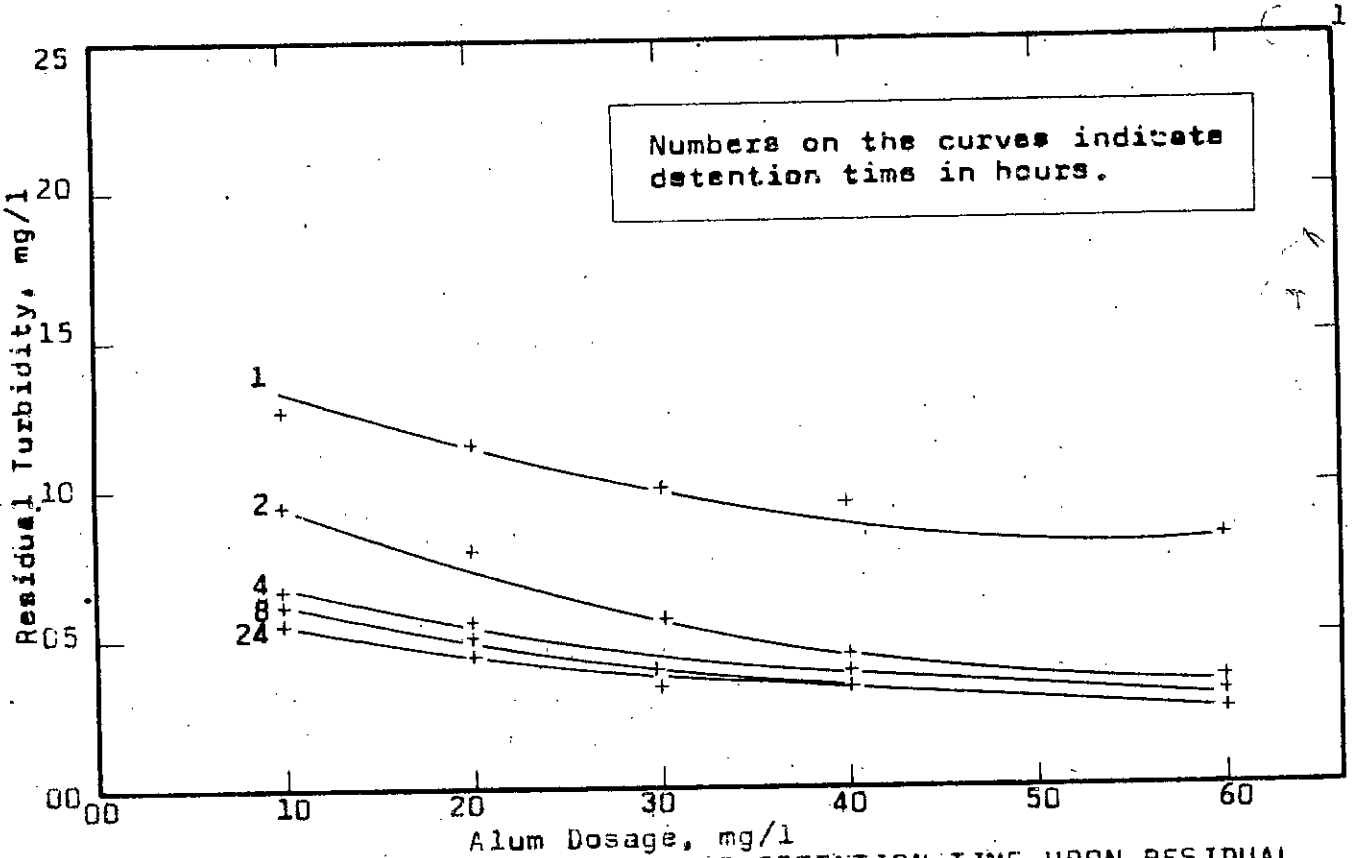


FIG.4.28 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.SP-2

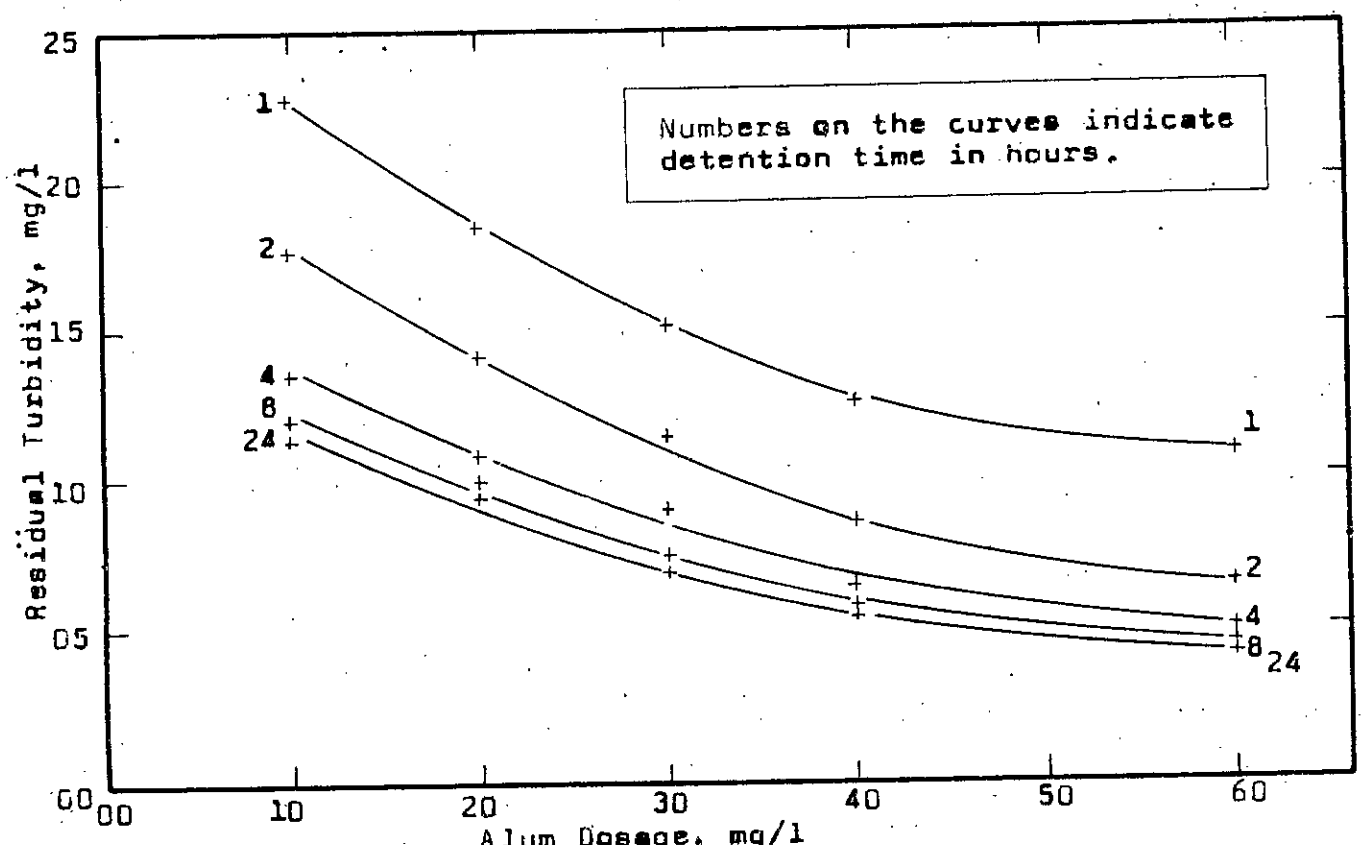


FIG.4.29 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO. SP-4

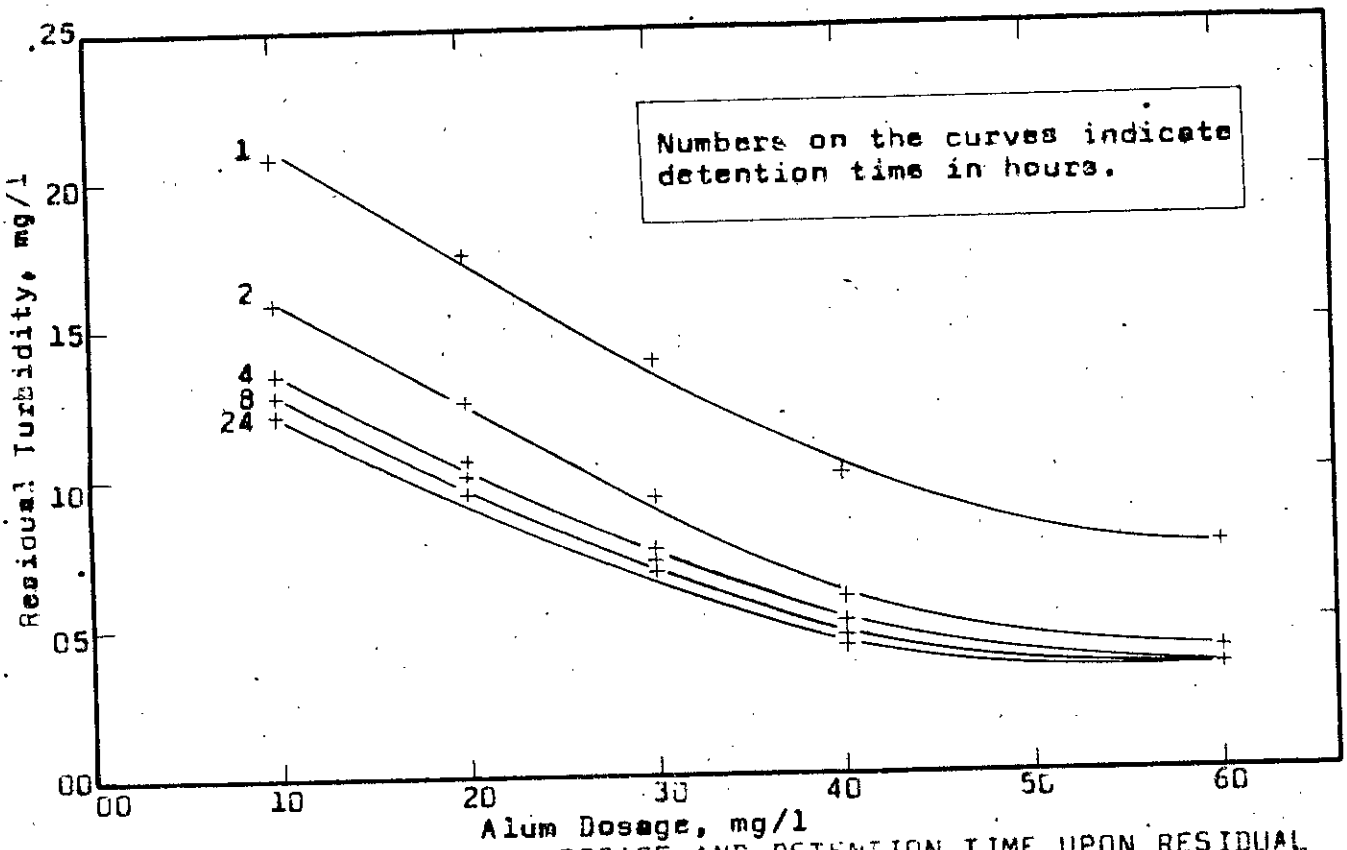


FIG.4.30 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.RL-1

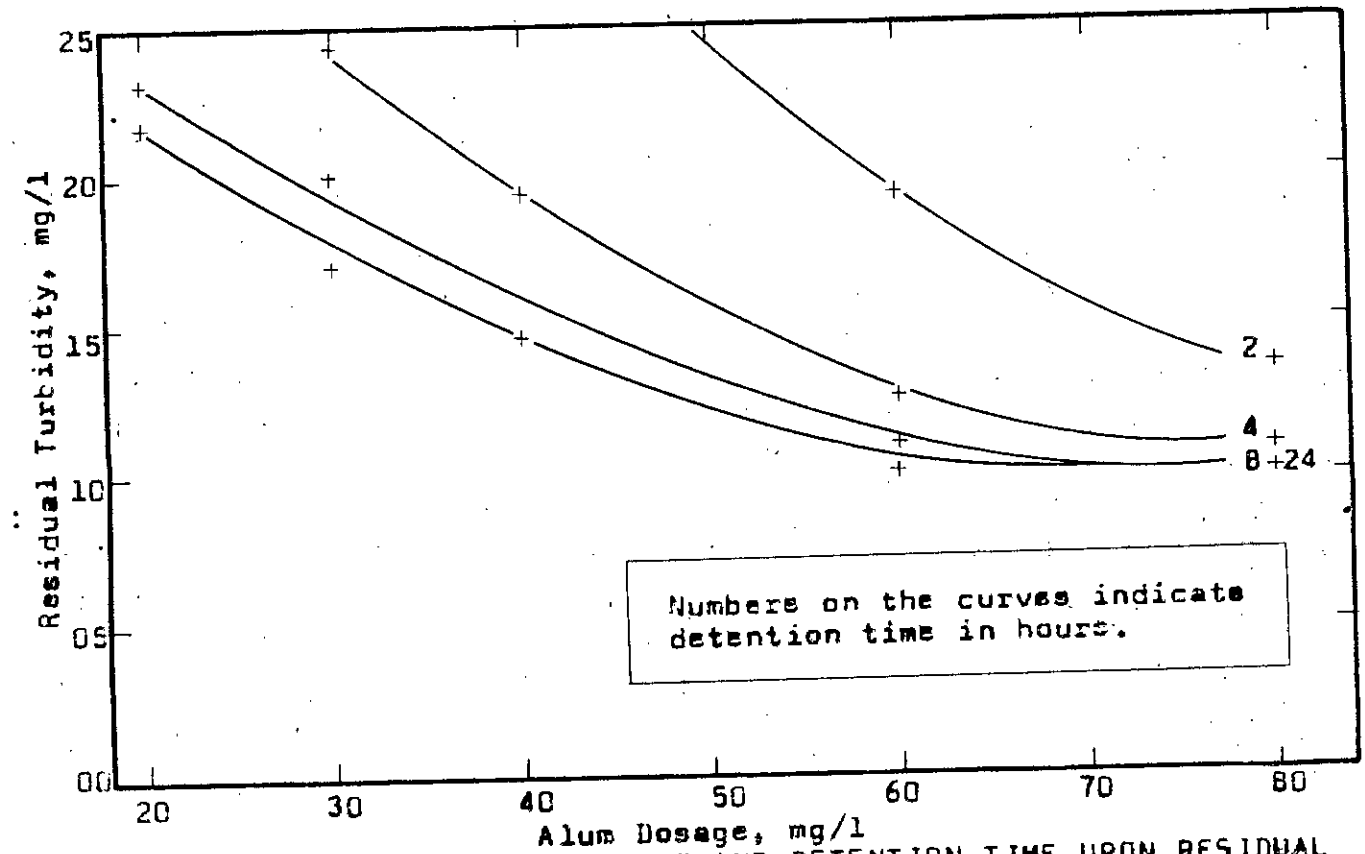
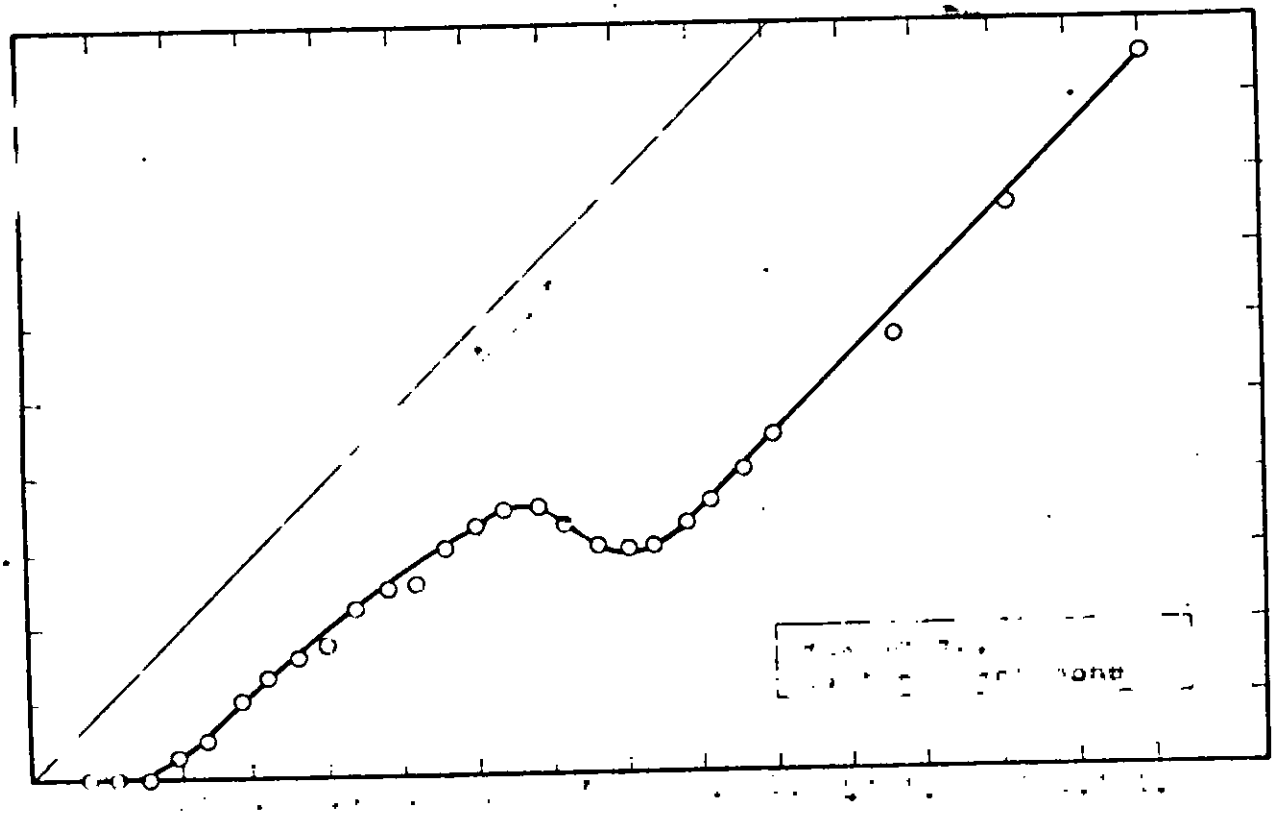
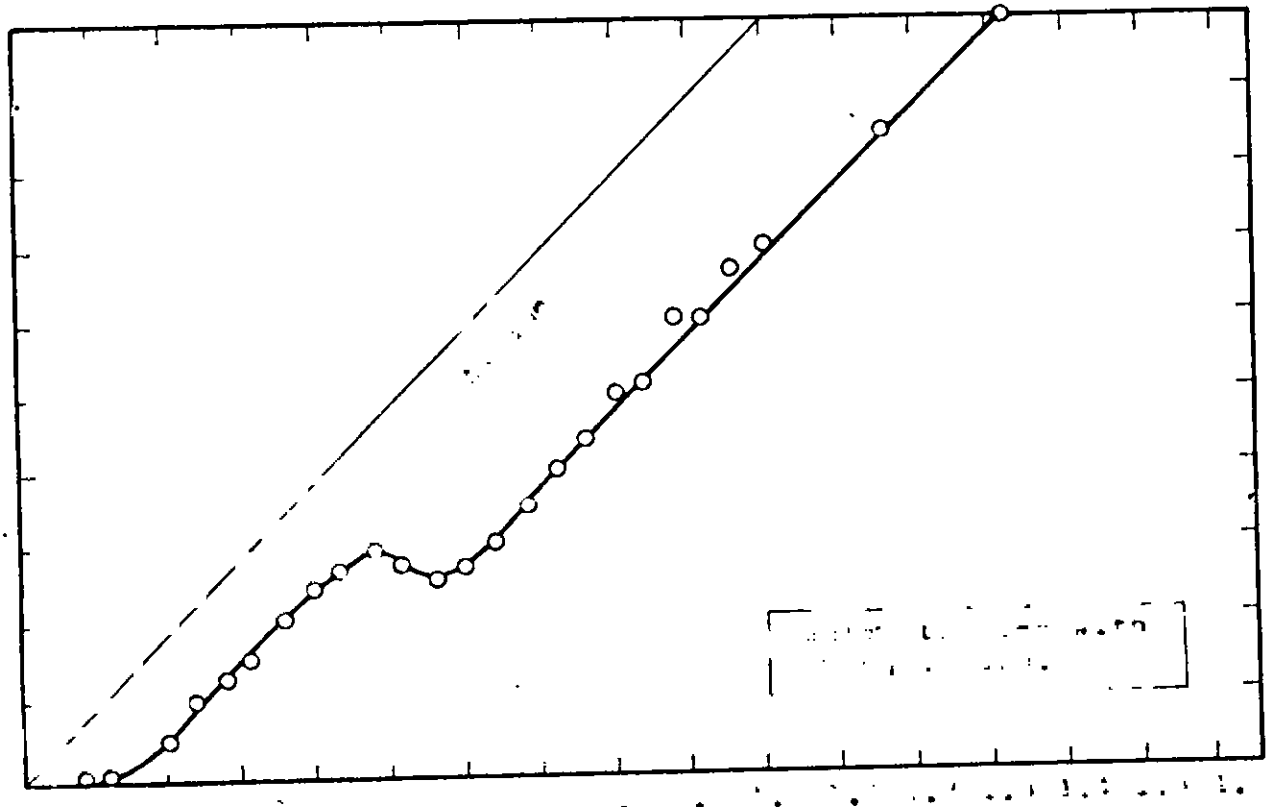


FIG.4.31 EFFECT OF ALUM DOSAGE AND DETENTION TIME UPON RESIDUAL TURBIDITY OF SAMPLE NO.RL-2





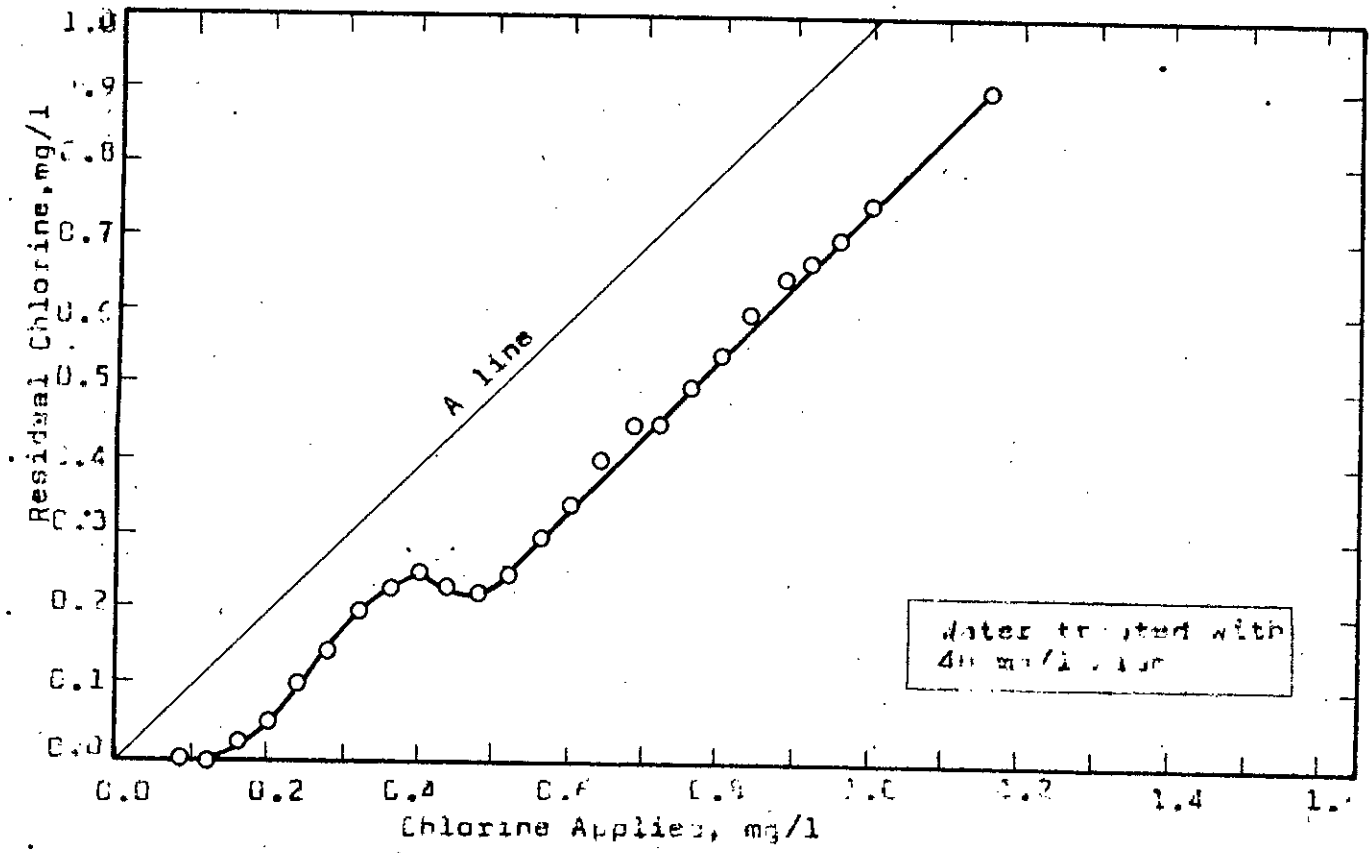


FIG.4.35c CHLORINATION CURVE OF WATER TREATED WITH 40 mg/l ALUM DOSAGE.

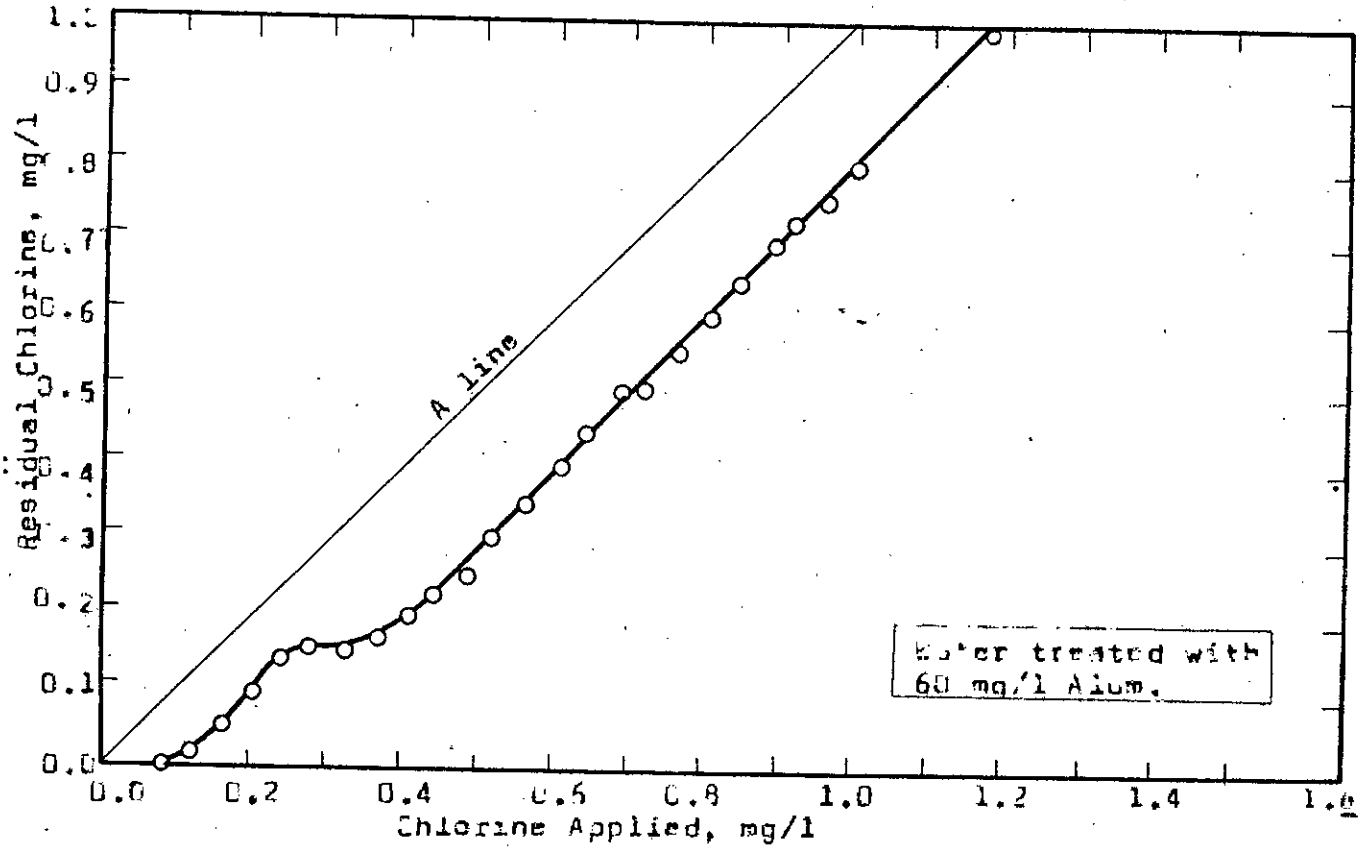


FIG.4.35d CHLORINATION CURVE OF WATER TREATED WITH 60 mg/l ALUM DOSAGE.

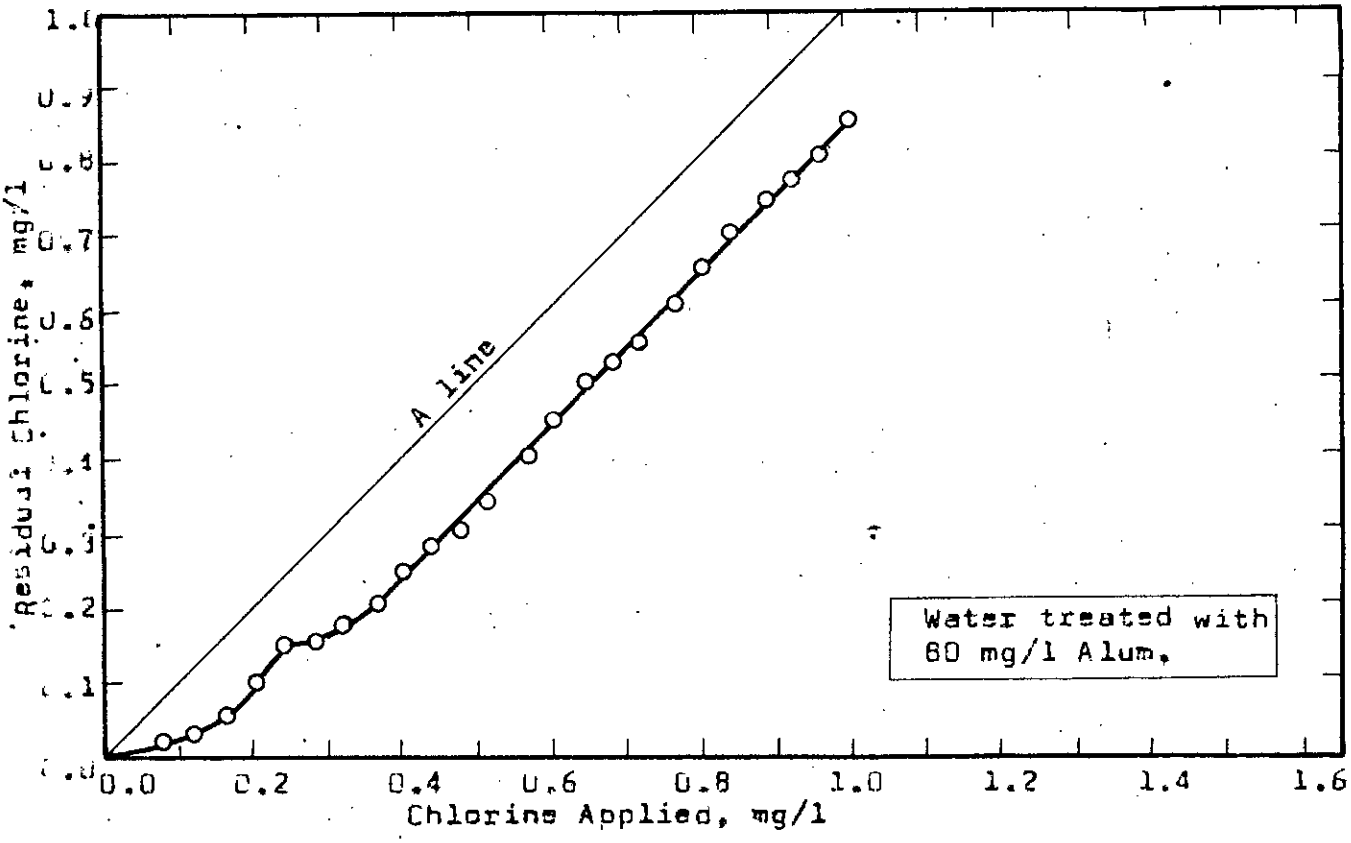


FIG.4.35e CHLORINATION CURVE OF WATER TREATED WITH 60 mg/l ALUM DOSAGE.

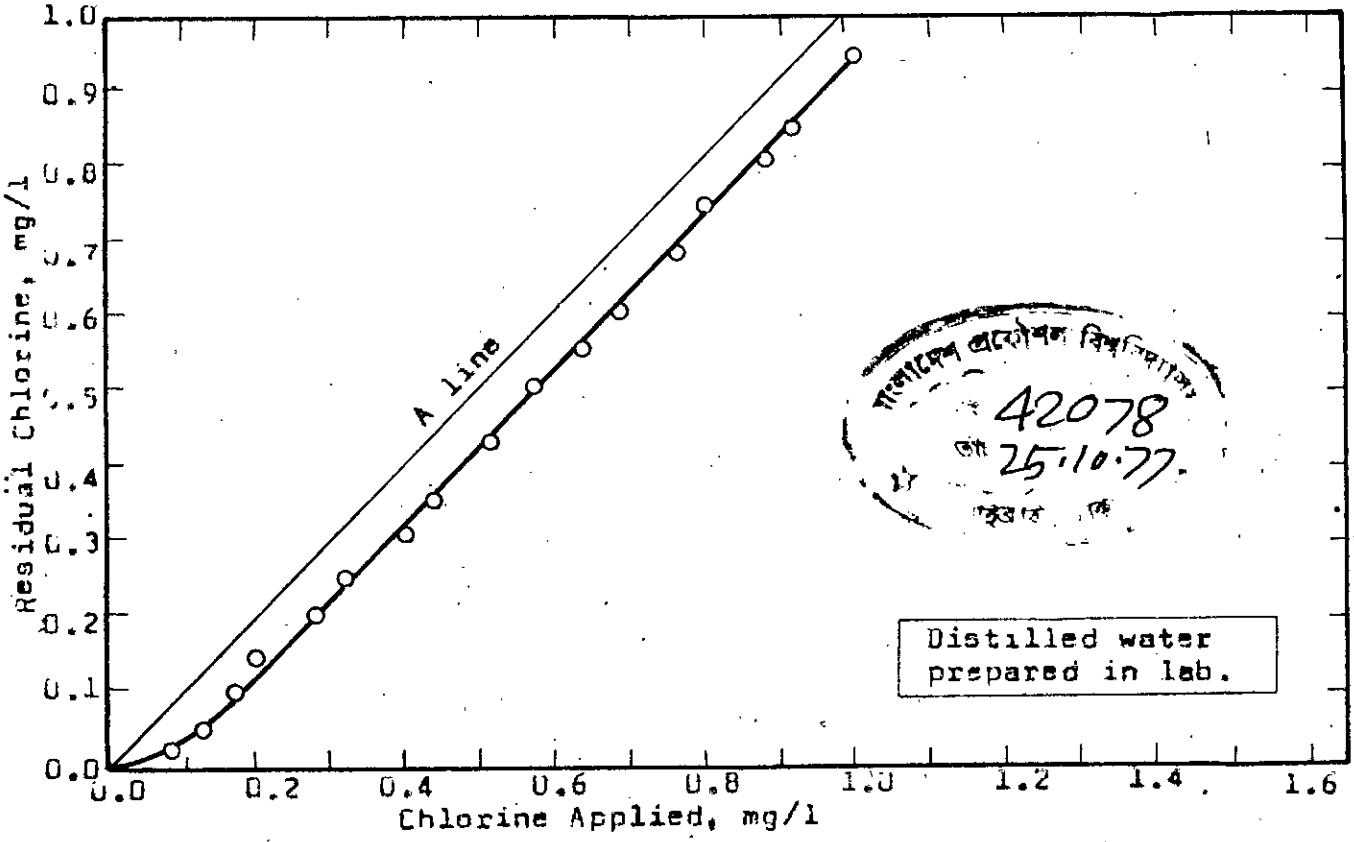


FIG.4.35f CHLORINATION CURVE OF DISTILLED WATER PREPARED IN THE LABORATORY.