REMOVAL OF IRON FROM GROUND WATER

BY

COAGULATION AND SEDIMENTATION

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Bangladesh University of Engineering & Technology, Dhaka

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ABSTRACT

Ground water is a major source of safe water for drinking and other domestic purposes for the rural / urban population of Bangladesh which may have iron content in excess of 5 mg/L. This study is an experimental investigation to observe the effect of different factors in iron removal and also to develop simple and cost effective iron removal method .

Relevant literature on chemistry of iron content water and unit processes of iron removal have been reviewed , and water use pattern and distribution of iron in ground water have also been focused.

Investigations were made at laboratory condition on artificial iron content water and natural ground water collected from tubewells of iron prone areas to find out effect of different unit processes and other related factors on iron removal. Experimental results shows that filtration is an effective mode of iron removal . However , considering the frequent cleaning of the filter bed and low yield, in this study emphasis have been given on sedimentation, for effective and efficient iron removal. As an aid in improving settling characteristics of the precipitated iron, coagulation is observed to be an important tool.

Aeration, coagulation and 30 min sedimentation can reduce iron concentration to allowable limit of 1 mg/L. However, the analysis also shows that iron removal increases with an increase in anion concentration. More pronounced effect is observed when the added anion is common to the anion already in solution, due to common ion effect. Alum used as coagulant is observed to be more effective than lime in iron removal. Whereas, the coagulant cost involved using alum as coagulant is 191.7% higher than lime.

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LIST OF ABBREVIATIONS

AWWA	American Water Works Association
DOE	Department of Environment
DPHE	Department of Public Health Engineering
IRP	Iron Removal Plant
NTU	Nephelometric Turbidity Unit
rpm	Revolution per minute
TCU	True Colour Unit
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organisation

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Supply of adequate quantity of water with satisfactory sanitary quality is essential for public health and well-being . In urban areas where municipal water supply is available , people have access to safe water. But in rural areas where municipal water supply is not available , a large number of people do not have access to safe and convenient source of water . Hand pump tubewells are regarded as the only means for collecting safe water for drinking and other domestic purposes because of numerous socio-economical and technical reasons.

A survey by Ahmed (1981) unfortunately reveals that only 32% of the rural population use tubewell water for drinking and a few use it for other domestic purposes although one tubewell for 104 people has been installed. However, the annual report of NGO Forum (1997) shows that 97% of the population use tubewell water for drinking , but only 26% use it for all domestic purposes . It has been observed that a substantial quantity of water is collected from unprotected surface water sources even in the presence of tubewell in the locality. Ground water quality of any area is of great importance for human being. The quality of ground water is directly and indirectly related to its intended use. Bacteriological quality carries little importance to the rural people, they prefer water which tastes good and is odorless and which does not change the color of food or does not stain clothes. High concentration of iron in ground water which causes various problems is one of the main reasons for this low consumption (Ali, 1990).

It has been estimated that about two-third of the population of the developing countries obtain their water from polluted and / or contaminated sources. The World Health Organisation (WHO) estimates that each year 500 million people suffer from diseases associated with unsafe water supplies. Due to largely poor water supplies an estimated 5 million infants die each year from diarrhoeal disease (Ahmed, 1989).

There is iron problem in almost all the areas of Bangladesh. A study made by Ahmed et. al. (1989) shows that shallow tubewell ground water of about 65% of the area of Bangladesh has average iron content more than 2 mg/L and in many locations it is more than 5 mg/L. Study by Huda (1995) and Hossain and Huda (1997) reveals that in Bangladesh deep tubewell ground water of 51000 sq. Km. area contain more than 1.0 mg/L of iron. Whereas, about 28000 sq. Km. area contain iron more than 5 mg/L. Iron problem is acute in ground water in the districts of Manikgonj, Gopalgonj, Norshingdhi, Narayangonj, Rajshahi, Bagerhat, Sylhet, Sunamgonj, Noakhali, Khulna and Kurigram.

To make water acceptable iron removal plant is essential. In an evaluation report prepared jointly by UNICEF and the Department of Public Health Engineering, Govt. of the People's Republic of

Bangladesh, on the performance of the existing plants, some of the problems , like clogging and cleaning difficulties of the treatment units, low yield and contamination during cleaning have been mentioned (Ahmed, 1987). There are four modern iron removal plants which have already been constructed for potable water supply in Chandpur, Serajgonj, Hobigonj and Gopalgonj under Dutch Assisted 18 DTP Water Supply, Drainage and Sanitation Project. A recent study reveals that each plant have some operation and maintenance problem from mechanical and electrical equipment. Due to disturbance in power supply, backwash is not done in time. As such filter run period shifts and effluent quality deteriorates (Kamal, 1996). In this respect further studies on unit processes of iron removal are important to find out a cost effective iron removal process. In this study major emphasis is given to have effective iron removal by mainly aeration, coagulation and sedimentation from iron containing ground water. Coagulation is tried as an aid in improving sedimentation.

1.2 RATIONALE OF THE STUDY

Collection of ground water through hand pump tubewell is the vital source of safe domestic water supply for the rural population of Bangladesh. Water collected are bacteriologically better, but chemical content often make the water undesirable for domestic and other use.

Ground water of Bangladesh usually has a high iron content and in some areas it goes beyond the tolerance of local people. High iron content is a very common problem in tubewell water supply. About 19.5% of the total area of Bangladesh has excessive iron problem in deep tubewell ground water (Fe > 5.0 mg/L) and 35.5% of the total area of Bangladesh contain iron more than 1 mg/L (Huda, 1995). Due to aesthetic problem people are not interested in using tubewell water which carries iron. People are more inclined to use the unprotected surface water sources, many of which are dangerously contaminated and completely unsuitable for domestic uses without any treatment. It seems that high iron content in ground water is deterring the use of tubewell water and the health of the rural community is indirectly affected as a result of using unsafe surface water.

In a survey conducted by UNICEF and WHO found that the use of tubewell water is substantially less, and the incidence of diarrhoeal diseases in iron problem areas is 53 percent higher than in the non-iron problem areas(Ahmed, 1987).

The country thus faces acute problems not only in terms of sufficient water supplies , but also in terms of water quality and diseases related to sanitation, where iron content in tubewell water is playing an important role.

Iron removal studies at household level and community level were attempted in places by different organisations. About 200- 300 community type iron removal plants have been constructed in the rural areas. All these plants can remove about 70-80 percent of iron effectively. But the main problem of all these plants is maintenance problem. The rural people are not interested in cleaning the plants and within only a few days the plants become abandoned. As a result many plants have been out of order and resulted in failure (Ali, 1990).

In this context , further studies are needed to develop a cost effective and easily maintainable type of iron removal plant giving emphasis mainly on sedimentation.

1.3 OBJECTIVES OF THE RESEARCH

Objectives of the research are

- Effect of aeration in removing iron
- Effect of pH in removing iron
- Optimum of coagulant required in removing iron
- Effect of settling time in removing iron
- Effect of anion concentration in water to remove iron in optimum coagulation condition
- To observe the trend of removal of iron of field water by aeration, coagulation and sedimentation.

1.4 ORGANISATION OF THE THESIS

The study is presented in six chapters, the first of which is general introduction. Chapter 2 and 3 contains a brief and selective review of the relevant literature. In these chapters problems associated with iron in ground water , iron chemistry, unit processes for iron removal is discussed.

In Chapter 4 , laboratory studies carried out on artificial water samples are described to determine different aspects of iron removal. Precipitation of soluble iron, flocculation of insoluble precipitated iron and separation from water are described.

In Chapter 5, experiments on natural ground water sample from iron problem areas are described with a view to find out the effect of different factors on iron removal in natural condition.

Conclusion and recommendation for future study are given in Chapter 6. Attempts are made to draw conclusions from various findings of the study. Recommendations presented in this chapter provides a basis for further study.

CHAPTER 2

IRON IN GROUND WATER

(LITERATURE REVIEW)

2.1 INTRODUCTION

The presence of iron in ground water is now considered to be a major problem throughout the world and produce numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply. In some places of Bangladesh the concentration of iron in ground water is at a much higher level than the limit acceptable to the rural people. People of those areas generally refuse to use tubewell water and inclined to use pond and river waters.

In this chapter relevant literature on occurrence and distribution of iron in ground water and techniques of iron removal have been reviewed. Water use pattern have also been focused.

2.2 OCCURENCE OF IRON

The element iron is an abundant and widespread constituent of rocks and soils. Dissolved iron is found in ground water from wells located in shale , sandstone and alluvial deposits.

In igneous rocks the principal minerals containing iron as an essential component include the pyroxenes ,amphiboles ,magnetite and the nesosilicates such as olivine . The composition of olivine ranges from Mg_2SiO_4 to Fe_2SiO_4 (forsterite to fayalite) with ferrous iron substituting freely for magnesium. Most commonly , the iron in igneous rocks is in the ferrous form , but may be mixed with ferric iron as in magnetite (Fe_3O_4)(Hem, 1970). Common minerals (deposits) of iron include ferric oxide and hydroxides such as hematite (Fe_2O_3) and ferric hydroxide [$Fe(OH)_3$] . Sedimentary forms of iron include sulfides, such as pyrite and marcasite; two minerals with identical chemical composition (FeS_2) but different crystalline structures; carbonates such as siderite ($FeCO_3$) ; and mixed oxides such as magnetite (Fe_3O_4) . The ferrous oxides and sulfides are the usual sources of dissolved iron in ground water . Weathering of iron silicates can produce dissolved iron in near surface water; however, this is a relatively slow process.

Ferrous iron (Fe^{2+}) is chemically reduced, soluble form that exist in a reducing environment (absence of dissolved oxygen and low pH). Many ground waters are low in dissolved oxygen and are supersaturated with carbon -di-oxide , owing to weathering of carbonate rocks or to increased carbon -di-oxide concentration in the soil gas. The lower pH value of ground water due to the presence of carbon-di-oxide and mineral acids and absence of dissolved oxygen creates favourable conditions to hold iron in high concentration in ground water as ferrous bicarbonate (Bell,1965).

$$Fe^{2+} + 2\,CO_2 + 2H_2O \longrightarrow Fe(HCO_3)_2 + 2H^+$$

Upon exposure to the atmosphere dissolution of carbon-di-oxide from supersaturated groundwater occurs , leading to an increase in pH value. At the same time aeration of the ground water occurs and increases the dissolved oxygen concentration .As a result rate of oxidation of soluble ferrous iron to insoluble ferric iron increases, which precipitates from solution as hydrous ferric oxides.

$$2Fe^{2+} + 4HCO_3^{-} + H_2O + \frac{1}{2}\ O_2 \longrightarrow 2Fe(OH)_3 + 4CO_2$$

The oxidation of iron in natural system is more complex than indicated by the above equation.

Iron can also enter in water through solution or infusion of organic bodies such as wood , leaves and so forth. Iron is an essential element in both plant and animal metabolism . Iron , therefore, is to be expected in organic wastes and in plant debris in soil and the activities in the biosphere may have a strong influence on the occurence of iron in water (Hem ,1970).

Iron may be present as soluble ferrous bicarbonate in alkaline well or spring waters; as soluble ferrous sulfate in acid drainage waters or waters containing sulfur ; as soluble organic carbon in colored swamp waters ; as suspended insoluble ferric hydroxide formed from iron bearing well waters , which are subsequently exposed to air ; and as a product of pipe corrosion producing red water (Ali , 1990).

2.3 IRON PROBLEM AREAS OF BANGLADESH

Ground water collected through handpump tubewells in Bangladesh carries a high concentration of iron and in many locations the concentration is much higher than the acceptable limit. This is probably because of the fact that most of the places of Bangladesh are underlain by alluvial deposits containing trace of iron compounds and shallow hand pump tubewells are drilled in such deposits to collect water.

A study by Ahmed ,et.al.(1989) about the ground water quality of shallow aquifers reveals that iron content of ground water in most of the places of Bangladesh is greater than 1.00 mg/L and in many locations the iron content of ground water is more than 5 mg/L. The study also shows that ground water of about 65% of the area of Bangladesh has average iron content more than 2 mg/L . A recent study on occurence of iron in deep tube well ground water have been performed by Hossain and Huda (1997). In that study it has been pointed out that 19.5% area of Bangladesh contain iron more than 5 mg/L and 64.5% of the total area contains iron less than 1 mg/L. Iron concentration in deep tubewell water in Bangladesh exceeding 1.0 mg/L and exceeding 5.0 mg/L are shown in Figure:2.1 and Figure: 2.2 respectively (Huda, 1995).

The World Health Organisation (1983) suggested a guideline value of 0.3 mg/L of iron for drinking water. This limit can hardly be maintained in rural water supply in Bangladesh . For this reason , the Department of Environment (DOE, 1991) , Bangladesh , recommended a desirable limit of 1 mg/L of iron in drinking water. But in the case of hand pump tubewells in rural areas , the maximum tolerable limit was set at 5 mg/L in the absence of a better source . This local standard is being followed in rural water supply in Bangladesh.

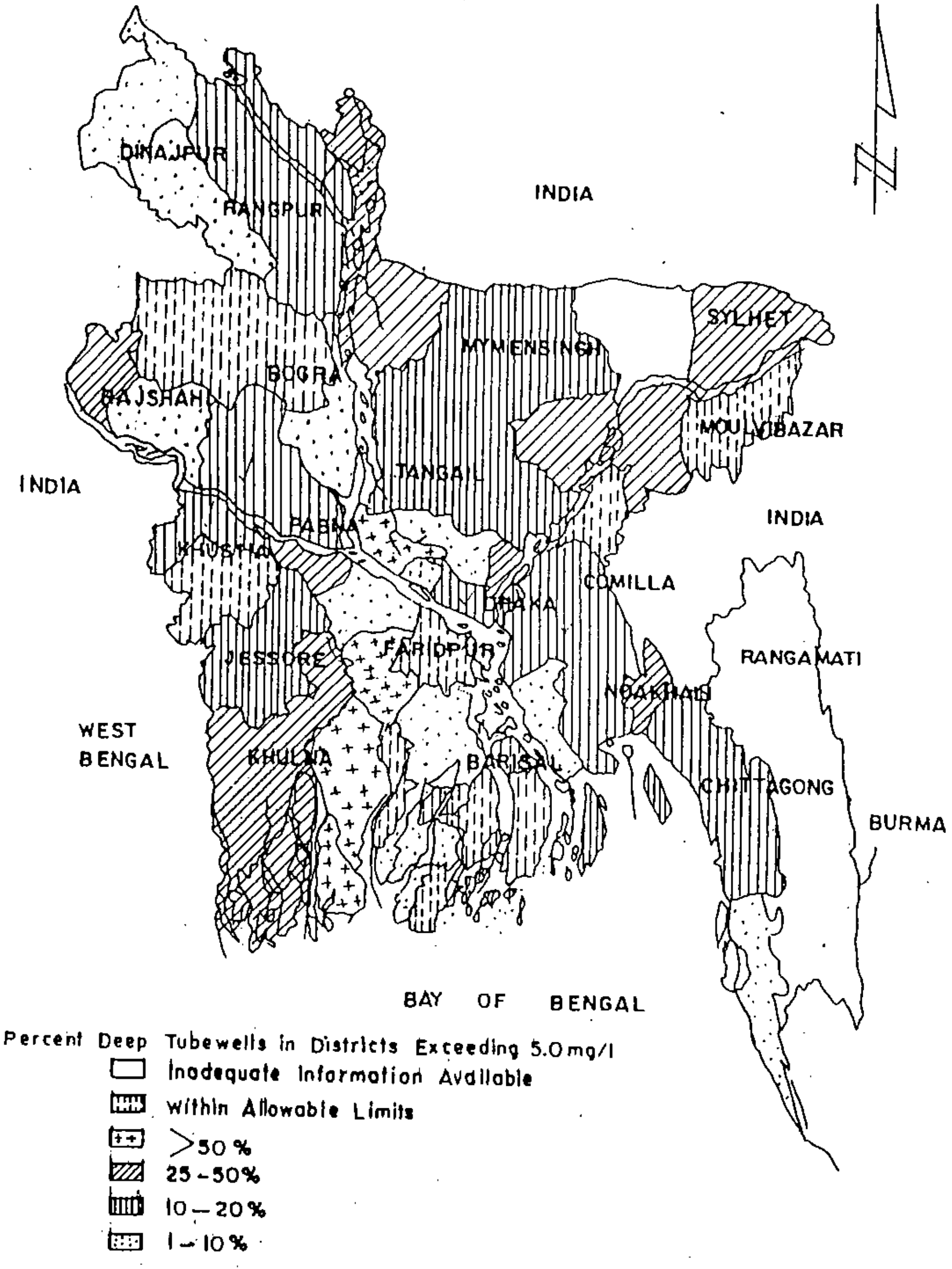


Figure : 2.1 Iron content in deep tubewell water of Bangladesh
(Iron> 1.0 mg/L)

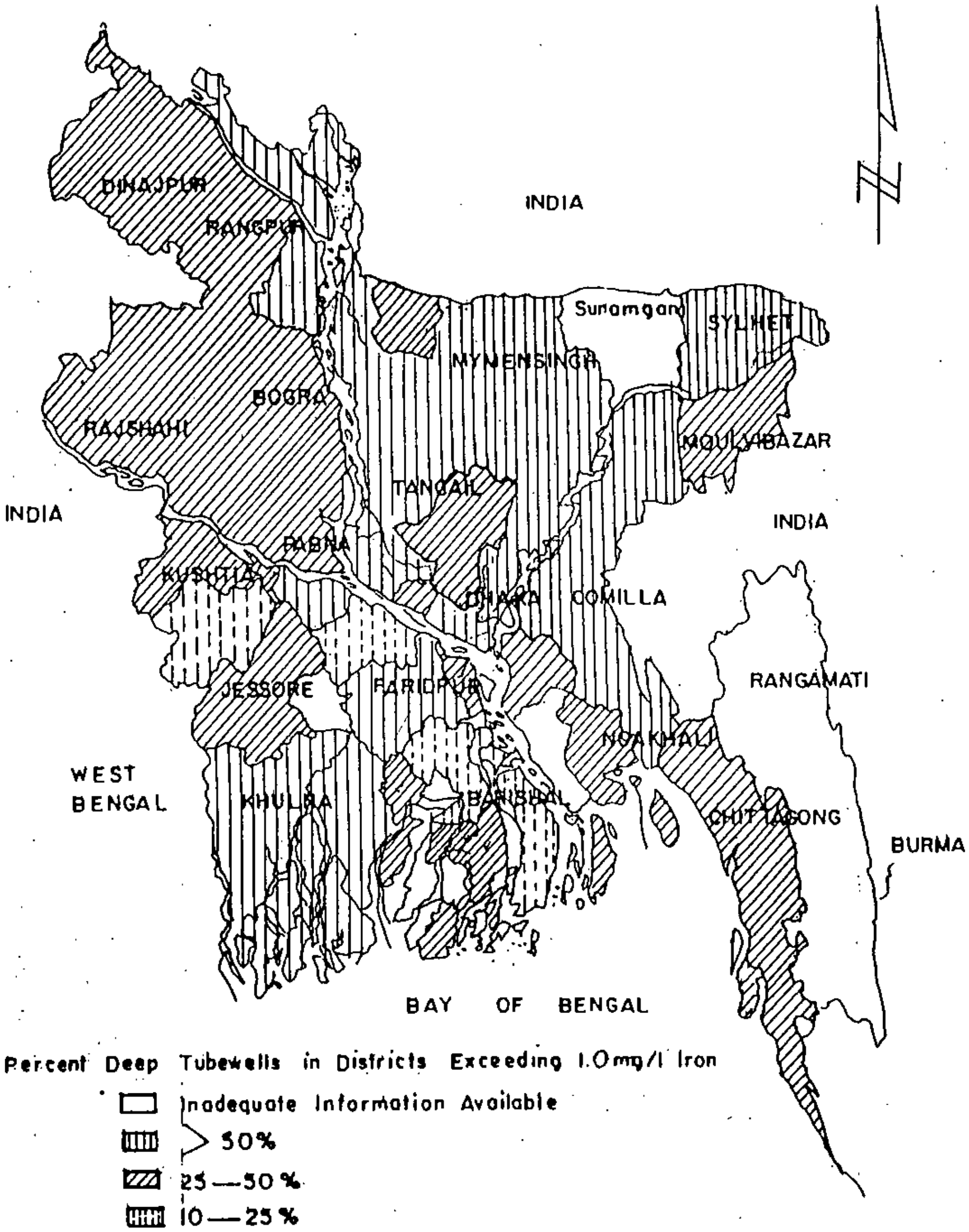


Figure : 2.2 Iron content in deep tubewell water of Bangladesh

(Iron> 5.0 mg/L)

Based on the distribution of iron bearing aquifers , allowable limits in Bangladesh and people's acceptability, the country may be divided into three iron problem areas (Ali, 1990).

Area Type-I : **Iron Problem Free Zones :**
Iron content of hand pump tubewell water in these zone is less than 1 mg/L . Rural people accept it as exellent water and installation of Iron Removal Plant (IRP) is not required.

Area Type-II: **Moderate Iron Problem Zones:**
Iron content of hand pump tube well water is between 1 to 5 mg/L. People consider this water as good , medium or bad depending on the concentration of iron . Installation of IRP in these zone is optional.

Area Type-III: **Acute Iron Problem Zones:**
Iron content of tubewell water is higher than 5 mg/L . In some places iron content has been found as high as 25mg/L . Installation of IRP is absolutely essential to increase tube well water consumption.

2.4 WATER USE PATTERN

Hand pump tubewell is the main source of safe water in rural areas of Bangladesh. In addition , unprotected traditional water sources like river , canal , pond and dug wells are also used by the rural population. Accessibility , quantity of water available and physical quality of water often determines mainly the choice of a source.

Per capita water consumption varies with socio-economic conditions and other field conditions. An average of about 40 lpcd consumption may be considered normal under rural living conditions. (Ahmed, 1987). For washing clothes and utensils and for bathing purposes unprotected surface water sources which are dangerously contaminated are used by rural consumers. Tubewell water is mainly used for drinking. Where tubewell water does not contain high concentration of iron , it is also used for cooking , washing utensils and sometimes it is used for bathing and washing clothes. Mean per capita collection from tubewells are only 35 percent of the total daily consumption and the rest comes from unprotected sources. The high concentration of iron in ground water in some areas is the main reason for the low consumption of tubewell water (Ahmed, 1987).

A survey was carried out about the water sources used by households for various domestic purposes in iron problem areas , which have been shown in Table : 2.1(Ali, 1990)

Table:2.1 Water sources used by households for various domestic purposes in iron problem areas (percentage)

Source	Drinking	Cooking	Laundry	Washing utensils	Bathing	Sanitary and others
Tubewell	100. 0	90.0	4.0	34.0	0.0	4.0
Other	0.0	10.0	96.0	66.0	100.0	96.0

(Source Ali: 1990)

The survey reveals that 100% people use tubewell water for drinking and water from other sources for bathing in iron problem areas . 90% people use tubewell water for cooking , but only 34% use it for washing utensils. On the otherhand 96% people use water from other sources for laundry , sanitary and other purposes.

After 90% removal of iron , about 67 percent increase in water collection from tubewells was observed i.e. about 2 gallon per capita per day water consumption increase has been observed. The rate of increase depends on initial consumption (avg. 3.0 gallon per capita per day). This water is generally utilised for cooking , washing clothes and utensils (Ahmed, 1981).

2.5 PEOPLE'S OPINION ABOUT THE NON-USAGE OF TUBEWELL WATER IN IRON PROBLEM AREAS OF BANGLADESH

Ahmed (1981) and Ali (1990) assessed general opinion of people about the overall quality of water they use. The opinion of the respondents against the concentration of iron in water has been shown in Figure: 2.3

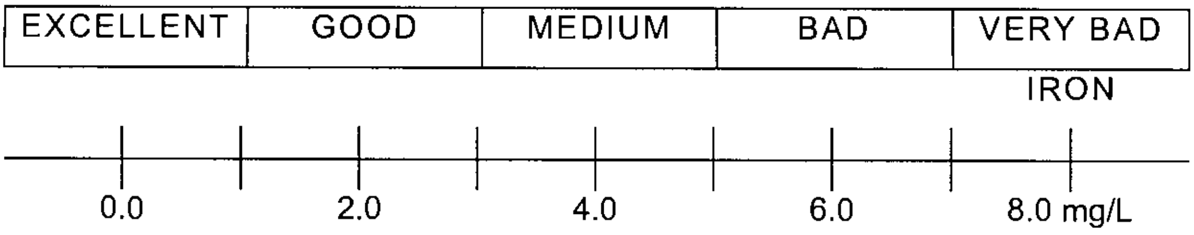


Figure:2.3 Opinion of the respondents against concentration of iron in water

The people in the problem area use tubewell water having 4.0 mg/l of iron without much hesitation but water of such quality is not acceptable in other regions of the country.

Ali (1990) assessed people's opinion about the causes of the non-usage of tubewell water in iron problem areas. Opinion of the people are presented in Table: 2.2 .

Table:2.2 Reasons for non-usage of tubewell water in an iron problem area (percentage).

Aesthetic (color)	Stain clothes and utensils	Odor	Taste	Makes hair sticky	Causes costiveness
88	72	22	30	42	2

Source: Ali (1990).

From Table: 2.2 it is evident that iron content water is mainly unacceptable from the aesthetic point of view. Staining clothes and utensils is also a vital reason for the non-usage of tubewell water in iron problem areas. Making hair sticky , taste and odor also affect the usage of iron content water to some extent. The use of tubewell water in iron problem area also causes costiveness which effects its usage to a very little extent.

2.6 PREVIOUS STUDY ON IRON REMOVAL UNIT PROCESS

Ahmed and Smith (1987) developed a low cost iron removal plant based on four major units, e.g. aeration channel, sedimentation and two brick chips adsorption chambers. Several plants were constructed and it was found to be effective in removing iron from No. 6 tubewell with yielding capacity of 9 to 13 L/min. The plants have been found to be very effective in removing soluble iron from tubewell water in excess of 90 percent.

Ahmed (1987) conducted some studies on horizontal flow roughing filter for the removal of iron from water. It was observed that in a roughing filter of 0.4 m long with 4 to 10 mm filter grain size and a filtration rate of 0.4 m /hr , an average of over 92% iron removal could be achieved during a total run of 100 hours. It was also observed that the most important factor that affects the performance of a roughing filter is the increasing depth of penetration of iron sludge with time.

In 1986-87 UNICEF developed an improved iron removal plant consists of three units e.g. perforated ferrocement channel, sedimentation chamber and brick chip filter. The plant was found to be effective in iron removal and the filter run was also satisfactory. A study by WHO, UNICEF and DPHE (1990) on these iron removal plants showed that iron removal was satisfactory. The iron concentration was reduced to 1.5 ppm (avg.) from 15 ppm (avg.) with average cleaning period of 12 days (with minimum of 5 days). With the same interval of cleaning it has been observed that the higher the concentation in raw water the higher the concentration in treated water but it was not exceeded 2.5 ppm.

Wong (1984) has shown that processes in which oxidation is followed by removal of suspended solids can effectively remove soluble iron and manganese from water. He has developed three common processes for removing iron and manganese, e.g. (i) aeration- filtration, (ii) chlorination- filtration, and (iii) potasium permanganate - manganese greensand filtration .

For the elimination of iron from hand pump tubewell water, Aowal (1981) proposed to introduce a spray aeration, a settling tank and a plain sand filter, all housed in a single chamber. Although an effective removal was achieved, the length of run between cleaning was very short, less than 24 hours. The top layer of fine sand was needed to be removed, washed and dried for the next use, which is not so easy.

" International Reference Centre for Community Water Supply and Sanitation" (1983) has described the advantages of coarse "roughing" filter which has large pores that are not liable to clog rapidly. The large pores also allow cleaning at relatively low backwash rate, since no expansion of the filter bed is needed. In upflow type roughing filters grain sizes of 15mm to 7mm arranged in different layers and a flow rate of 0.5 to 1.0 m/ hour have been recommended.

Equina (1979) has made a study on the pretreatment of water containing iron and manganese using a horizontal - flow filter with crushed stone as the filter media. A regression analysis was made to determine the factor(s) affecting the filter performance. The length of the filter run was found to be the most important factor for the removal of iron from ground water. At the filtration rate of 0.4 cu.m./sq.m./h, iron with the average concentration of 1.24 mg/L could be removed by 47%.

Kibret (1986) has shown that dry filter is one of the alternatives that can be applied for iron removal and the process uses the self purification capacities of iron bacteria. Investigations made on the pilot plants showed that iron removal process by dry filtration depends on the hydraulic load , filter depth, size of filter material , the development of the micro-organisms, and iron concentration in the raw water. Dry filter does not only remove iron but it also removes manganese, ammonia , carbon dioxide and provides sufficient oxygen supply to the treated water. The results obtained from the test plants were not below the standard limits except from the full scale production plant. However, complete removal of iron by dry filter is feasible provided the best possible favourable combinations of the factors on which iron removal depends are found.

2.7 IRON REMOVAL TECHNIQUES

To remove soluble iron it is generally accepted that an oxidation process followed by a suspended solids removal process(es) is most effective. Usually oxidation of soluble iron is accomplished by simple aeration or chlorination / potassium permanganate application. Coagulation / flocculation with sedimentation and filtration are employed as solid removal processes .

Other processes , such as ion exchange , chlorine dioxide- filtration , stabilization with polyphosphates etc. , have also been applied but with less frequency , owing to cost and operational considerations. Removal processes are selected on the basis of iron concentration and other conditions.

More specifically , the methods used in the removal of iron are :

i) a) Aeration - sedimentation - filtration method
   b) Chlorination - sedimentation - filtration method
   c) Potassium permanganate - manganese greensand filtration method
ii) Flocculation and sedimentation method
iii) Manganese zeolite process
iv) Stabilization method

2.7.1 Aeration - Sedimentation - Filtration Method

This method was studied and developed by Wong (1984) and typically includes an aerator , retention tank and filters. Oxygen from the atmosphere reacts with iron in raw water to produce relatively insoluble salts of ferric oxide. This method is generally recommended for water with high concentration , above 5 mg/L of iron. The rate of reaction depends on pH . It is more rapid at higher pH values . Retention time of several hours may be necessary after aeration depending on raw water characteristics . Sometimes sedimentation tanks with sludge collection and removal facilities are used instead of a simple retention tank if iron concentration is high . Pressure filters preferably with dual media of anthracite and sand are used to remove iron . The major disadvantage of this method is that the initial cost is too high.

2.7.2 Chlorination - Sedimentation - Filtration Method

The process consists of a chemical feed system, a small retention tank and filter. The process needs a pH adjustment system through feeding caustic soda and lime. The process generally recommended for removal of low iron concentration less than 2 mg/L.

Either gaseous chlorine or hypochlorite can be used as the oxidizing agent. The filters used in this process are similar to those used in aeration-filtration process (Wong,1984).

2.7.3 Potassium Permanganate-Manganese Greensand Filtration Method.

This method is recommended for removal of low to moderate concentration upto 5 mg/L of iron. Equipment for this process is similar to that for chlorination filtration process but differs in the primary oxidizing agent and the filter media. A 1-4% solution of $KMnO_4$ is continuously fed into the raw water line, prior to filtration to reduce the amount of soluble iron going to the filter. Manganese treated greensand has the ability to oxidize and to filter. However its oxidation capacity is limited and the bed must be regenerated with potassium permanganate after back wash. The process has an advantage in that the greensand can act as a buffer. If the feed of $KMnO_4$ does not oxidize all the soluble iron, the greensand will oxidize and filter it.

Major disadvantages of this process are high operational costs associated with chemical requirements and filter bed deterioration if the pH falls below 7.1. In some cases, chlorine is used in conjunction with $KMnO_4$ to reduce chemical costs (Wong,1984).

2.7.4 Flocculation And Sedimentation Method

Sung and Forbes (1984) pointed out that oxidation of soluble iron is not the entire picture in iron removal processes. When ferrous iron solution is oxygenated, their study showed that the precipitate is roughly concentrated in the submicron size range. To enhance the settling character they proposed to promote coagulation / flocculation before settling.

Owens (1963) has suggested to use calcium hydroxide as the coagulant. Upon addition of lime iron hydroxide precipitates out in the suspended sludge blanket in a solids contact unit. This is very effective in the removal of colloidal particles.

2.7.5 Manganese Zeolite Process

Manganese zeolite is made by coating natural greensand (glauconite) zeolite with oxides. Manganese dioxide removes soluble iron until it becomes degenerated . The filter is regenerated using potassium permanganate ($KMnO_4$).

$$Z\text{-}MnO_2 + Fe^{2+} \longrightarrow Z\text{-}Mn_2O_3 + Fe^{3+}$$

$$Z\text{-}Mn_2O_3 + KMnO_4 \longrightarrow Z\text{-}MnO_2 \text{ (Regeneration)}$$

Manganese zeolite filters are generally pressure type. Disadvantages of the regenerative -batch process are the possibility of soluble manganese leakage when the bed is nearly degenerated, and the waste of excess $KMnO_4$ needed to regenerate the greensand (Clark ,1977).

2.7.6 Stabilization Methods

The alternative to iron removal is stabilization or dispersion . According to Clark et. al. (1977) sodium hexametaphosphates at dosages of 5mg per mg of Fe plus Mn have been used for this purpose . While this treatment will stabilize iron in suspension, it reportedly is not suitable where iron concentration of 1 mg/L is exceeded. Moreover ,when the water is heated, the polyphosphate will revert to orthophosphate and lose its dispersing properties. The application of polyphosphate must take place prior to aeration or chlorination because the polyphosphates do not effectively stabilize precipitated ferric hydroxide. Polyphosphate dosages are limited to less than 10 mg/L because the availability of phosphorus may stimulate bacterial growths in distribution systems.

2.8 PREVENTIVE TREATMENT OF IRON

Preventive measures may sometimes be used with reasonable success. Sodium hexametaphosphate has been found to be effective in sequestering iron in some supplies. When applied in proper dosage, before oxidation of the iron occurs , metaphosphate tends to hold iron in solution. Metaphosphate does not prevent oxidation of iron but stops agglomeration of the individual tiny particles of iron oxides. Thus the sequestered oxides pass through the distribution system without creating accumulation which periodically cause badly discolored water. Success of this treatment is very difficult to predict, since it depends on the concentrations of iron, the level of chlorine residual established for disinfection, and the time of passage through the distribution system. The latter is established by the extent of the distribution system, pipe sizes in the network , and location and volume of storage reservoirs. Reduced iron in water promote the growth of autotrophic bacteria in distribution mains. Heavy chlorination or addition of copper sulfate in the isolated sections of water mains followed by flushing has been effective in some cases. The only permanent solution to iron problem is removal by proper treatment of water (Ali, 1990).

CHAPTER 3

CHEMISTRY OF IRON AND IRON REMOVAL PROCESSES (LITERATURE REVIEW)

3.1 INTRODUCTION

Iron exist in chemically reduced soluble form in ground water. In presence of oxygen soluble iron oxidizes to insoluble form which then precipitated out. Different unit processes are involved in effective removal of iron from water.

In this chapter relevant literature on chemistry of iron content water and unit processes of iron removal have been reviewed.

3.2 CHEMISTRY OF IRON CONTENT WATER

Iron (II) (Fe^{2+}) is a chemically reduced , soluble form that may exist in a reducing environment. Upon exposure to the atmosphere dissolution of carbon-di-oxide and H_2S from supersaturated ground water occurs ,leading to an increase in pH value. At the same time aeration of the ground water occurs and increases the dissolved oxygen concentration . Thus aeration and dissolution of carbon -di-oxide increases the rate of oxidation of soluble ferrous iron to insoluble ferric iron. But the oxidized and precipitated iron particles are so small in size that it is very difficult to separate them through sedimentation . Coagulation and flocculation are the process by which these small particles are allowed to grow or flocculate to sizes that settle at satisfactory velocities.

3.2.1 Solubility of Iron

In the pH range encountered in natural waters , soluble ferrous iron consists primarily of Fe^{2+} and $FeOH^+$. While greatly limited in solubility at neutral pH ,the aqueous ferric ions consists predominantly of $Fe(OH)_2^+$ and $Fe(OH)_4^-$ (O'Connor ,1971). In alkaline water devoid of sulfide , phosphate and organic hydroxide ,ferrous carbonate , ferric hydroxide or mixture there of depending on the concentration of oxidizing agents and pH . According to Ghosh , et al.(1966) in alkaline natural water, the solubility of ferrous iron is limited by the solubility of ferrous carbonate in the pH range of 6-9 , above which the solubility equilibrium of ferrous hydroxide becomes limiting again. Theoretically ,iron that precipitates from a supersaturated solution of this type would be either ferrous carbonate or ferrous hydroxide depending on the pH. Under practical conditions , however, the precipitation of basic carbonates , e.g. $[Fe(OH)_2.FeCO_3]$ with somewhat different solubility characteristics is probable , especially in the pH range of 8 to 11.

On aeration or by the addition of oxidizing agents , iron is oxidized from the ferrous to ferric form. Once oxidized , the solubility of iron is severely limited over a wide range of pH values from 4 to 13 by the solubility of ferric hydroxide . Figure 3.1 shows plots of the solubility of Fe(II) and Fe(III) in water having a concentration of total carbonic species ,10^{-3}M (Stumm,1964). To take advantage of this solubility restriction ,the basic step in the removal of iron is oxidation of ferrous iron to ferric iron .

Ferric ions , generally , have a stronger tendency to form complexes

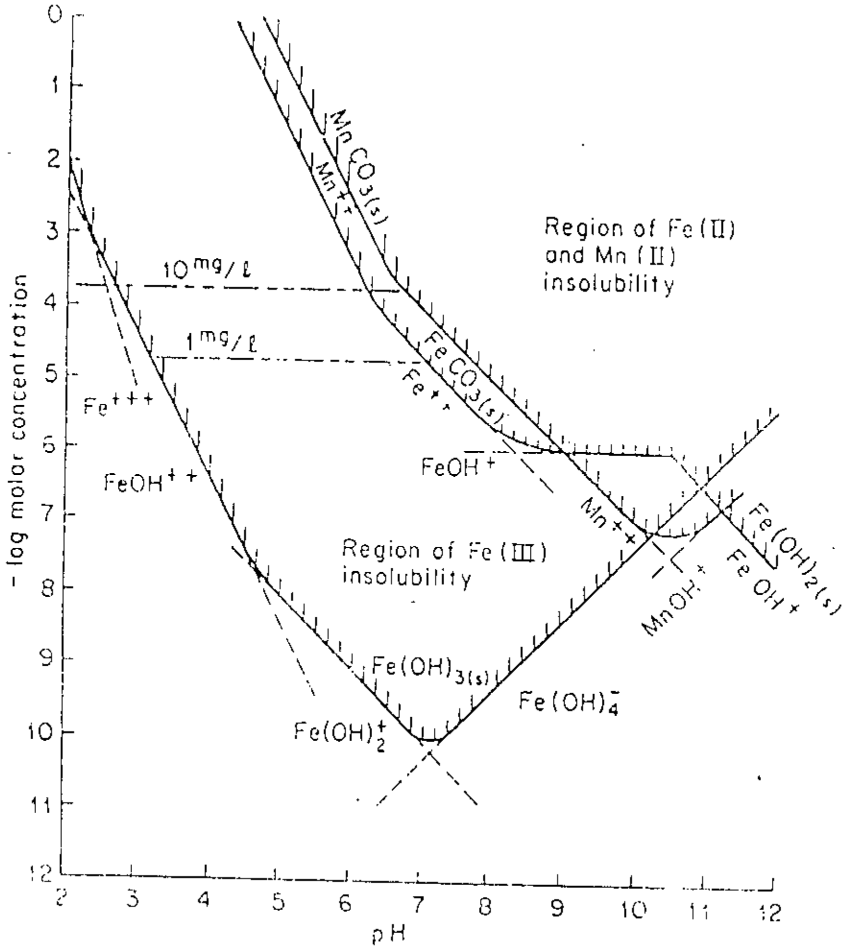


Figure 3.1 Solubility of Fe (II) , Mn (II) and Fe (III) in carbonate-bearing water ($C_T = 10^{-3}$ M) . (Stumm , 1964)

than ferrous ions . Complex formation of ferric ions with o-phosphate silicate and many organic bases is stable and very difficult to precipitate .

3.2.2 The Kinetics Of Iron Oxidation

In the presence of dissolved oxygen , soluble ferrous iron (Fe^{2+}) oxidizes to ferric oxides or hydroxides. The stoichiometric relationship being (O'Connor, 1971)

$$Fe^{2+} + \frac{1}{4}O_2 + 2OH^- + \frac{1}{2}H_2O \xrightarrow{\qquad} 2Fe(OH)_{3(s)}$$

which indicates that 1 mg/L of oxygen will oxidize 7 mg/L of ferrous iron. So the oxygen demand and correspondingly the oxygen gas transfer requirements are very small. It is beleived that the oxidation of ferrous iron proceeds stepwise through various ferrous -ferric species .

Effect of Fe^{2+} and pO_2

Gosh et al (1966) stated that the rate of ferrous iron oxydation is of the first order with respect to ferrous iron concentration , Fe^{2+} and the partial pressure of oxygen , pO_2

Thus the rate law constant

$$-\frac{d}{dt}[Fe^{2+}] = k_1[Fe^{2+}]pO_2$$

It was also observed that the rate of iron oxidation remains unaffected by dissolved oxygen if the concentration exceeds 5 mg/L.

Effect of pH Value

Usually ground water contains a high concentration of CO_2 . The addition of O_2 to water not only results in the oxidation of ferrous iron , but also serves to remove CO_2 resulting in an increase in pH. Oxidation of ferrous iron increases rapidly at pH of 7.0 or above and is very slow below 6.0 . Reaction rates are strongly pH dependent . Stumm and Lee (1961) indicated that an increase of one pH unit , causes 100 fold increase in the rate of reaction i.e. there is a second order relationship between the rate of reaction and the hydroxyl ion concentration.

Therefore,

$-d/dt[Fe^{2+}] = K\ [Fe^{2+}]\ pO_2\ [OH^-]^2$

Where,

d[Fe(II)]/dt = Rate of Iron(II) oxidation, mol/ (L)(min)

Fe(II) = Ferrous ion concentration, mol/L

pO_2 = Partial pressure of oxygen, atmosphere

OH = Hydroxide ion concentration, mol/L

K = Reaction rate constant = $8.0(+2.5)*10^{13}$ $L^2/(min)(atm)(mol)^2$ at 20.5°C

It has been observed that , the half time for Fe^{2+} oxidation at pH 7.02 is approximately 4 minutes and at pH 7.24 it is around 2 minutes, implying complete (>99%) oxidation of Fe^{2+} in a relatively short time in well aerated water at pH values greater than 7.2 and alkalinity above 450mg/L as $CaCO_3$ (Stumm and Lee,1961).

Effect of Alkalinity

Stumm and Lee reported that the reaction rates obtained in solutions of lower alkalinities tend to be of smaller magnitude and more scattered than those obtained in solutions of higher alkalinities.

Robinson and Dixon (1968) mentioned that in order to obtain complete oxidation of the ferrous iron, the bicarbonate alkalinity of the water should be in excess of 100mg/L as $CaCO_3$. Generally , if the concentration of alkalinity reaches 130 mg/L as $CaCO_3$ all of the ferrous iron will be oxidized almost immediately , and any further addition of chemicals would appear to be unnecessary . Low alkaline water needs some oxidizing agent ($KMnO_4$) without raising pH and alkalinity or some chemical additive (Na_2CO_3) to raise both pH and alkalinity.

Effect of Temperature

The reaction rate is dependent on temperature. For a given pH value, the rate increases about 10 fold for a 15^0 c increase in temperature , which is mainly caused by the change in $(OH)^-$ concentration due to temperature dependence of the ionization constant of water (Stumm et. al., 1961).

Effect of Ionic Strength

Sung and Forbes (1984) showed that the rate constant K is also a function of ionic strength and the presence of complex forming anions . They observed a linear variation (decrease) of the rate constant up to an ionic strength of 0.25 M in their study . At values greater than this , increasing ionic strength actually increases the rate constant.

Effect of Chloride And Sulphate

Sung and Morgan (1980) observed that chloride and sulphate ions have a significant retarding influence on the rate constant in the pH range from 6.5 to 7.2 . Later Sung and Forbes (1984) mentioned that for typical fresh water iron removal , chloro-complexes of iron could probably be ignored , because the effect of ionic strength and chloro- complexation may not be as important as the effects of temperature and pH .

Effect of Organic Matter

Ferrous iron is capable of forming complexes with organic matter and ,as such , is resistant to oxidation even in the presence of dissolved oxygen . The relative strength of such complexes that has a stability constant of approximately 10^4 (Theis and Singer ,1974).

Catalytic Effect

For a given pH value and oxygen concentration the addition of as little as 0.02 mg/L of Cu^{2+} , reduces the oxygenation time by a factor of 5 (Stumm and Lee,1961).

Sung and Morgan (1980) studied the effect of ferric hydroxide on the oxygenation of ferrous iron and stated that auto catalysis is noticeable only for pH around 7 and above . Cox (1969) has described the use of contact bed oxidation in iron removal . The purpose of contact bed according to him , is to facilitate oxidation of iron or manganese through the catalytic action of previously precipitated oxides of these minerals on the gravel or ore.

3.2.3 Rate Of Iron Precipitation

When alkaline groundwaters supersaturated with respect of ferrous carbonate are aerated , the pH increases because of the loss of carbon dioxide , thereby further increasing the degree of supersaturation . As a result , the precipitate formed may be expected to contain both ferrous carbonate and ferric hydroxide . The rate of precipitation of iron would therefore be determined by the rate of oxidation of ferrous iron plus the rate of ferrous carbonate precipitation (Ghosh *et.al.* ,1966) (see Fig 3.2).

In water having low alkalinities and , hence , low buffer capacities , the pH will decrease gradually as the iron hydrolyses resulting in an increase in acidity of the waters (Ghosh *et. al.* , 1966). In such cases it has been suggested to use soda ash , lime or caustic soda to raise the bicarbonate alkalinities to 100-130 mg/L as $CaCO_3$. Potassium permanganate can be used as an oxidant to oxidize ferrous iron in natural water without raising the pH or the alkalinity .

3.3 UNIT PROCESSES OF IRON REMOVAL

The methods used to remove inorganic iron is entirely different to those used for organic iron . Inorganic iron refers to the clear and sparkling well water that turn turbid on exposure to air . Organic iron is coloured with humic acids. For selection of iron removal method , type of iron present should be detected at first .

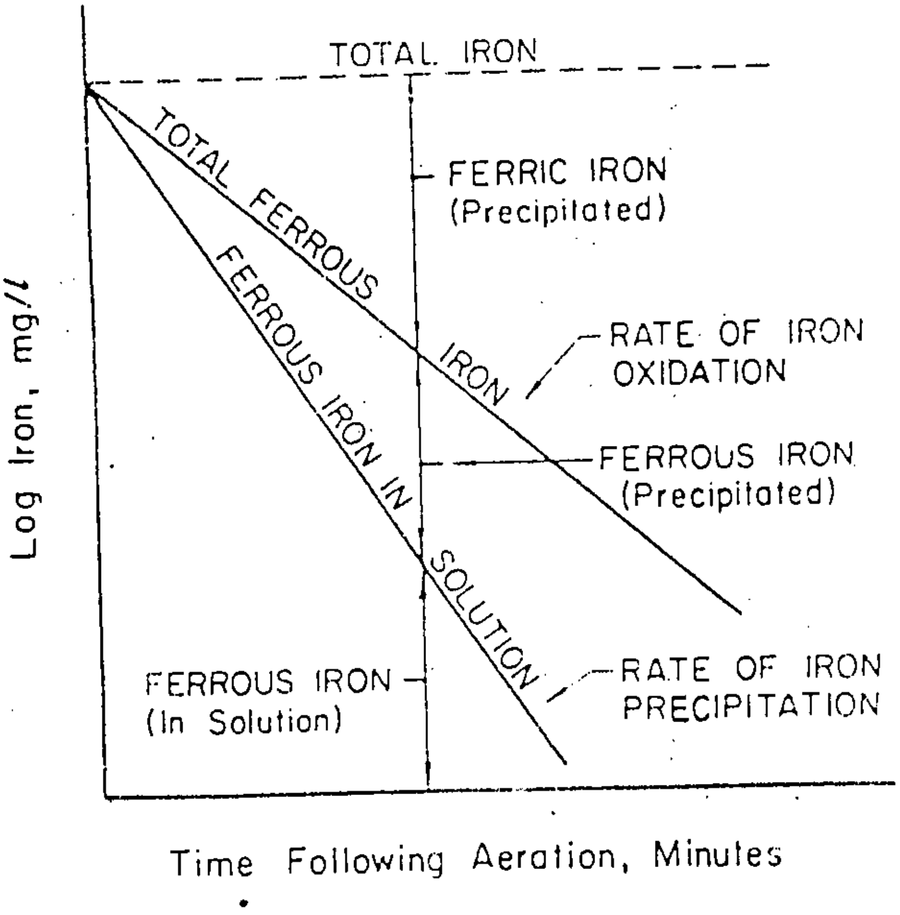


Figure: 3.2 Rate of iron oxidation and rate of iron precipitation (Ghosh et. al., 1966).

3.3.1 Aeration

This is the process of bringing water into intimate contact with air with the objective of (a) addition of oxygen ,(b) removal of carbon - di-oxide ,(c) removal of various organic compounds responsible for taste and odor. This is a physical phenomenon in which gas molecules are exchanged between a liquid and a gas at a gas- liquid interface.

In water treatment plant for iron removal , aeration is done with the aims of removal of carbon-di-oxide from water which in turn will result in an increase in pH value and in the mean time addition of oxygen to water to oxidize dissolved ferrous iron to insoluble ferric iron.

The solubility or addition of a gas depends on :

- its partial pressure in the atmosphere in contact with water
- the water temperature
- the concentration of impurities.

The rate of precipitation or removal of a gas is controlled by:

- the degree of supersaturation
- the water temperature
- the interfacial area between a gas and water

The common gas transfer equation is represented as (Fair et. al. , 1958).

$$C_t = C_0 + (C_s - C_0)\{1 - \exp[-K_g t]\}$$

where ,

C_t and C_0 = Concentration at time t=t and t=0 respectively

C_s = the saturation concentration at a given temperature.

K_g = a proportionality factor for existing conditions of exposure . It is a function of A/C , the area of interface per unit volume of liquid .

Therefore,

$$C_t = C_0 + (C_s - C_0)\{1 - \exp[-k_g (A/C)t]\}$$

Where ,

k_g = gas transfer co-efficient. Becker (1924) reports the following value in centimeters per hour for the absorption of oxygen in the temperature range 3.5 to 35°C , $k_g = 32.3 \times 1.018^{T-20}$. The value can be both higher and lower in different circumstances.

The above equation indicates that oxygen transfer can be optimized, no matter what its direction by controlling four major parameters:

I. generating the largest practicable area ,A, of interface between a given water volume , C , and air.

II. preventing the build-up of thick interfacial films , or by breaking them down to keep the transfer co-efficient , k_g , high.

III. inducing as long a time of exposure , t , as possible.

IV. ventilating the aerator and its components to maximize oxygen transfer.

In iron removal process , aeration is required to precipitate the ferrous bicarbonate to ferric hydroxide in accordance with the following equations:

$$Fe\,(HCO_3)_2 \xrightarrow{\text{aeration}} Fe(OH)_2 + 2CO_2$$

further aeration :

$$4Fe\,(OH)_2 + O_2 + 2\,H_2O \xrightarrow{\text{aeration}} 4\,Fe\,(OH)_3$$

In order that the reaction will go to completion and precipitate the ferric hydroxide , it is necessary that the pH be approximately 7 or higher . If possible the pH should be raised to 7.5 to 8.0 , but even so the reaction may take 15 minutes retention before it is complete and in some cases as much as 1 hour retention has been necessary (Walker , 1978). The length of retention time depends on the degree of aeration and the dissolved oxygen content of the aerated water . Aeration can be optimized by increasing contact time and interfacial area.

3.3.2 Coagulation

In many water treatment facilities , a chemical coagulation process is used to enhance the removal of colloidal and dissolved substances from water.

When ferrous iron solution is oxygenated the precipitate is roughly concentrated in the submicron size range . Agglomeration of particles into groups increases the effective size and therefore the settling velocities.

3.3.2.1 Destabilization of colloids

The effective removal of the colloidal and suspended particulates from water depends on a reduction in particulate stability .The destabilization of colloid can be accomplished by different mechanism . LaMer (1964) has divided these into two catagories

- Processes that effect a reduction of the total potential energy of interaction between the electrical double layers of two similar particles.
- Processes that aggregate colloidal particles into a three-dimensional floc network by the formation of chemical bridges.

La Mer (1964) has designated the first as coagulation and the second as flocculation .

In the field of water and waste water treatment coagulation is considered as a chemical destabilizing process caused by the addition of some reagent to the colloidal system which includes the aggregation of particles , whilst flocculation implies the aggregation of particles under the influence of velocity gradients (Hossain, 1990).

According to common engineering usage ,the term flocculation describes the particle transport step , while the term coagulation is used to describe the overall process of aggregation , including both destabilisation and transport (Weber, 1972).

The destabilization and aggregation of colloidal system have been explained by four models:

i)The double-layer compression
ii) Adsorption and charge neutralization
iii) Enmeshment in a precipitate (Sweep flocculation)
iv) Adsorption and interparticle bridging

In practice , the colloidal destabilization is likely to be caused by more than one method . The mechanisms of colloidal destabilization are briefly described in the following sections.

Double Layer Compression

In this model the destabilization of colloids , only electrostatic interactions are considered significant . Ions of similar charge to the primary charge of the colloids are repelled and counter ions are attracted . Destabilization by counter-ions is accomplished by compressing the diffuse layer surrounding the colloidal particles. The reduction of energy barrier between two particles enhances agglomeration. Ions acting only in this way are usually refered to as indifferent ions (Hossain, 1990).

A mathematical model for the effect of indifferent electrolytes on the colloidal stability has been developed by Verwey and Overbeek (1948) . The main features of the model are as follows:

a) The concentration of coagulant necessary to destabilize a colloid is independent of the ions
b) Charge reversal and restability of colloid cannot occur.

Hahn and Stumm (1968), Gregory (1978) and Bratby (1980) have shown that high concentration of electrolyte in the solution results in high concentrations of counter-ions in the diffuse layer. This will cause a reduction in the thickness of the diffuse layer and consequently lowering the energy barrier which ,effectively , control the range over which electrical forces operate between particles.

The double layer compression provides a good conceptual understanding of some electrostatic phenomena involved in coagulation. Unfortunately ,they do not describe phenomena which are important in water treatment processes (Weber,1972). Coagulants in water treatment systems are generally not indifferent electrolytes ,they can undergo many interactions in addition to electrostatic attraction and repulsion. Moreover, many colloids are stabilized by hydration effects in addition to charge effects. To understand coagulation mechanism in water treatment processes, it is necessary to consider other modes of destabilization.

Adsorption and Charge Neutralization

The charge on a colloid can be neutralized by the addition of molecules of opposite charge which have the ability to adsorb onto colloids. In the process of destabilization of colloids , it is helpful to consider the energy involved in the electrostatic interactions between a colloid particle and a coagulant ion. Bonding of very short range type such as hydrogen-bonding will occur. Also coordinating reactions and ion exchange reaction can take place and lead to ion adsorption and neutralization of the particle charge (Hossain, 1990).

According to Stumm and O'Melia (1968) and O'Melia (1972), the destabilization of colloid by counter-ions brought about by the adsorption of counter-ions of the surface of particles causing neutralization of charge. Amount of coagulant required to coagulate colloids is linearly proportional to the surface area of colloids and at excess coagulant dose , restabilization can occur, leading to charge reversal.

Enmeshment in Precipitate

The use of a metallic salt as a coagulant in water treatment can lead to a precipitate of metal hydroxides. Colloidal particles may serve as condensation nuclei for these precipitates or may enmeshed (sweep) in the precipitates. Coagulants such as $Al_2(SO_4)_3$, $FeCl_3$, $MgCO_3$ and $Ca(OH)_2$ can induce coagulation through the formation of insoluble $Al(OH)_{3(s)}$, $Fe(OH)_{3(s)}$, $Mg(OH)_{2(s)}$ and $CaCO_{3(s)}$.

Working with dispersed clay on water , Packham (1965) showed that the rate of precipitation of metal hydroxide increases with increasing concentration of the colloidal particles to be removed . This suggested an inverse relationship between the optimum coagulant dose and the concentration of colloids . Under such conditions , the use of a coagulant aid can reduce the required dose.

This mechanism predominates in water treatment applications where pH values are generally maintained between pH 6 and 8.

Generally , the appraisal indicates that the destabilization of colloids in water and waste water treatment is probably accomplished either by adsorption and charge neutralization (ACN) or by both ACN and enmeshment within the hydroxides of the coagulant (Weber , 1972).

Adsorption and Interparticle Bridging

LaMer and Co-workers (1958, 1962) and others have developed a bridging theory which provides an acceptable qualitative model for the destabilization of colloidal dispersions by polymers of high molecular weight . This model suggests that high molecular weight polyelectrolytes form interparticle bridges using segments of the molecule to attach themselves to each particle. Bridged particles become interlocked with other bridged particles during the flocculation process and three dimensional polymer particle complex is formed having favourable settling characteristics . Attachment may result from coulombic attraction if the polymer and particle are of opposite charge or from ion exchange , hydrogen bonding , or Vander Waals forces if they are of similar charge (O'Melia, 1972).

The early theory by Healy and LaMer (1962) indicated that the optimum dosage for maximum flocculating effect occurs when half of the available surface sites on the solid particles have been covered with polymer. For homogeneous suspensions there is a direct relationship between particle concentration and optimum polymer dosage. Polymer doses that saturate the available surfaces of the dispersed phase produce restabilization , because no sites are available for the formation of polymer bridges .

In many practical applications , the colloidal particles and the polymer have opposite charge . For such cases , Gregory (1969) has shown that charge neutralization is largely responsible for the colloidal destabilization rather than interparticle bridging.

3.3.2.2 Factors Influencing Coagulation

Optimum coagulation treatment of a raw water represents the attainment of a very complex equilibrium in which many variables are involved .Thus , for a given water, there will be interrelated optima of conditions such as pH , turbidity , chemical composition of the water , type of coagulant , and such physical factors as temperature and mixing condition (AWWA , 19 71).

Effect of pH

Early investigators of the coagulation process in water treatment showed that pH was the single most important variable of the many that had to be considered . These investigators clearly established that there is at least one pH range for any given water within which good coagulation -flocculation occurs in the shortest time with a given coagulation dose. The extent of the pH range is affected by the type of coagulant used and by the chemical composition of the water as well as by the concentration of coagulant . The pH zone of least solubility for the hydrolysis products of aluminum ranges from 5.5 to 7.8. While pH zone for optimum coagulation by ferric sulfate is 5.5 to 8.8.

Effect of Salts:

Natural waters are never pure water but are dilute solutions of inorganic salts of varying concentration and composition. The effects of these salts on the coagulation process have been extensively studied and have been shown to exert an influence , depending on the specific ion and its concentration . The principal effects of the presence of certain ions are to alter (i) the pH range of optimum coagulation (ii) the time for flocculation (iii) the optimum coagulant dose and (iv) the residual coagulant in the effluent.

Extensive experimentation has led to the following generalizations on the effects of ions on coagulation:

- In general , coagulation with aluminum or iron salts is subject to greater interference from anions than from cations.Thus , ions such as sodium , calcium and magnesium have relatively little effect on coagulation.
- Anions extend the optimum pH range for coagulation to the acid side to an extent dependent on their valency . Thus monovalent anions such as chloride and nitrate have relatively little effect , while sulfate and phosphate cause marked shifts in pH optima.

While the above effects can readily be demonstrated in the laboratory , the application of this knowledge in practical coagulation of natural waters is difficult .Natural waters contain a complex mixture of ions , and it simply is not possible to separate the effects of the individual ions from the net effect of all ions .The proper dose of coagulant and the optimum pH must be determined for each water , but knowledge of the effects of ions can lead to a more informed approach to the determination.

Effect of Nature of Turbidity

Nature of turbidity also influence the coagulation process . At optimum pH condition

- A certain minimum of coagulant must be added for any turbidity concentration in order to provide an enmeshing mass of floc.
- With increase in turbidity additional amount of coagulant is generally required , but the dosage of coagulant will not increase linearly with increase in turbidity .
- Paradoxically , with very high turbidities relatively smaller coagulant doses are required because of the high collision probabilities ; for the same reason the very low turbidities are frequently more difficult to coagulate.

Effect of Coagulant:

One of the factors influencing coagulation is the coagulant type . While alum is by far the most commonly used coagulant , iron salts can be used as well . A significant advantage of iron salts over aluminum is the broader pH range for good coagulation. Lime alone can also be used . But much more lime is generally required when it is used alone than when it is used with sulfate of iron.

Effects of Physical Factors :

As temparature decreases , the viscosity of water increases , and hence the rate of settling of floc is decreased . While decrease of temperature is known to decrease the rate of chemical reaction , this effect on coagulation is probably too small to be significant. It has been observed , however , that the optimum pH value is decreased by decreases in temperature and that this shift becomes more important with smaller doses of coagulant.

Presence of Nuclei:

It was once thought that nuclei or particles were essential for coagulation or the initial formation of floc , it is currently agreed that hydrolysis and subsequent precipitation of coagulants can be obtained in the complete absence of solid suspended particles . Particles , particularly as the numbers increases , do influence the rate of flocculation and contribute to increased density of floc and hence increased settling velocities.

Effect of Mixing :

Mixing creates turbulence . Rapid mixing is essential to uniformly disperse the coagulant and to promote collisions of coagulant particles with turbidity particles . Rapid mixing should be maintained for 30 to 60 sec . Slow mixing is required for floc growth following the rapid mixing stage. The degree of agitation must be great enough to keep the floc particles suspended and in motion , but not so great that the floc is disintegrated by the shearing force. Detention times as little as 10 min , but more frequently 30 to 60 min , are generally adequate to produce a floc that will settle in a reasonable time.

Effect of Alkalinity :

The coagulation of metallic salts releases hydrogen ions as well as coagulant species . These hydrogen ions neutralize alkalinity . If the initial alkalinity of a water is low , further reduction will destroy its buffering capacity and the pH will drop rapidly . Since optimum pH values must be maintained for best coagulation and since alkalinity must be present for hydroxide floc formation , lime [Ca $(OH)_2$] or soda ash (Na_2CO_3) usually added to low alkalinity waters. Coagulant dose is effected depending on turbidity and alkalinity of water (Peavy et.al., 1985).

- Water with high turbidity and low alkalinity is easily coagulated by adsorption and charge neutralization with relatively small dosages of coagulant .
- Water with high turbidity and high alkalinity will require higher coagulant dosage to ensure sweep coagulation .
- Water with low turbidity and high alkalinity require moderate coagulant dosage and the principal coagulation mechanism is sweep coagulation.
- Water with low turbidity and low alkalinity is difficult to coagulate . So addition of turbidity or alkalinity or both will be advantageous.

3.3.2.3 Destabilization of water

Destabilization is induced by the addition of a suitable coagulant . Commonly used metal coagulants in water treatment are : (i) those based on aluminum , such as aluminum sulfate (alum) , sodium aluminate etc. and (ii) those based on iron , such as ferric and ferrous sulfate , ferric chloride . Both Al(III) and Fe (III) are hydrolyzing metal ions and a knowledge of the aqueous chemistry of these ions is essential to an understanding of their role in coagulation.

Destabilization of Water by Aqueous Al

Aluminum (III) salts are by far the most widely used coagulant in water treatment . The different aluminum species exhibited in water are directly associated with coagulation . Thus it is necessary to consider the aqueous chemistry of these coagulants. The aqueous chemistry of aluminum is complex and diverse because of numerous hydrolysis intermediates formed prior to precipitation of aluminum hydroxide , $AL(OH)_{3(S)}$ (Hossain, 1996).

Matijevic et. al (1964) provided a fairly clear description of the hydrolysis species of Al^{3+} and their interactions with the colloids in the context of coagulation and restabilization. When aluminum salts are added to water , the metal ion Al^{3+} hydrates , coordinating six molecules of water and forming an aquometal ion , $Al(H_2O)_6{}^{3+}$. The aquometal ion can then react and form several hydrolysis species. Some of the simplest being monomeric and dimeric hydroxocomplexes where coordination occurs with OH^- ligands that replace the six coordinated water molecules.

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

$$\begin{tikzcd}
{[Al(H_2O)_6]^{3+}} \arrow[d] & \\
{[Al(H_2O)_5(OH)]^{2+}} \arrow[r] \arrow[d] & {[Al(H_2O)_4(OH)_2]^{+}} \arrow[dddl] \\
{[Al_6(OH)_{15}]^{3+}} \arrow[d] & \\
{[Al_8(OH)_{20}]^{4+}} \arrow[d] & \\
{[Al(OH)_3(H_2O)_3]_{(s)}} \arrow[d] & \\
{[Al(OH)_4]^{-}} &
\end{tikzcd}$$

Amirtharajah and Mills (1982) and others have reported a number of aluminum polymers that may possibly be involved in coagulation and flocculation processes . These are : $Al_{13}(OH)_{34}^{5+}$, $Al_7(OH)_{17}^{4+}$, $Al_8(OH)_{20}^{4+}$,$Al(OH)_{15}^{3+}$, $Al_2(OH)_2^{4+}$, $Al_2(OH)^{5+}$, $Al_4(OH)_8^{4+}$, $Al_{13}O_4(OH)_{24}^{7+}$, $Al_3(OH)_4^{5+}$, $Al_{13}(OH)_{32}^{7+}$, and $Al_{14}(OH)_{34}^{8+}$, to name but a few.

Dempsey et. al (1984) contend that the evidence for the existence of such polymers is myriad and indirect . However , the degree of alkalinity in the solution is an important determinant in aluminum species . Other dominant factors include the concentration of reactants , contamination by other substances , pH , temperature and reaction time . Matijevic et. al. (1964) have found that the hydroxometal complexes readily adsorb on surfaces and the charges that they carry may cause charge reversals of the surfaces that they adsorb on , second , the sequential hydrolysis reactions release H^+ ions , which lowers the pH of the solution in which they are formed ;

and the concentration of the various hydrolysis species will be controlled by the final concentration of H^+ ions , that is , by the pH . These findings are in keeping with the individual suggestions O'Melia and Stumm (1967) and O'Melia (1972).

Hundt and O'Melia (1988) reported the work of Baes and Mesmer (1976) . In this , they described the aqueous chemistry of Al using five monomers Al^{3+} , $Al(OH)^{2+}$,$Al\ (OH)_2\ ^+$, $Al(OH)_3$ and $Al\ (OH)^4$; three polymers $Al_2(OH)_2^{4+}$, $Al_3(OH)_4^{5+}$ and $Al_{13}\ O_4(OH)_{24}^{7+}$ and a solid precipitate $Al\ (OH)_{3\ (s)}$. They also have discussed the influence of the chemical behaviour of anions of Al in solution. The presence of anions with a strong affinity for Al , such as sulphate , greatly affects the Al species in solution . Sulphate , a tetrahedral polyvalent anion , tends to link OH-Al polymers together , but in a distorted arrangement . Therefore , most basic salts containing sulphate are amorphous . In the presence of sulphate less alkali is necessary to produce a visible precipitate than when solutions containing chloride or nitrate salts are titrated . They also presumed a screening effect , that accelerates the formation of polymers and assists in the linking of planer complexes to form the solid lattice.

Sullivan and Singley (1968) have estimated the quantity of mononuclear aluminum species (monomers) at different pH . The estimates are given in Figure 3.3 . The dominant species upto pH 4.5 is Al^{3+} ,from 4.5 to 8.0 it is $Al(OH)_3$ and above pH 8.0 it is $Al(OH)_4\ ^-$.

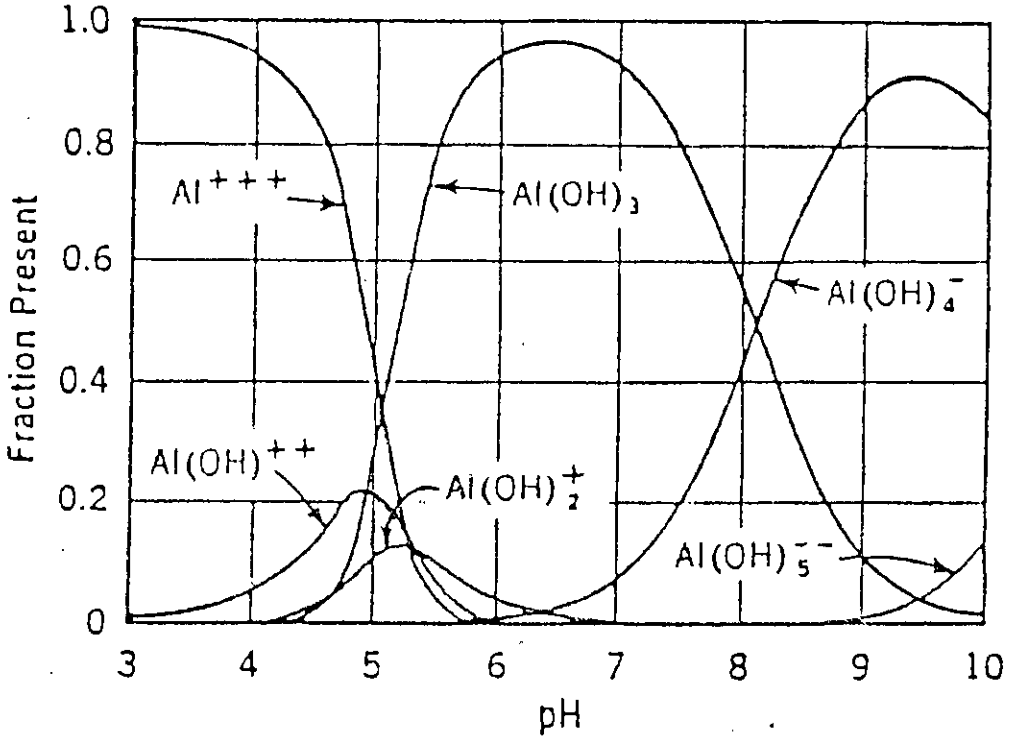


Figure 3.3 Species present as function of pH for 1x10^{-4} M Aluminum perchlorate (Sullivan & Singley, 1968.)

Destabilization of Water by Aqueous Fe

The aqueous chemistry of iron is similar to that of aluminum . Thus iron undergoes a series of hydrolytic reactions prior to precipitation of $Fe(OH)_{3(s)}$. When iron salts are added to water , it will dissociate to yield trivalent Fe^{3+} ions , which hydrates to form the aquometal ion , $Fe\ (H_2O)_6^{3+}$. The aquometal ion can then react and form several hydrolysis species including mononuclear species and polynuclear species.

Stumm and O'Melia (1968) and others have given the stepwise conversion of the tripositive iron ion to negative iron ion as pH increases as follows :

$$\begin{tikzcd}
{[Fe\ (H_2O)_6]^{3+}} \arrow[d] & \\
{[Fe\ (H_2O)_5\ OH]^{2+}} \arrow[d] \arrow[r] & {[\ Fe\ (H_2O)_4(OH)_2\ ]^{+}} \arrow[ddl] \\
{[Fe_2\ (OH)_2]^{4+}} \arrow[d] & \\
{[Fe\ (H_2O)_3(OH)_3]_{(s)}} \arrow[d] & \\
{[Fe(H_2O)_2(OH)_4]^{-}} &
\end{tikzcd}$$

The charge on hydrolysis products and the precipitation of metal hydroxides are both mainly controlled by pH. Sullivan and Singley (1968) have estimated the quantity of mononuclear iron species (monomers) at different pH . The estimates are given in Figure 3.4. The dominant species upto pH 4.0 is Fe^{3+} , from 4.0 to 6.0 it is $Fe(OH)_3$ and above pH 6.0 it is $Fe(OH)_6\ ^{2-}$.

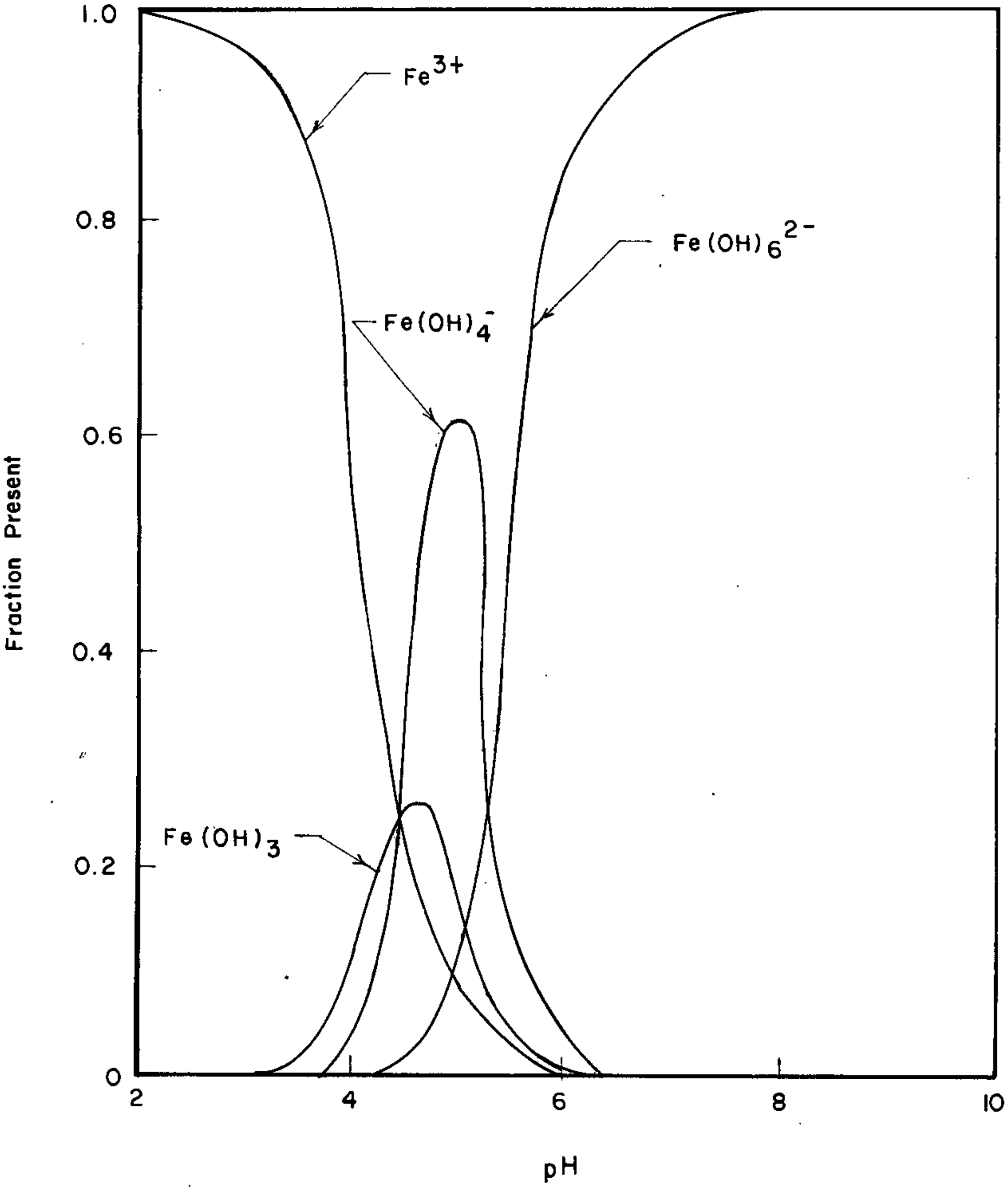


Figure 3.4 Species present as function of pH for 1×10^{-5} M Iron (III) Perchlorate (Sullivan & Singley, 1968.)

3.3.2.4 Chemical precipitation

Chemical precipitation is one of the most commonly used process in water treatment. Coagulation with alum , ferric or ferrous sulfate and lime involve chemical precipitation.

The classical solubility product expression for the dissolution of a sparingly soluble salt is:

$K_{sp} = [A^{y+}]^x [B^{x-}]^y$

while the dissolution reaction is

$A_x B_{y\,(s)} \leftrightarrows xA^{y+} + y B^{x-}$

K_{sp} is called the solubility product constant.

The value of the solubility product constant gives indication of the solubility of a particular compound. If the actual concentration of the ions in solution are such that the ion product $[A^{y+}]^x [B^{x-}]^y$ is less than the K_{sp} value, no precipitation will occur. Further , if the actual concentration of ion in solution are so great that the ion product is greater than the K_{sp} value ; precipitation will occur.

Now if an ion of a sparingly soluble salt is present in solution in a defined concentration , it can be precipitated by the other ion common to the salt , if the concentration of the second ion is increased to the point where the ion product exceeds the value of the solubility product constant. Such an influence is called common ion effect.

The common ion effect is an example of Le Châtelier's principle , which states that if stress is applied to a system in equilibrium , the system will act to relieve the stress and restore equilibrium , but under a new set of equilibrium conditions (Benefield et. al. , 1990).

3.3.3 Sedimentation

Sedimentation is the removal of particulate matter , chemical floc and precipitate from suspension through gravity settling (Hammer , 1977). The sedimentation process in water treatment provides for the settling and removal of heavier and larger suspended particles from water. Most commonly , it is used for removal of flocculated particles prior to filtration . The removal efficiency in the sedimentation basin determines the subsequent loadings on the filters and accordingly , has a marked influence on their capacity , the length of filter runs and the quality of the filtered water.

The basic theory of sedimentation assumes the presence of discrete particles. But particles in water are not spherical. The effect of irregular shape is not pronounced at low settling velocities, and most sedimentation devices are designed to remove small particles which settle slowly. Larger particles which settle at higher velocities will be removed whether or not they follow Stokes' or Newton's law.

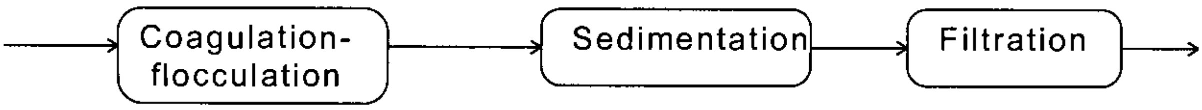
Flocculent particles such as those resulting from coagulation of water will agglomerate while settling , with a resultant increase in particle size. The density of the composite particle may decrease due to the inclusion of water , but the overall result is generally an increase in settling velocity.

The factors that effect sedimentation are , density of particles, density of water , size of particle , velocity of settling particle , drag co-efficient , acceleration due to gravity, detention period , effective depth of the settling basin etc. Sedimentation can be accelerated by increasing particle size or decreasing the distance a particle must fall prior to removal. The first is achieved by coagulation and flocculation prior to sedimentation . The second can be achieved by making the basin shallower or by providing tube settlers.

3.3.4 Filtration

Filtration is a unit process widely used in water treatment for the removal of particulate materials. In this process , water passes through a filter medium and particulate materials either accumulate on the surface of the medium or are collected through its depth. Filters have been found effective for removing particulates of all size ranges , provided that proper design parameters are used.

Fig:3.5 Application of filters in conventional water treatment



The principal mechanisms that are believed to contribute to the removal of material in filter are (a) impaction, (b) interception , (c) sedimentation, (d) adhesion , (e) biological growth etc.

The efficiency of filtration is dependent on various design variables. A decrease in porosity of the granular media will increase the particulate removal efficiency .In addition , increasing the filter depth or decreasing the filter media size will improve particle capture.

Two general types of filters are commonly used in water treatment : the slow sand filter and the rapid sand filter.

3.3.4.1 Slow sand filtration

A slow sand filter consists of a layer of ungraded , fine sand through which water is filtered at a low rate. The traditional rate of filtration used for normal operation is 0.1 m/hr, although it is possible to produce safe water at rates as high as 0.4 m/hr. The sand bed thickness varies between 1.0 and 1.4 m. Filter sand should have an effective size between 0.15 and 0.35 mm and a uniformity co-efficient between 1.5 and 3. Slow sand filters are most practical in the treatment of water with turbidity below 50 NTU , although higher turbidities can be tolerated for a few days. The best purification occurs when the turbidity is below 10 NTU .

The filter is cleaned by periodically scraping a thin layer of dirty sand from the surface when it becomes too clogged with impurities at intervals of several weeks to months. The low rate of filtration allows the formation of an active layer of micro-organisms , called the *schmutzdecke* on the top of the sand bed which provide biological treatment. This layer is particularly effective in the removal of micro-organisms from water (Schulz and Okun , 1984).

3.3.4.2 Rapid sand filtration

A rapid sand filter consists of a layer of graded sand, or in some instances , a layer of coarser filter media (e.g. , anthracite) placed on top of a layer of sand , through which water is filtered.

The rate of filtration used for normal operation is much higher than slow sand filter. Normal filtration rate is 4 m/hr. , although it can be as high as 21 m/hr. Effective size of the filter sand is 0.55 mm and higher and uniformity coefficient 1.5 and lower.

The filter is cleaned by backwashing with water. Because of the higher filtration rates , the space requirement for a rapid sand filtration plant is 20% of that required for slow sand filters (Schulz and Okun , 1984).

3.3.4.3 Roughing filtration

Roughing filters allow deep penetration of suspended materials into a filter bed and they have a large silt storage capacity.

Roughing filtration uses much larger media than either slow or rapid filtration and the media size is greater than 2.0mm. The rate of filtration , can be as low as those used for slow sand filters or higher than those used for rapid sand filters, depending upon the type of filter , the nature of the turbidity and the desired degree of turbidity removal. Roughing filters are limited , however, to average raw water turbidities of 20 to 150 NTU.

The solid materials retained by the filters are removed by flushing or if necessary , by excavating the filter media , washing it and replacing it. There are basically two types of roughing filters, which are differentiated by their direction of flow and are

- vertical flow roughing filters
- horizontal flow roughing filters

CHAPTER 4

STUDY ON ARTIFICIAL IRON CONTAINING WATER

4.1 INTRODUCTION

In Bangladesh presence of iron in ground water is a contributing factor to the non-usage of tubewell water. This in turn is creating different health related problems in rural areas as consumers decide to use water of doubtful quality.

In this chapter artificial iron content water was prepared at the laboratory. Laboratory studies were carried out on different aspects of iron removal, like oxidation and precipitation of soluble iron , flocculation and coagulation of precipitated iron particles and the separation of insoluble iron from water.

4.2 PREPARATION OF ARTIFICIAL IRON CONTAINING WATER

Distilled water was used as the main source of water for the experiments at room temperature. The water had a pH value around 7.0.

Stock solution of iron was prepared by dissolving 0.27203 gm of $FeSO_4$ (dried / anhydrous) in 100 ml of deionized water. Molecular weight of anhydrous ferrous sulphate ($FeSO_4$) is about 152.01 in which iron , Fe , portion is one third of the total weight . The strength of the stock solution comes to 1 mg of iron /ml.

Every time before use the iron solution was shaked thoroughly so that $FeSO_4$ remains in solution. Then desired portion of iron solution was mixed with iron free distilled water to give resultant iron concentrations of 20, 15 , 10, etc mg/L . The stock solution prepared at a time was used within one week of preparation.

4.3 BATCH STUDY

4.3.1 Jar Test

The traditional laboratory tool for coagulation studies is the " jar tests" . Jar tests were carried out in accordance with the procedure set out in Water Research Association .

As illustrated in Fig .4.1, the jar test was performed using a series of glass containers that hold at least 1 litre and are of uniform size and shape. Normally six jars are used with stirring device having six number vertical stirring rods. Each stirring rod is provided with a paddle at its lower end , and all the rods are turned at the same rate by means of the driving shaft, which is geared directly to a variable speed motor giving a maximum rotation of 250 rpm .

Jars containing 500 ml of water sample in each of known iron content were placed under the vertical shaft paddle stirrer. The water in the jars were stirred rapidly at 80 rpm for about 1 minute to ensure complete dispersion and then slowly at 20 rpm for 15 minute to aid in the formation of flocs.

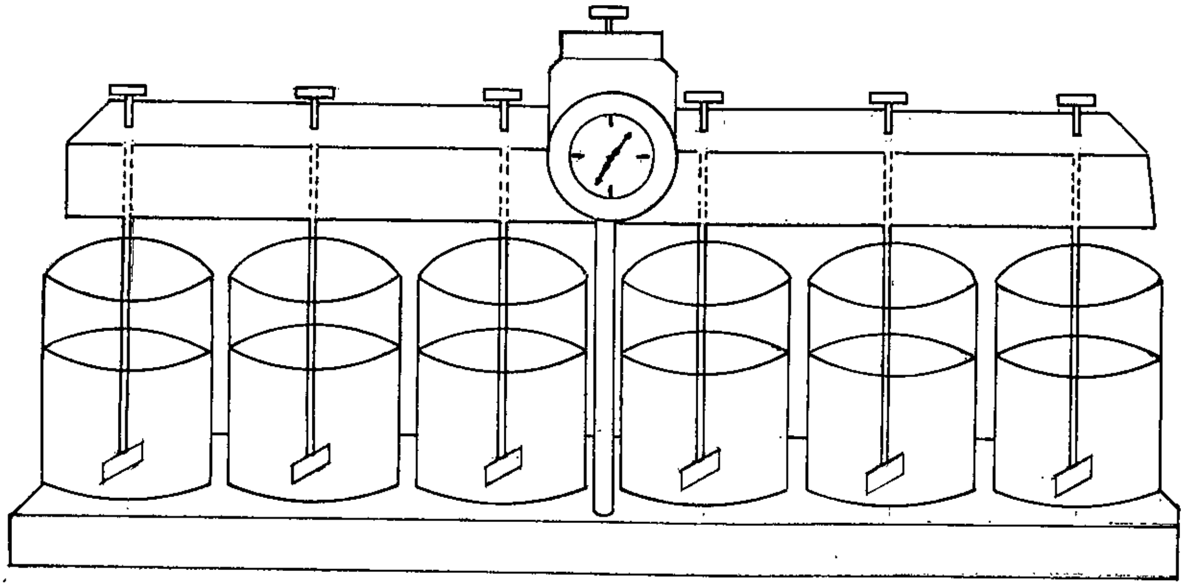


Figure: 4.1 Experimental set-up for the jar test

4.3.2 Measurement Of Iron Concentration

Water samples were tested in the laboratory to measure iron concentration according to standard procedure , and are described in Appendix- " A"

4.3.3 pH Measurement

The pH was measured by a pH meter .

4.4 EFFECT OF pH ON IRON REMOVAL

In this section artificial water sample containing same amount of initial iron concentration with different pH were used. Residual iron concentration of the samples were determined after coagulation using lime and sodium hydroxide as coagulant and sedimentation allowing a fixed settling time.

4.4.1 Experimental Set-Up

Artificial water sample having 20 mg/L of initial iron concentration was used. 500 ml of the sample water was taken in each of different jars .The pH value of artificial water sample was varied by using saturated lime (4 g/L) at different doses of 15, 22, 26, 30, 34,40, 50 and 330 ml i.e. 120, 176, 208, 240, 272, 320, 400 and 2640 mg/L which results in pH values of 7, 7.4, 7.7, 8.16, 8.5, 8.9, 9.3 and 11.68 respectively. Variation of pH with lime dose is presented in Appendix: B , Figure:B_1. All these samples of varied pH value were coagulated (as described in Art. 4.3.1). The stirred water was allowed to settle for 15 min. , after which a portion of the supernatant was drawn off from different jars and transferred to tubes for the determination of iron concentration (as described in Art.4.3.2).

Again 500 ml of water sample with 20 mg/L of initial iron concentration was taken in each of the six different jars and pH was varied by using NaOH solution (4g/L) at different doses of 1, 2, 4, 7.5, 8 and 10 ml i.e. 8, 16, 32, 60 , 64 and 80 mg/L which results in pH values of 7, 7.4, 8.3, 9.6, 9.9 and 10.4 respectively. All these samples were then coagulated (as described in Art. 4.3.1). The stirred water samples were at first allowed to settle for 15 min. , after which a portion of the supernatant was drawn off from each of all the six jars and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2).

The results are given in tabular form in Appendix -"B" , Table :B_1 and B_2. The residual iron concentration in water samples with different pH value after coagulation with lime and sedimentation is shown in Figure:4.2. The residual iron concentration in water samples with different pH value after coagulation with sodium hydroxide and sedimentation is shown in Figure: 4.3.

4.4.2 Results And Discussions

It is observed from Figure: **4**.2 that residual iron concentration decreases with increase in pH value i.e. iron removal increases with the increament of pH. However, after a certain value of pH iron removal exhibit a decreasing trend. This pH value is observed to be 9.3 when lime is used as coagulant to coagulate artificial iron content water with initial Fe concentration of 20 mg/L.

It is observed from Figure 4.3 that iron removal increases with the increase in pH value. However , after a certain value of pH iron

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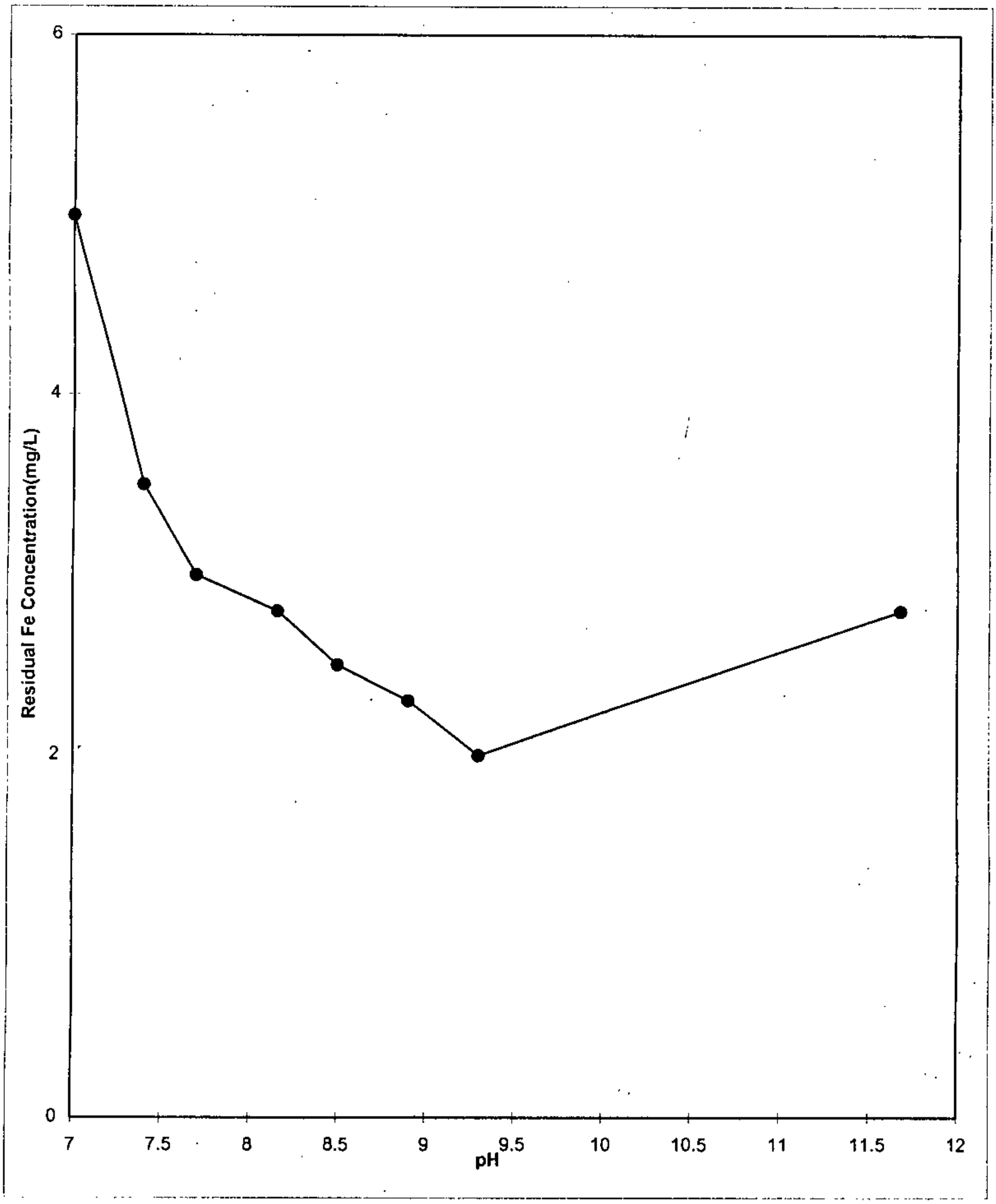

Figure: 4.2 Residual Fe concentration at different pH of artificial water sample containing initial Fe concentration of 20 mg/L after coagulation with lime and 15 min. sedimentation

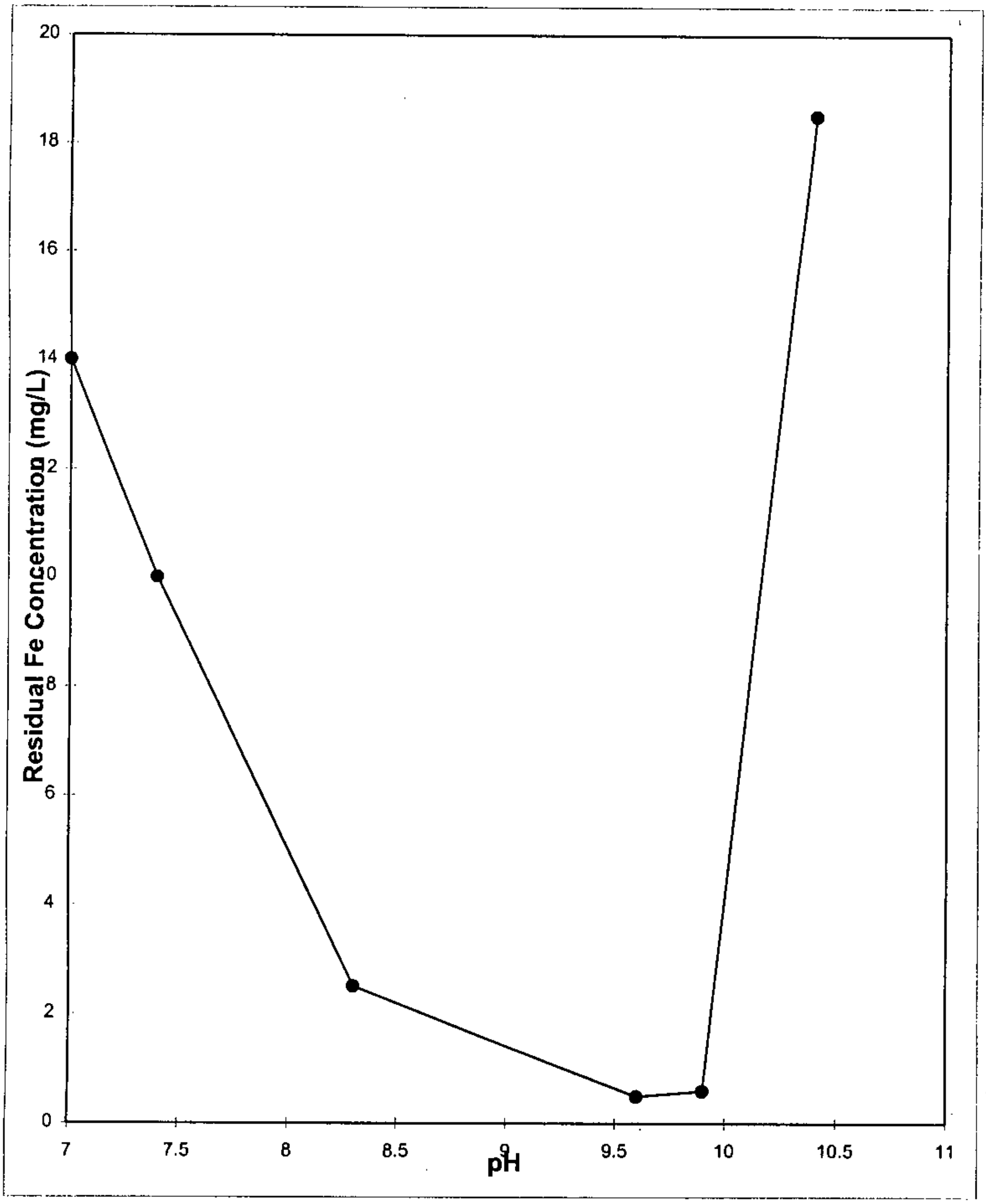

Figure:4.3 Residual Fe concentration of artificial water sample (initial Fe concentration 20 mg/L) with pH after coagulation with sodium hydroxide and 15 min. sedimentation.

removal exhibit a decreasing trend. This pH value is observed to be 9.6 when sodium hydroxide is used as coagulant to coagulate artificial iron content water with initial Fe concentration of 20 mg/L.

Figure:4.2 indicates that as pH changes from 3.5 to 9.3 iron removal increases from 5% to 90% when lime is used as coagulant . Residual iron concentration varies from 19 to 2.0 mg/L. However, as pH changes from 9.3 to 11.68 iron removal decreases from 90% to 86%. Residual iron concentration varies from 2.0 to 2.8 mg/L.

Figure:4.3 indicates that as pH value increases from 7 to 9.6 iron removal increases from 30% to 97.5% when sodium hydroxide is used as coagulant . Residual iron concentration varies from 14 mg/L to 0.5 mg/L. However, when pH value increases from 9.6 to 10.4 , iron removal decreases from 97.5% to only 7.5%. Residual Fe concentration varies from 0.5 to 18.5 mg/L.

From literature review (Chapter-3, Art. 3.2.1) it is clear that iron mainly precipitated out of solution due to the formation of insoluble ferric hydroxide [$Fe(OH)_3$]. But after a certain pH value the formation of soluble $Fe(OH)_4^-$ increases while insoluble $Fe(OH)_3$ decreases leading to decrease in iron removal.

Within pH range 7-8 iron removal of 82.15% on average was observed after coagulation and 15 min. settling when lime is used as coagulant . While within the same pH range iron removal of only 51.65% observed when NaOH was used as coagulant. This indicates that lime is more effective as coagulant than sodium hydroxide in iron removal and will remove 59.05% higher than sodium hydroxide within the same pH range. Lime when added to a solution it increases the pH value as well as it acts as coagulant . But sodium hydroxide only increases the pH value and it remains in solution. Within pH range 7-8 oxidized insoluble iron will precipitated out of solution in both the cases. However, due to coagulation effect smaller precipitates are also removed when lime is used resulting in higher iron removal.

4.5 IRON REMOVAL WITH SEDIMENTATION TIME

In this section three different artificial water samples containing different initial iron concentration were used. Residual iron concentration of the different samples was observed at different sedimentation time after aeration and coagulation .

4.5.1 Experimental Set-Up

The three water samples used have initial iron concentration 20 mg/L , 15 mg/L and 10 mg/L respectively. 500 ml of each artificial water sample was taken in each of the three jars. The water samples were coagulated (as described in Art.4.3.1) using 176 mg/L of lime as coagulant and pH of the samples were adjusted to 7.4. The stirred water samples were allowed to settle and a portion of the supernatant from each of the three jars was drawn off after different time intervals of 10min ,30min , 1 hr, 2hr ,4hr ,12hr , 24hr, and transferred to tubes for the determination of iron concentration (as described in Art.4.3.2).

Then again 500 ml of artificial water sample having initial iron concentration of 20 mg/L was taken in each of four jars. The samples were coagulated (as described in Art. 4.3.1) using sodium hydroxide, NaOH (caustic soda) as coagulant at different doses of

16, 32, 60 and 80 mg/L and resulting pH values were 7.4, 8.3, 9.6 and 10.4 respectively. The stirred water samples were allowed to settle and a portion of the supernatant was drawn off from each of the four jars after different time intervals of 5, 10, 15, 45 and 90 minutes and transferred to tubes for the determination of iron concentration (as described in Art: 4.3.2).

The difference of iron concentration between original samples and supernatant is a measure of flocculation performance. The results are given in tabular form in Appendix -"B" , Table :B_3 and B_4. The residual iron concentration in water samples of different initial iron concentration after coagulation with lime at different settling time are shown in Figure:4.4 and residual iron concentration after coagulation with sodium hydroxide at different pH after different sedimentation time are shown in Figure: 4.5 .

4.5.2 Results And Discussions

It is clear from Figure :4.4 that for all water samples with different initial iron concentration of 10, 15 and 20 mg/L, residual iron concentration decreases with an increase in settling time following a characteristic pattern after coagulation with lime at pH 7.4. But the rate of increase of iron removal diminishes with the increase of settling time. About 90% iron removal is experienced in all the cases after only 1 hr of settling. However, after 24 hr settling iron removal of about 98% is observed. Residual iron concentration of the water samples with initial Fe concentration of 10 mg/L, 15 mg/L and 20 mg/L becomes 0.2 mg/L, 0.3 mg/L and 0.35 mg/L respectively after 24 hr. settling.

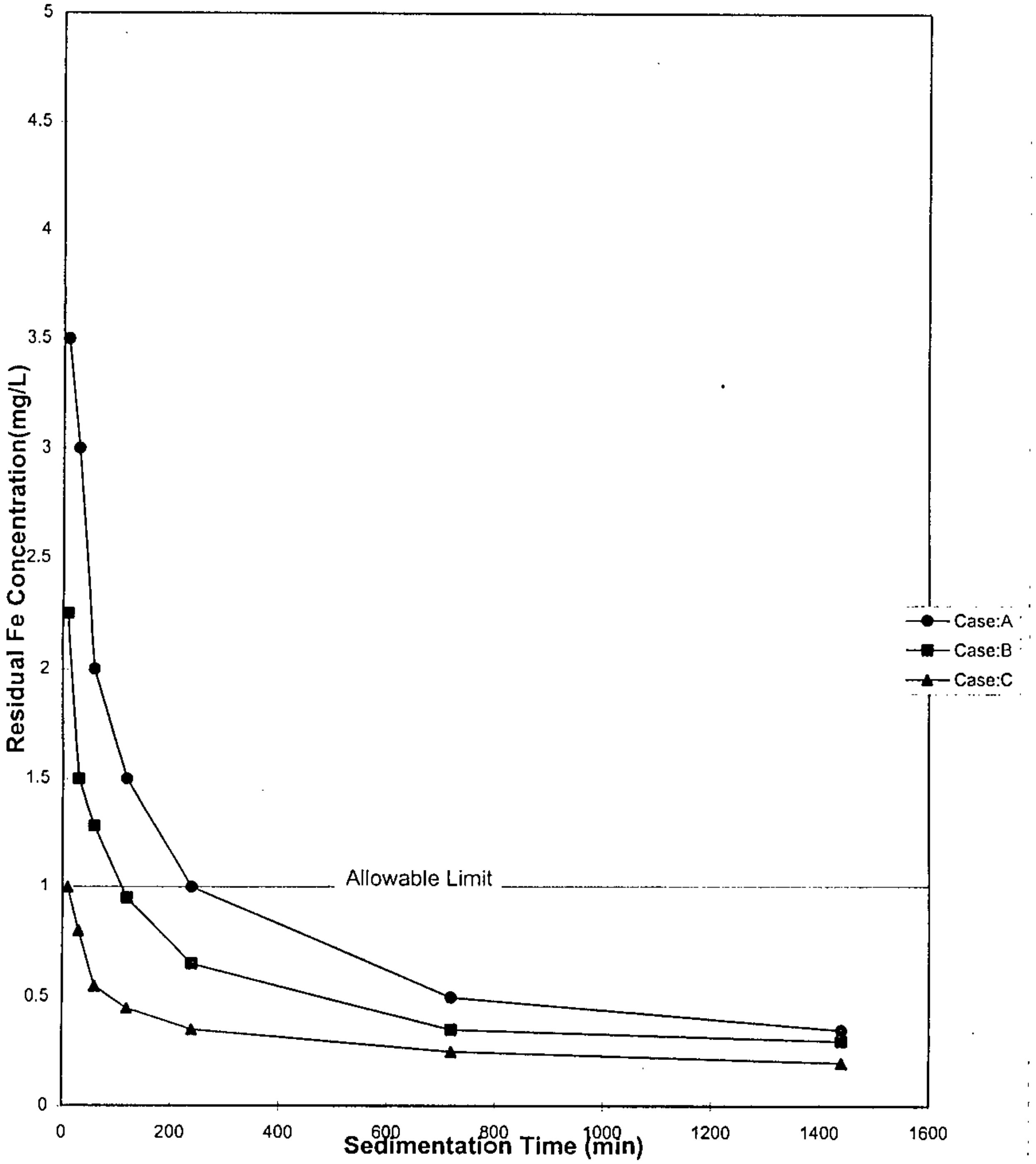

Figure:4.4 Residual Fe concentration with sedimentation time after coagulation with lime at pH 7.4 of three artificial water samples containing different initial Fe concentration. (i) Case A:Initial Fe concentration 20mg/L (ii) Case B: Initial Fe concentration 15mg/L (iii) Case C: Initial Fe concentration 10 mg/L

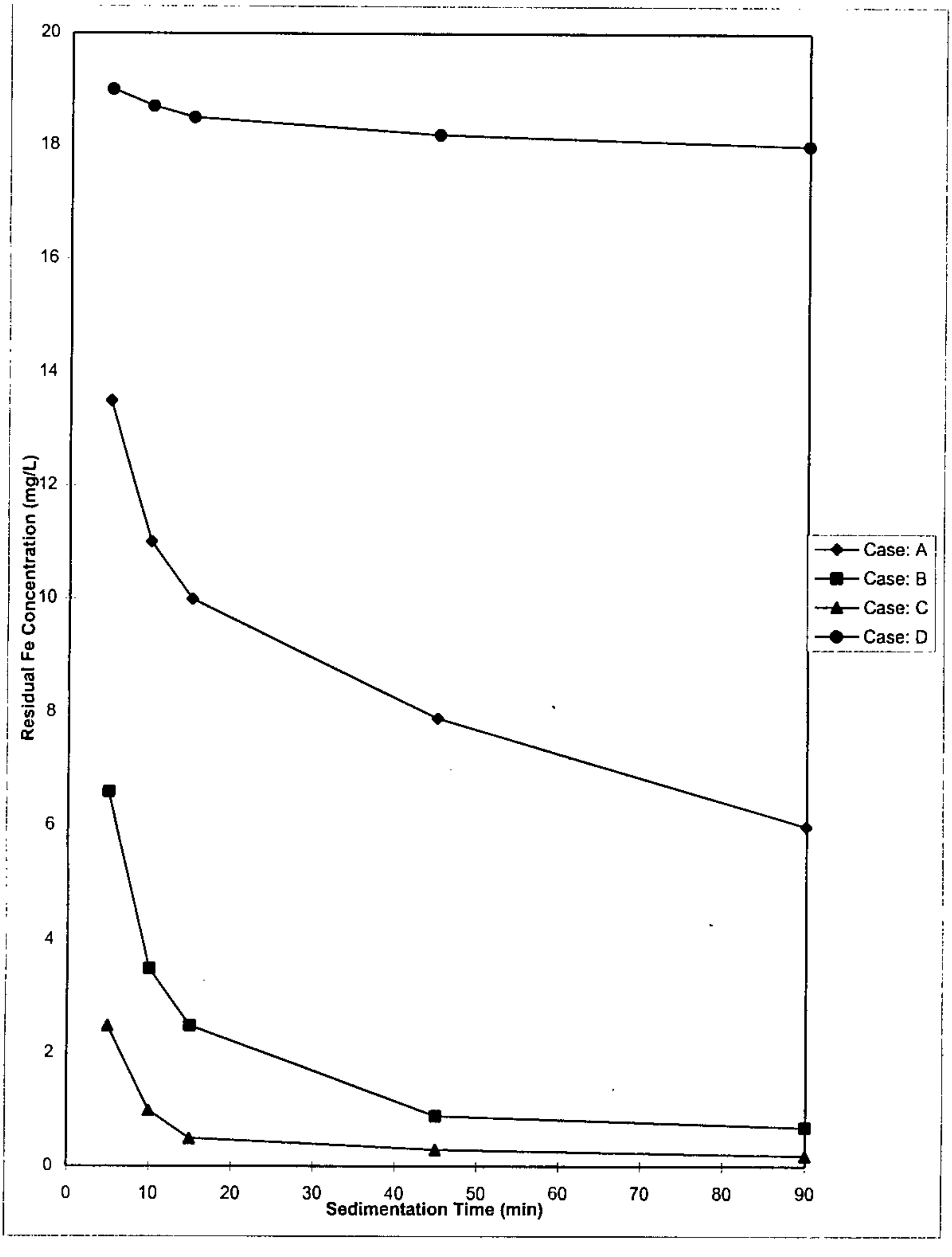

Figure: 4.5 Residual Fe concentration of artificial water sample containing initial Fe concentration of 20 mg/L with sedimentation time after coagulation with NaOH (i) Case A: at pH 7.4 , (ii) Case B: at pH 8.3 (iii) Case C: at pH 9.6 (iv) Case D: at pH 10.4

This is in line with the fact that oxidized insoluble ferric iron will tend to precipitate out of the water . As longer time is allowed for precipitation then smaller particles will settle leading to a decrease in residual iron concentration in the sample.

Figure :4.4 also indicates that optimum sedimentation time for artificial water sample having initial iron concentration 20 mg/L is 240 min , which corresponds to residual iron concentration of 1 mg/L. Optimum sedimentation time for artificial water sample having initial iron concentration 15 mg/L is also 240 min, which corresponds to residual iron concentration of 0.65 mg/L. Optimum sedimentation time for artificial water sample having initial iron concentration 10 mg/L is 120 min , which corresponds to residual iron concentration of 0.45 mg/L.

Allowable limit of iron in drinking water for Bangladesh is 1 mg/L as recommended by the Department of Environment. Test results indicates that sedimentation time required to attain this standard value of residual iron concentration for the three artificial water samples having initial iron concentration of 20, 15 and 10 mg/L at a pH value of 7.4 after coagulation with lime are 240 min , 110 min and 10 min respectively and the result is shown in Figure: 4.6 .

It is observed from Figure:4.5 that after coagulation with NaOH, residual iron concentration decreases with an increase in sedimentation time following a characteristics pattern at different pH. At pH 10.4 iron removal increases with sedimentation time at a very low rate. While between pH 7.4 to 9.6 rate of increase of iron removal with time is high . Sedimentation time required to attain

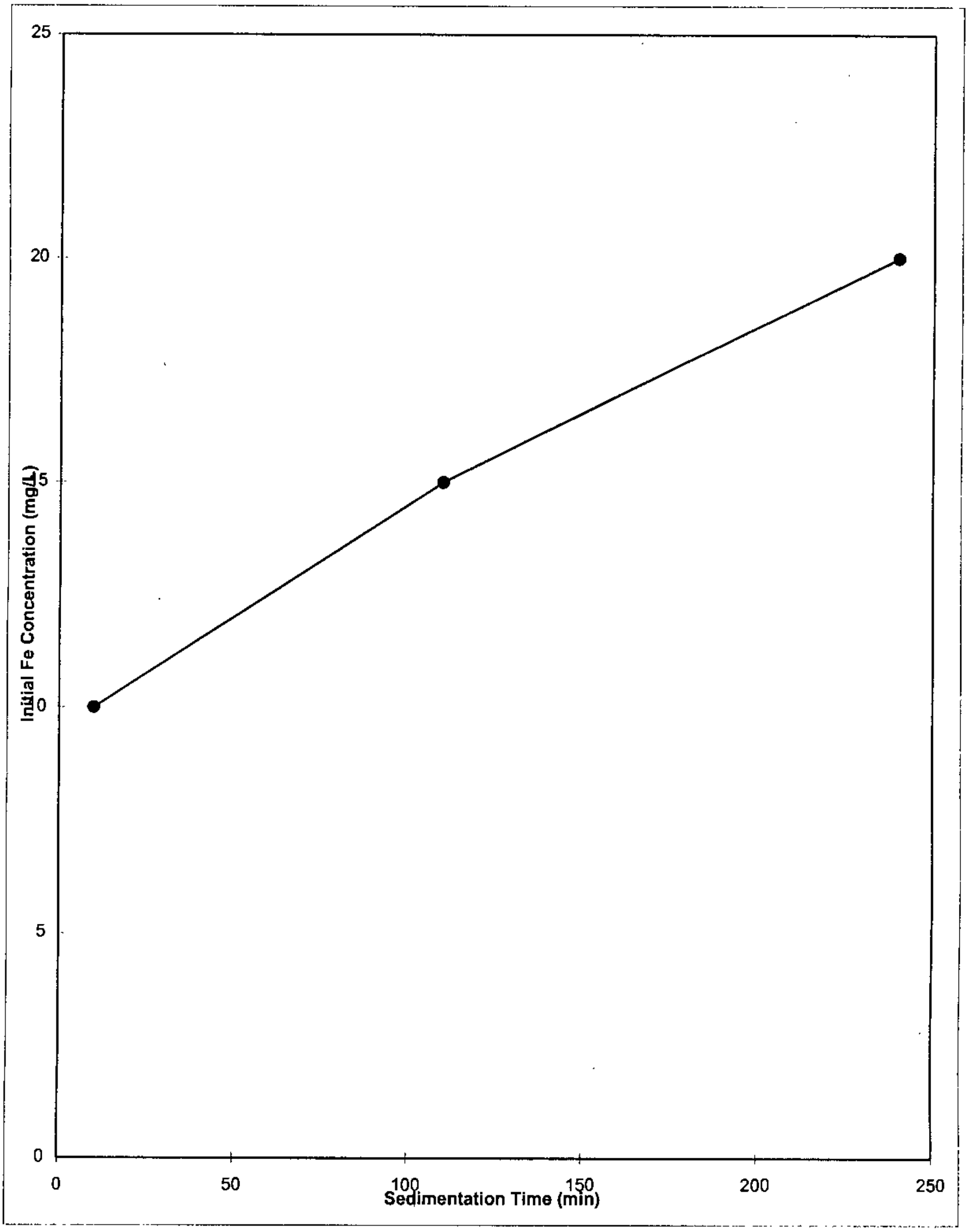

Figure: 4.6 Initial Fe concentration with sedimentation time required to attain residual iron concentratio of 1 mg/L (allowable limit) after coagulation with lime .

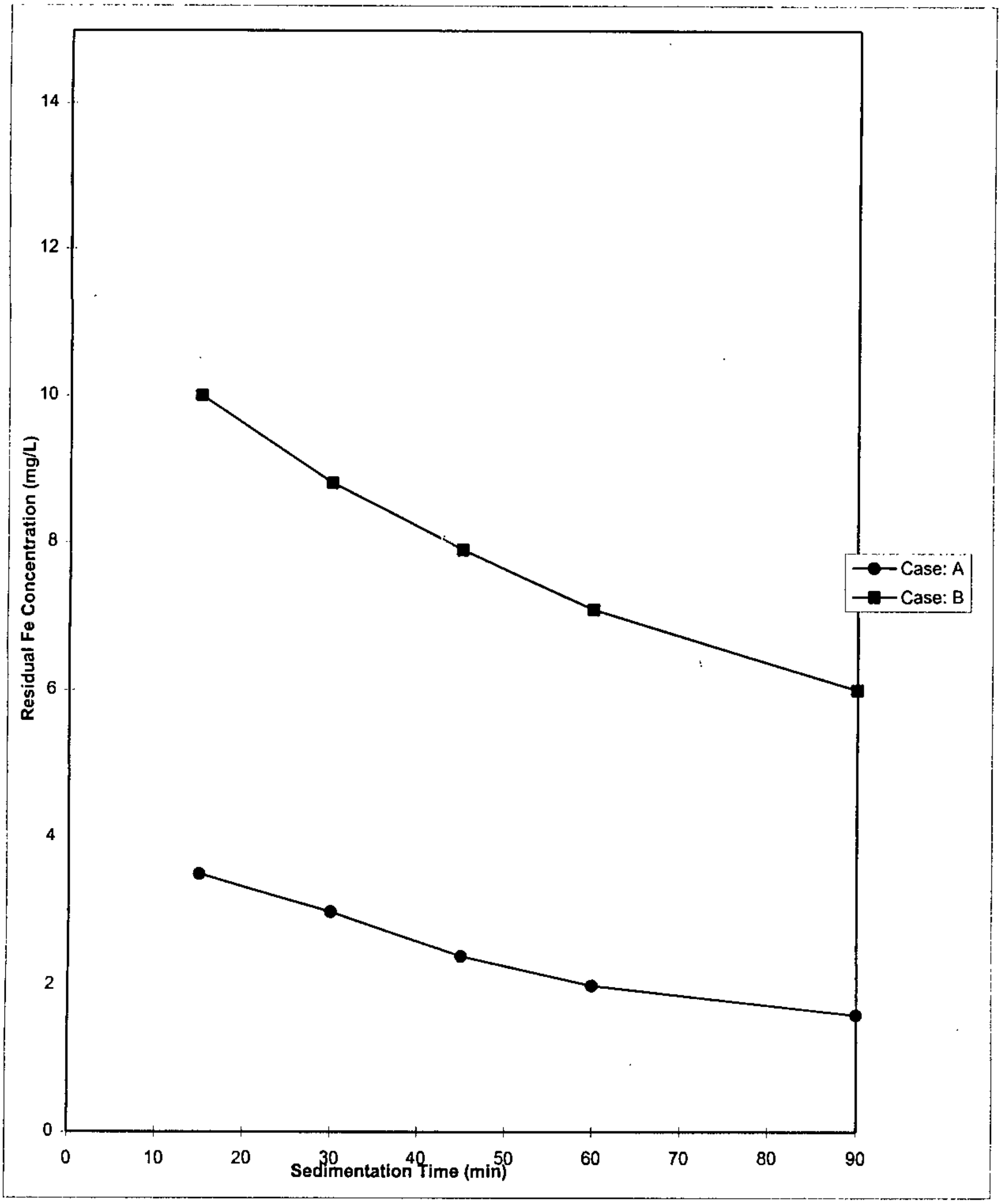

Figure:4.7 Residual Fe concentration with sedimentation time of artificial water sample (initial Fe concentration = 20 mg/L) after coagulation at pH 7.4 using (i) Case A: Lime as coagulant (ii) Case B: Sodium hydroxide as coagulant.

allowable limit of 1 mg/L at pH 8.3 and 9.6 are 50 min and 10 min. respectively after coagulation with NaOH.

Effect of sedimentation time on iron removal at pH 7.4 for both lime and sodium hydroxide coagulation is presented in Figure:4.7. It is also clear that lime is more effective than caustic soda in iron removal. After 15 min. sedimentation iron removal is 82.5% with residual iron concentration of 3.5 mg/L when lime is used as coagulant. Whereas iron removal is only 50% and residual iron concentration is 10 mg/L when caustic soda is used as coagulant. Similarly after 90 min. sedimentation, lime coagulation and caustic soda coagulation results in iron removal of 92% and 70% with residual iron concentration of 1.6 mg/L and 6 mg/L respectively.

Figure 4.8 represents the effect of added OH^- ion (NaOH) concentration on iron removal at different sedimentation time. In all the cases residual iron concentration decreases with an increase in OH^- ion concentration upto a certain limit after which iron removal again shows a decreasing trend. In this case after OH^- ion concentration reaches to a value of 25.5 mg/L which corresponds to pH value of 9.6, iron removal exhibits a decreasing trend. With an increase in added OH^- ion concentration from 6.8 mg/L to 25.5 mg/L iron removal after coagulation and 90 min. sedimentation increases from 70% to 99%. But with an increase in added OH^- ion concentration from 25.5 mg/L to 34 mg/L iron removal decreases from 99% to only 10%. Corresponding values are presented in tabular form in Appendix: B, Table: B_5.

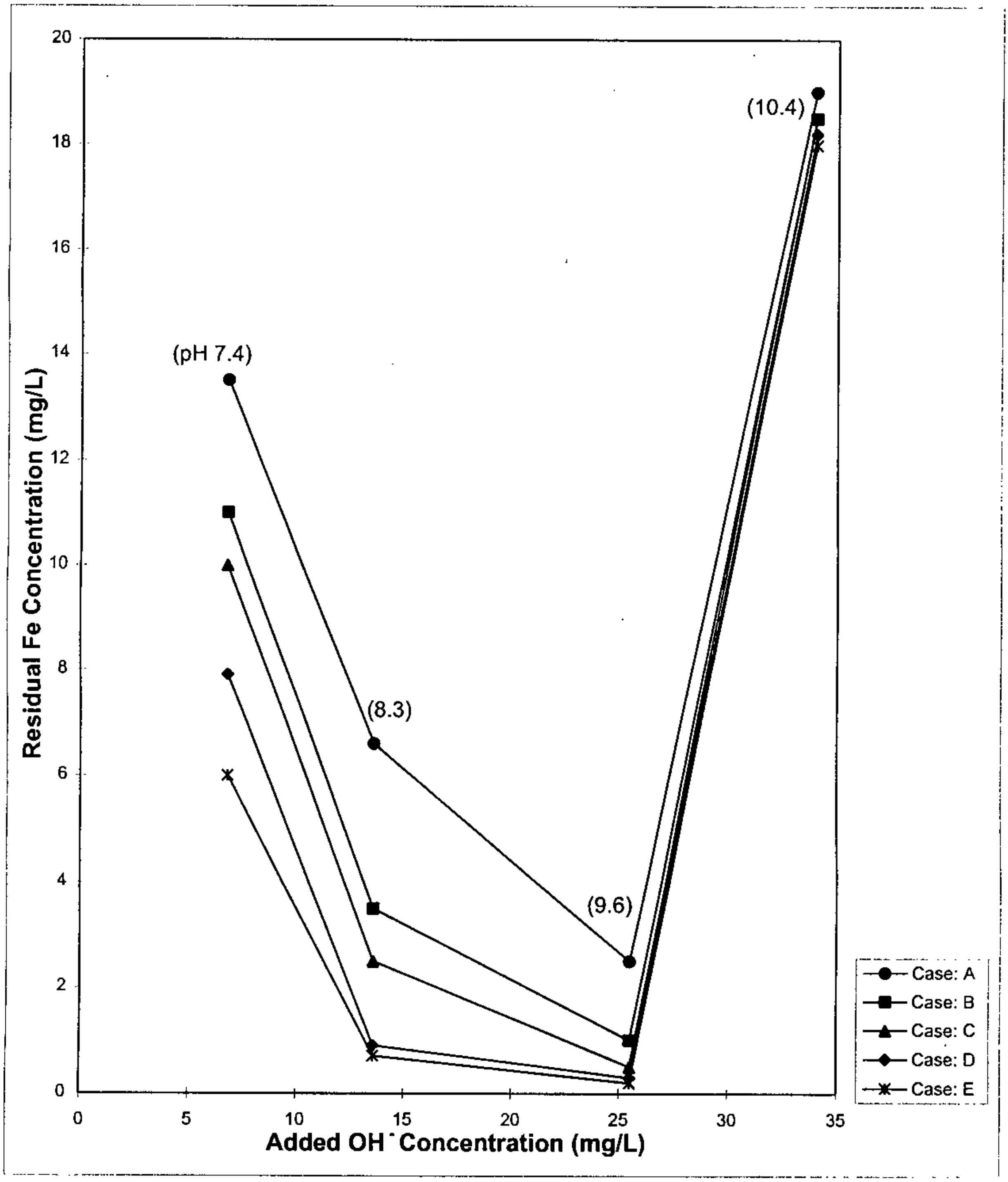

Figure:4.8 Residual iron concentration of artificial water sample (initial Fe conc. : 20 mg/L) with added OH^- ion concentration (NaOH) after coagulation and (i) Case A : 5 min sedimentation (ii) Case B : 10 min sedimentation (iii) Case C : 15 min sedimentation (iv) Case D : 45 min sedimentation (v) Case E : 90 min sedimentation

Increase of OH^- ion concentration effects the oxidation of ferrous iron to ferric iron and thus effects iron removal. Further attention is needed on change of alkalinity in this respect.

4.6 EFFECT OF ALKALINITY ON IRON REMOVAL

In this section artificial iron containing water sample with different alkalinity were used. Residual iron concentration as well as colour and turbidity of the samples were observed.

4.6.1 Experimental Set- Up

500ml of artificial water sample having initial iron concentration of 20 mg/L was taken in each of the seven jars. Alkalinity of artificial water sample was varied using Na_2CO_3 solution (4g/L) to give alkalinity values of 8, 32, 100, 120, 130, 226 and 267 mg/L as $CaCO_3$ which results in pH values of 4.8, 6.0, 6.7, 6.8, 6.9, 7.5 and 8.2 respectively. All these samples were then coagulated (as described in Art. 4.3.1). The stirred water samples were allowed to settle for 30min., after which a portion of the supernatant was drawn off from all the seven jars and transferred to tubes for the determination of iron concentration (as described in Art 4.3.2).

Then again 100ml of artificial water sample containing initial iron concentration of 10 mg/L was taken in each of the eight jars. Alkalinity of the artificial water samples was varied using Na_2CO_3 solution (4g/L) to give alkalinity values of 6, 16, 32, 100, 120, 130, 226 and 267 mg/L as $CaCO_3$. All these samples were then mixed properly. Then colour and turbidity of all the water samples were measured.

Then again 100ml of artificial water sample containing initial iron concentration of 10 mg/L was taken in each of the seven jars. Alkalinity and pH of the artificial water samples were varied using different doses of NaOH solution (4g/L) to give pH values of 3.7, 4.4, 4.8, 5.8, 6.3, 7.3 and 9.1 with corresponding alkalinity values of 0, 4.85, 12.62, 19.51, 21.69, 49.04 and 56.92 mg/L as $CaCO_3$. All these samples were then mixed properly. Then turbidity of all the water samples were measured.

The results are given in tabular form in Appendix -"B", Table: B_6 , B_7 , B_8. The residual iron concentration with alkalinity is shown in Figure : 4.9 and variation of colour and turbidity with alkalinity are presented in Figure: 4.10, 4.11 and 4.12.

4.6.2 Results And Discussions

It is clear from Figure: 4.9 that residual iron concentration decreases with an increase in alkalinity. However, rate of increase of iron removal diminishes with increase in alkalinity. At lower alkalinity iron removal is very much insignificant.

At an alkalinity value of 32 mg/L as $CaCO_3$ iron removal of 55% is experienced. However, with an increase in alkalinity value to 130 mg/L as $CaCO_3$ iron removal increases to 91% with residual iron concentration of 1.8 mg/L. Whereas, at alkalinity values above 130 mg/L as $CaCO_3$ the rate of increase of iron removal is low. With an increase in alkaliny from 130 mg/L as $CaCO_3$ to 226 mg/L as $CaCO_3$,

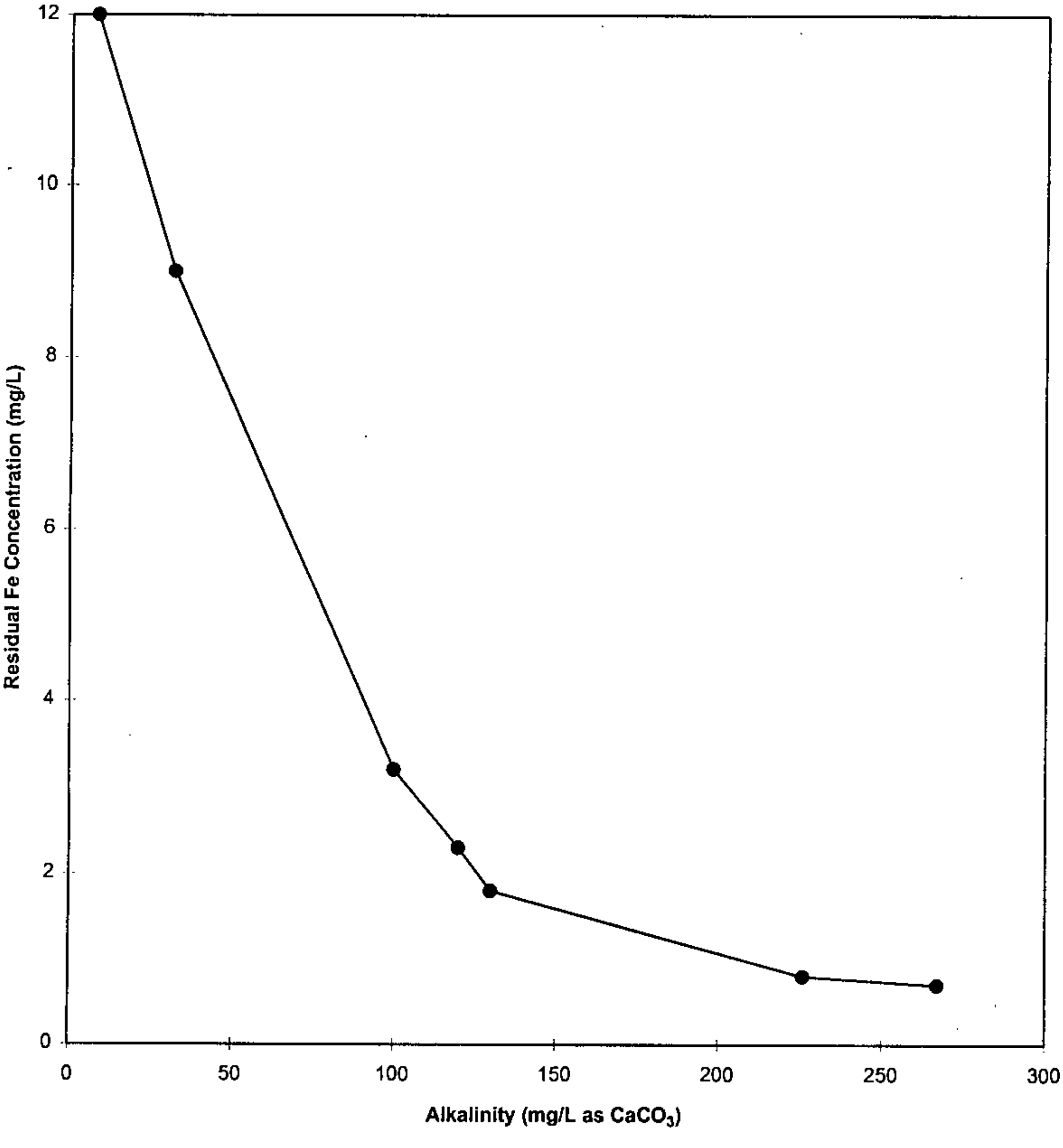

Figure: 4.9 Residual iron concentration of artificial water sample (initial Fe concentration : 20 mg/L) with different alkalinity (varied using Na_2CO_3) after coagulation and 30 min. sedimentation.

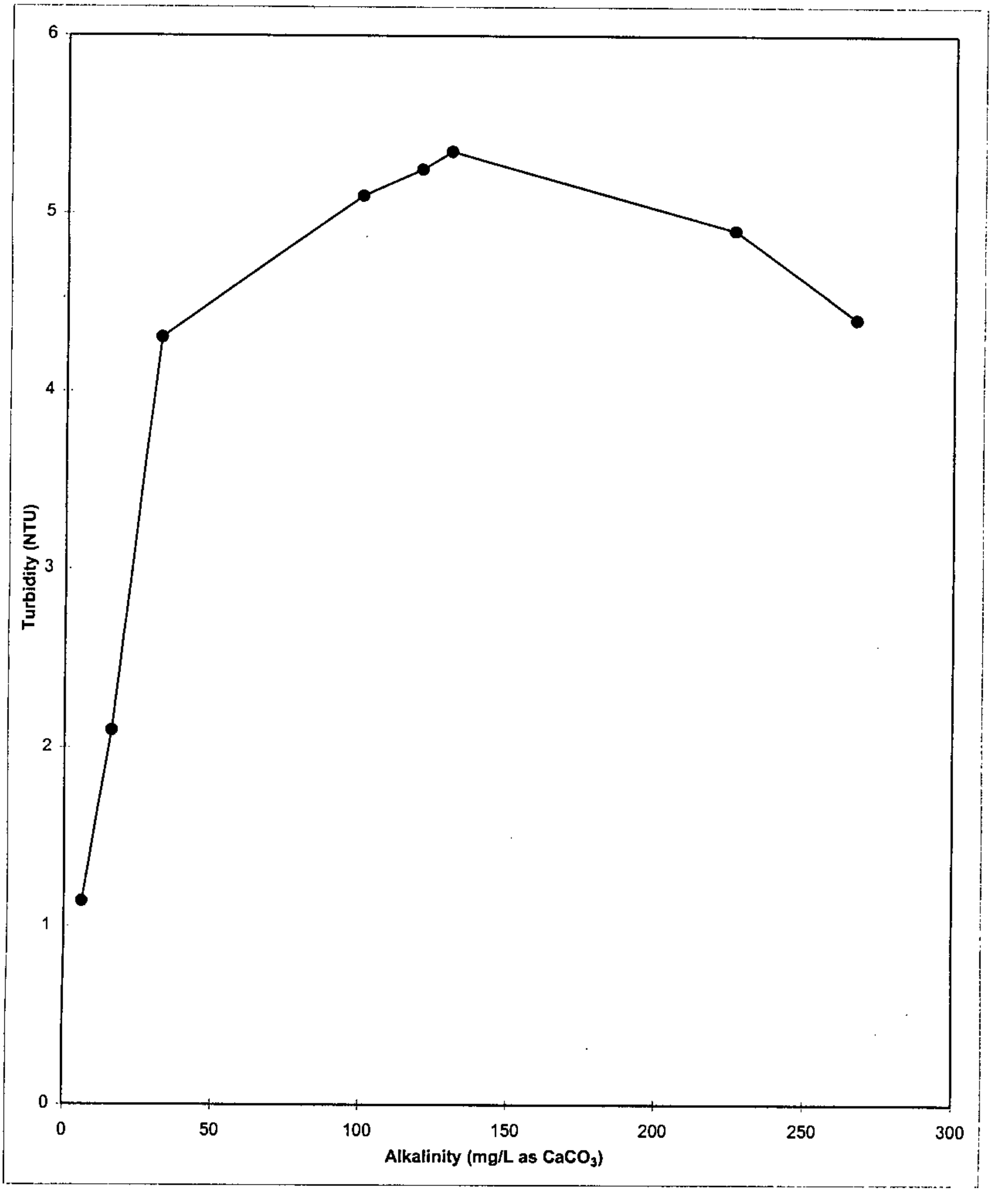

Figure:4.10 Variation of turbidity of artificial iron containing water sample (initial Fe concentration: 10mg/L) with alkalinity varied with Na_2CO_3

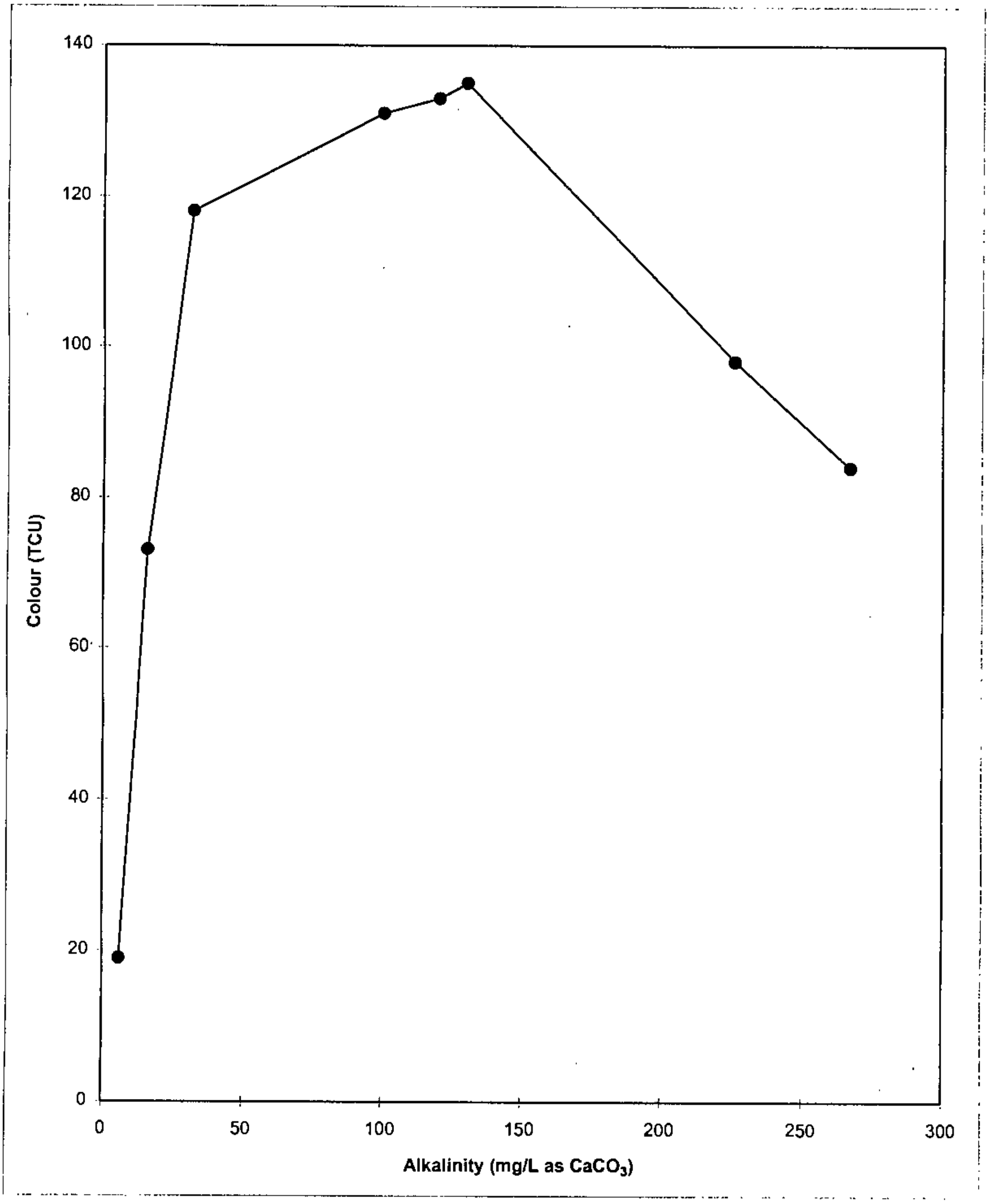

Figure:4.11 Variation of colour of artificial iron containing water sample (initial Fe concentration: 10 mg/L) with different alkalinity (varied with Na_2CO_3)

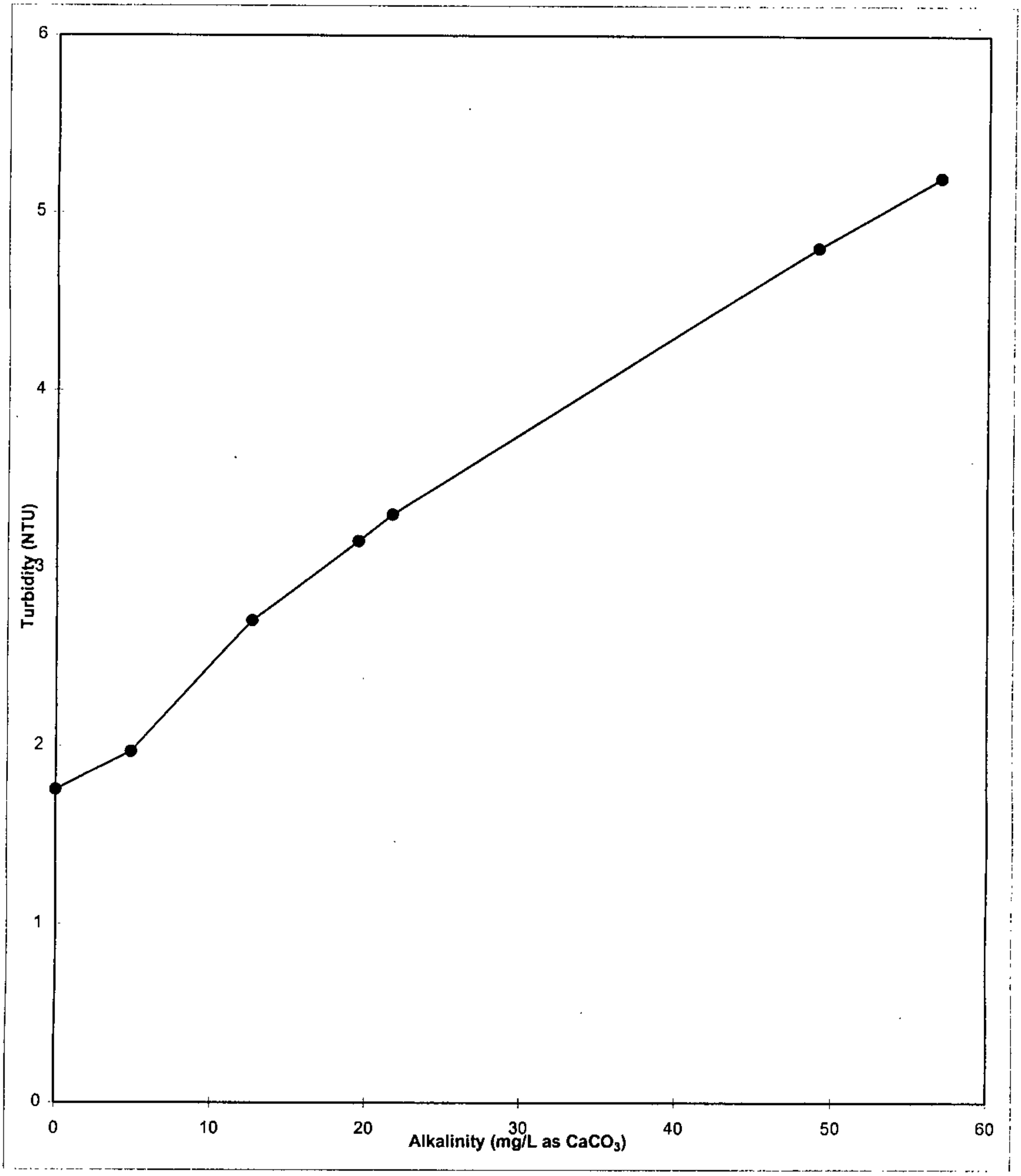

Figure:4.12 Variation of turbidity of artificial iron containing water sample (initial Fe concentration: 10 mg/L) with different alkalinity (varied using NaOH) increase in iron removal of only 6% and decrease in residual iron concentration from 1.8 mg/L to 0.8 mg/L is experienced. With an increase in alkalinity from 130 mg/L as $CaCO_3$ to 267 mg/L as $CaCO_3$, only 6.5% increase in iron removal is experienced. Residual iron concentration decreases from 0.8 mg/L to 0.7 mg/L. It is also clear that at pH value of 6.9 iron removal of 91% is observed when alkalinity value is 130 mg/L as $CaCO_3$. Whereas,at the same pH value of 6.9 iron removal of only 32.9% is experienced when alkalinity value is 35 mg/L as $CaCO_3$.

From literature review (Chapter 3 , Art: 3.2.2) it is clear that iron mainly precipitated out of solution due to the oxidation of soluble ferrous iron to ferric oxides and hydroxides. However, for complete oxidation of the ferrous iron, alkalinity of water should be in excess of 100 mg/L as $CaCO_3$. Whereas, if the concentration of alkalinity reaches 130 mg/L as $CaCO_3$ all of the ferrous iron oxidizes almost immediately. As such concentration of alkalinity in excess of 130 mg/L as $CaCO_3$ does not have significant effect on iron removal. However, due to the increase in pH value iron removal exhibit increasing trend.

Figure: 4.10 indicates that turbidity of the artificial iron containing water sample (initial Fe concentration: 10 mg/L) increases with an increase in concentration of alkalinity . However, after a certain value of alkalinity turbidity exhibit decreasing trend. With an increase in concentration of alkalinity from 6 to 130 mg/L as $CaCO_3$ turbidity increases from 1.14 to 5.35 NTU. Whereas, with an increase in concentration of alkalinity from 130 mg/L as $CaCO_3$ to 267 mg/L as $CaCO_3$ turbidity decreases from 5.35 to 4.4 NTU.

Figure: 4.11 indicates that colour of the artificial iron containing water sample (initial Fe concentration: 10 mg/L) increases with an increase in concentration of alkalinity. However, colour exhibit decreasing trend after a certain value of alkalinity. With an increase in concentration of alkalinity from 6 to 130 mg/L as $CaCO_3$ colour increases from 19.0 to 135.0 TCU i.e. 116 TCU increase in colour is observed. Whereas, with an increase in concentration of alkalinity from 130 mg/L as $CaCO_3$ to 267 mg/L as $CaCO_3$ colour decreases from 135 TCU to 84 TCU i.e. 51 TCU decrease in colour is observed.

Turbidity and colour in these cases were created due to the formation of insoluble ferric iron upon oxidation of soluble ferrous iron. With the increase in alkalinity oxidation of ferrous iron i.e. formation of ferric irons also increases. However, when concentration of alkalinity reaches 130 mg/L as $CaCO_3$ then oxidation of ferrous iron becomes complete. As such at this point turbidity and colour exhibit maximum value. At alkalinity values in excess of 130 mg/L as $CaCO_3$ due to the precipitation of some of the insoluble ferric irons, turbidity as well as colour shows decreasing trend.

From Figure: 4.12 it is clear that turbidity is increasing with an increase in concentration of alkalinity. In this case NaOH was used to increase alkalinity of the water samples. With an increase in concentration of alkalinity from 0 to 56.92 mg/L as $CaCO_3$, turbidity increases from 1.76 to 5.2 NTU. In fact this is mainly due to the formation of insoluble ferric iron which increases with an increase in alkalinity.

4.7 EFFECT OF COAGULANT DOSE ON IRON REMOVAL

In this section different doses of coagulant (alum) was added to artificial water sample having same initial iron concentration. Residual iron concentration was observed at different coagulant dose after coagulation and sedimentation.

4.7.1 Experimental Set- Up

The water sample used have initial iron concentration of 20 mg/L. 500ml of water sample was taken in each of the five jars. Alum was added as coagulant at different doses of 10, 17.5, 20, 40 and 60 mg/L in different jars and were then coagulated (as described in Art. 4.3.1). The stirred water samples were allowed to settle for 30min. A portion of the supernatant was drawn off from each of the five jars and transferred to tubes for the determination of iron concentration (as described in Art 4.3.2).

The difference of iron cencentration between original sample and coagulated one gives a measure of iron removal. The results are given in tabular form in Appendix -"B", Table: B_9 and residual iron concentration with coagulant dose is shown in Figure : 4.13.

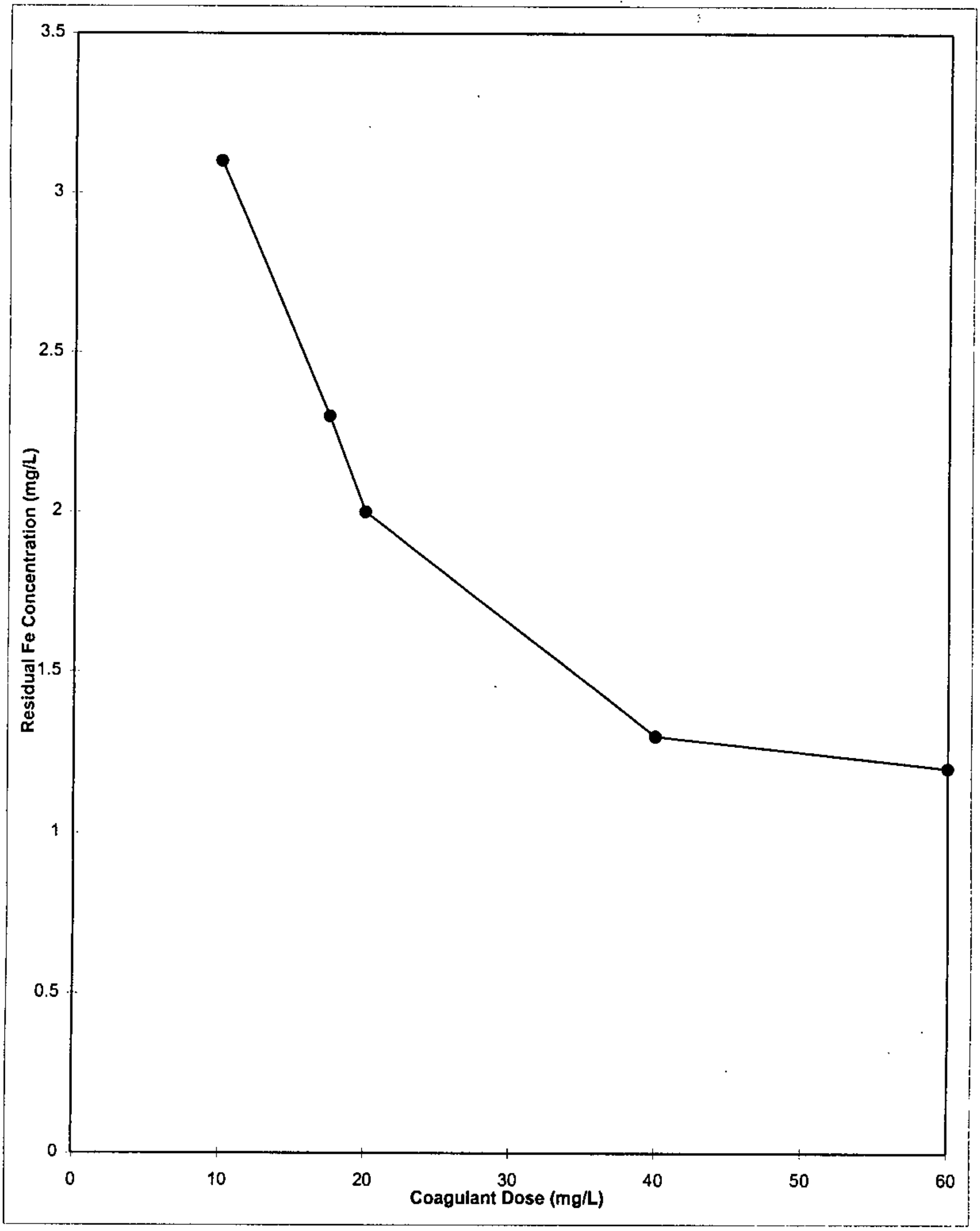

Figure:4.13 Residual iron concentration of artificial water sample (initial Fe concentration: 20 mg/L) with coagulant dose after coagulation using alum as coagulant and 30 min. sedimentation.

4.7.2 Results And Discussions

It is observed from Figure: 4.13 that residual iron concentration decreases with the increase in coagulant dose. In other words iron removal increases with the increase in coagulant dose. But the rate of increase in iron removal diminishes with increase in coagulant dose.

It is observed that with an increase in alum dose from 10 mg/L to 20 mg/L iron removal increases from 84.5% to 90%. Residual iron concentration varies from 3.1 mg/L to 2.0 mg/L. Similarly, as alum dose increases from 20 mg/L to 40 mg/L, iron removal increases from 90% to 93.5% (i.e. 3.5% increase in iron removal). Residual iron concentration varies from 2.0 mg/L to 1.3 mg/L. However, when alum dose increases from 40 mg/L to 60 mg/L iron removal increases from 93.5% to 94% only (i.e. 0.5% increase in iron removal). Residual iron concentration varies from 1.3 mg/L to 1.2 mg/L. Optimum coagulant dose in this case is 40 mg/L of alum with corresponding residual iron concentration of 1.3 mg/L.

Iron remain in water in soluble ferrous form which upon oxidation become insoluble ferric iron. However, these precipitated iron particles are very small in size. After coagulation these particles flocculate and increase in size and settling velocity; thereby increases removal by sedimentation.

At a coagulant dose of 60 mg/L iron removal of 94% with corresponding residual iron concentration of 1.2 mg/L is observed when alum is used as coagulant. However, at the same coagulant dose of 60 mg/L iron removal of 70% with corresponding residual iron concentration of 6.0 mg/L is experienced when lime is used as coagulant. So, alum used as coagulant is more effective than lime in iron removal.

4.8 EFFECT OF Cl^- AND SO_4^{-2} ION CONCENTRATION IN REMOVAL OF IRON

In this section different amount of anion was added to artificial water sample having same initial iron concentration to observe its effect on iron removal . Residual iron concentration was observed in each case.

4.8.1 Experimental Set-Up

The water sample used have initial iron concentration of 20 mg/L . Stock solution of Na_2SO_4 was prepared by dissolving 1.47916 gm of Na_2SO_4 in 1000 ml of distilled water . The strength of the stock solution comes to 1 mg of SO_4^{-2} / ml . Then 0 , 12.5 , 25, 50, 100 and 250 ml of the stock solution were added to the artificial iron content water sample to have 500ml samples containing added SO_4^{-2} ion concentration of 0, 25 , 50, 100, 200 and 500 mg/ L respectively.

Stock solution of NaCl was prepared by dissolving 1.649 gm of NaCl in 1000 ml of distilled water . The strength of the stock solution comes to 1 mg of Cl^{-1} / ml . Then 0 , 12.5 , 25, 50, 100 and 250 ml of the stock solution were added to artificial iron content water sample to have 500ml samples containing added anion (Cl^{-1} ion) concentration of 0, 25 , 50, 100, 200 and 500 mg / L respectively .

All the samples thus prepared having initial iron concentration 20 mg/L but different added anion concentration were coagulated (as described in Art. 4.3.1) using fixed amount of lime (176 mg/L) as coagulant and pH of the samples were maintained at 7.4. The stirred samples were allowed to settle for 15 min and a portion of the supernatant was drawn off and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2).

The results obtained are presented in tabular form in Appendix-"B" , Table:B_{10} and the residual iron concentration of water samples with different added anion concentration are shown in Figure:4.14.

4.8.2 Results And Discussions

It is found from Figure:4.14 that anion concentration effects the iron removal i.e. residual iron concentration decreases with increase in anion concentration. But for the same water sample SO_4^{-2} ion has more pronounced effect than Cl^- ion.

Iron removal from artificial water sample with initial Fe concentration 20 mg/L after coagulation and 15 min sedimentation is 82.5% leading to residual Fe concentration of 3.5mg/L. But when anion (SO_4^{-2} and Cl^-) is added then iron removal increases . Iron removal increases from 82.5% to 91.25% when SO_4^{-2} is added as anion at a dose of 500 mg/L. However, iron removal increases from 82.5% to 86.5% when Cl^- is added as anion at same dose. Residual iron concentration decreases to 1.75 mg/L and 2.7 mg/L after addition of 500 mg/L of SO_4^{-2} and Cl^- respectively.

This can be explained by common ion effect which is an example of Le Châtelier's principle (as described in Chapter:3, Literature Review section).

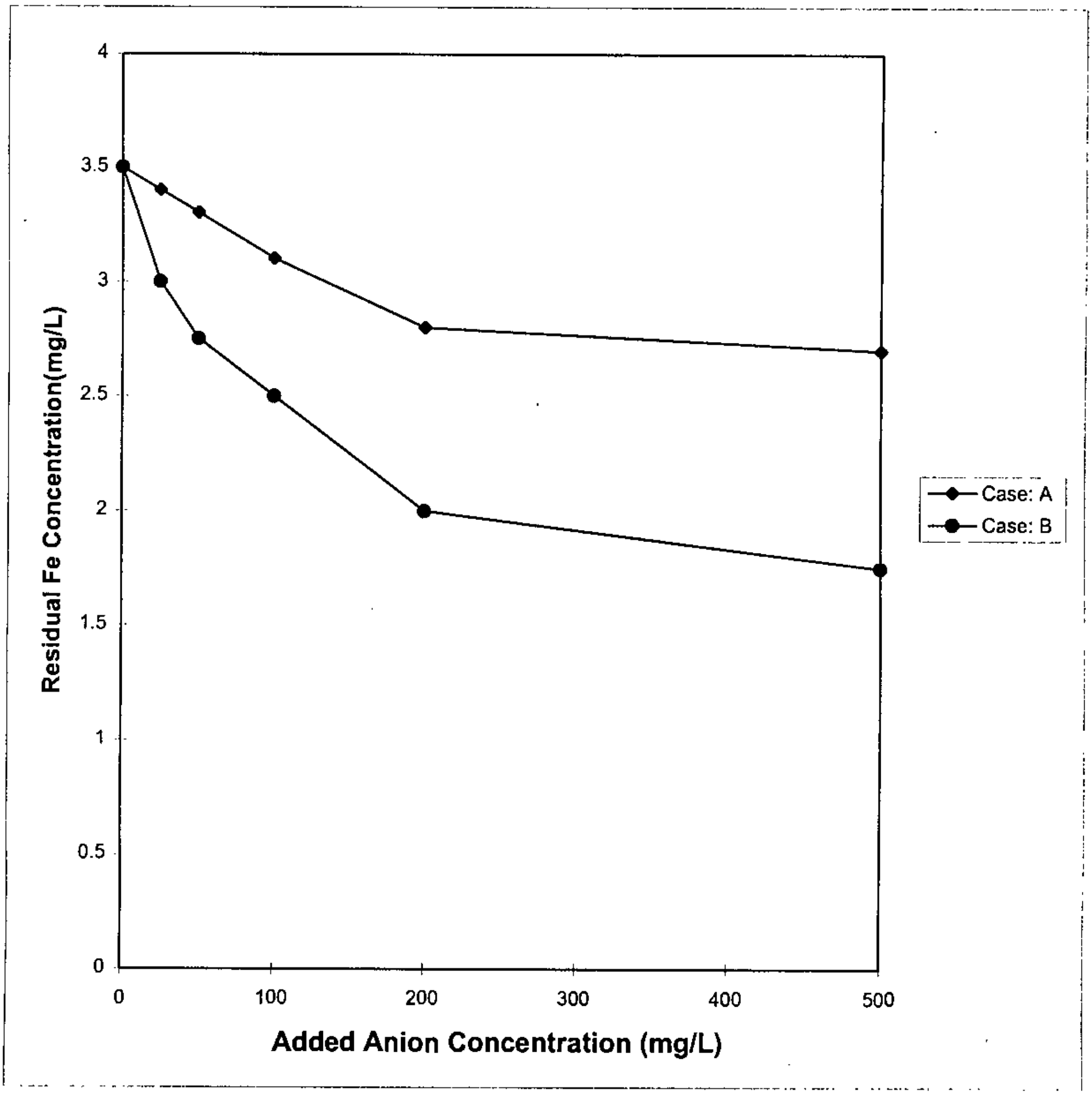

Figure:4.14 Residual Fe concentration of artificial water sample containing 20 mg/L initial iron concentration after coagulation with lime (176 mg/L) and 15 min. sedimentation at pH 7.4 with different added anion concentration (i) Case: A ; Cl^- (ii) Case: B; SO_4^{-2}.

The common ion effect express that an ion of a sparingly soluble salt can be precipitated by increasing the concentration of the second ion to the point where the ion product exceeds the value of the solubility product constant, K_{sp} which is an indication of the solubility of that compound. It is in line with the fact that if stress is applied to a system in equillibrium, the system will act to relieve the stress and restore equillibrium. Artificial iron content water was prepared by using stock solution of ferrous sulfate ($FeSO_4$) i.e. Fe^{+2} and SO_4^{-2} ions were present in the sample water. This solution has a specific solubility product constant , K_{sp} , which is equal to the product of ion concentration. When SO_4^{-2} was added as anion to the water sample then it contributes to increase the concentration of SO_4^{-2} ion in the solution . As a result in the sample water the ion product exceeds the value of the solubility product constant , K_{sp}. As per common ion effect as described in Art. 3.3.2.4, to restore equilibrium condition in the water sample , iron precipitate will come out of the solution. As the amount of added SO_4^{-2} ion concentration increases , the precipitation of iron also increases leading to a decrease in residual iron concentration. But when Cl^- ion added to the artificial water sample, containing anion SO_4^{-2} then it can not effect the solubility product constant.

Further attention is needed to find out a correlation between the addition of anion and corresponding decrease in residual iron concentration.

4.9 SUMMARY OF FINDINGS

The study results obtained can be summarised as follows :

- Iron removal increases with an increase in pH value. But after a certain value of pH iron removal exhibit a decreasing trend. This pH value is observed to be 9.3 when lime is used as coagulant and 9.6 when sodium hydroxide is used as coagulant for water having initial Fe concentration 20 mg/L.

- Lime as coagulant is more effective than sodium hydroxide in iron removal. Within a pH range 7-8 iron removal of 82.15% is experienced after coagulation with lime and 15 min. sedimentation. Whereas , within the same pH range iron removal of only 51.65% observed when sodium hydroxide is used as coagulant .

- Iron removal increases with an increase in sedimentation time. But the rate of increase of iron removal diminishes with the increase of settling time. However, about 90% iron removal is experienced after coagulation with lime and 1 hr. settling.

- Optimum sedimentation time for artificial water sample having initial iron concentration of 20 mg/L, 15 mg/L and 10 mg/L are 240 min, 240 min and 120 min respectively.

- Sedimentation time required to attain allowable limit of 1mg/L of residual Fe concentration for the three artificial water samples having initial iron concentration of 20, 15 and 10 mg/L are 240 min., 110 min. and 10 min. respectively after coagulation with lime at pH 7.4.

- After coagulation with NaOH residual iron concentration decreases with the increase in sedimentation time at different pH. However , allowable limit of 1 mg/L is attained after settling time of 50 min and 10 min at pH 8.3 and 9.6 respectively for water sample having initial Fe concentration of 20 mg/L.

- Iron removal increases with an increase in OH^- ion (NaOH) concentration upto a certain limit after which iron removal again shows a decreasing trend. This value of OH^- ion concentration is observed to be 25.5 mg/L that corresponds to a pH value of 9.6 for artificial iron content water with initial Fe concentration 20 mg/L.

- Iron removal increases with an increase in alum dose after coagulation and sedimentation. However, rate of increase of iron removal diminishes with increase in alum dose.

- Iron removal increases with an increase in alkalinity. However, above an alkalinity value of 130 mg/L as $CaCO_3$ rate of increase of iron removal with increase in alkalinity is very much insignificant. Oxidation of iron becomes complete as alkalinity reaches 130 mg/L as $CaCO_3$ and all of the ferrous iron oxidizes almost immediately to produce insoluble ferric iron. As such alkalinity above 130 mg/L as $CaCO_3$ does not effect iron removal.

- Turbidity and colour of artificial iron containing water sample increases with an increase in alkalinity. However, after a certain value of alkalinity both turbidity and colour exhibit decreasing trend. This alkalinity value was found to be 130 mg/L as $CaCO_3$.
- Residual iron concentration decreases with an increase in anion concentration . SO_4^{-2} ion has more pronounced effect than Cl^- ion due to the common ion effect.

CHAPTER 5

STUDY ON IRON CONTAINING NATURAL GROUND WATER

5.1 INTRODUCTION

In many parts of Bangladesh ground water contain iron to objectionable limit. It contributes to non-usage of tubewell water in iron problem areas. Different techniques have been tried for iron removal in different time.

In this chapter ground water was collected from iron problem areas. Effect of different unit processes and other factors on iron removal were studied in the laboratory.

5.2 SAMPLING

5.2.1 General

A sample is a part taken from a large quantity and is representative of the whole amount . The samples must be collected , packed , shipped and manipulated prior to analysis in a manner that safeguards against change in the particular constituents or properties to be examined.

5.2.2 Location , Collection And Quality Of Water

Location of sampling is that point from where a sample is collected to represent the characteristics of the whole amount . For this study samples were collected from shallow tube wells of fifteen places of Manikgonj district.

Table:5.1 Characteristics of natural ground water collected from Manikgonj district

Sample No	Tubewell location & identification	pH	CO_2	Alkalinity as $CaCO_3$	Chlorine Cl	Iron	PO_4	NO_3	SO_4	Hardness as $CaCO_3$
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	STW water Bachelor Mess , Joyra	6.9	96	310	21	24	0.155	0.1	44.16	194
2	Mr Mazid, Natun Basti	6.8	77	283	29	13.5	0.154	0.2	43.2	218
3	Mr Sirajul Islam, Natun Basti	6.7	59	291	24	13	0.332	0.4	19.2	220
4	Siddique Khan Market, Manikgonj Bus stand	6.6	75	417	46	25.5	0.08	0.1	13.44	288
5	Mr. Momin Chowdhury, Ulukundi	6.7	32	304	19	15.5	0.113	0.1	41.28	194
6	Mr. Krishna Dev , Dhighi	6.5	64	329	29	26	0.269	0.2	36.48	564
7	Mr. Minhazuddin , Dhighi	6.5	66	274	31	13.5	0.253	0.2	62.4	226
8	Mr. Komolesh Saha ,Chand nagar	6.6	42	264	22	35	0.225	0.3	39.36	216
9	Chand Nagar Market	6.5	90	315	17	30	0.18	0.3	29.76	224
10	Mr. Izuddin , Ghar para	6.5	37	315	22	13	0.125	0.2	33.6	244
11	Udaysena Club , Sheota	6.4	50	340	55	35	0.115	0.3	32.64	344
12	Mr.Milon, Bandutia	6.3	145	449	31	20	0.116	0.4	14.4	264
13	Mr.Hafizuddin , Pouli	6.3	103	428	20	14	0.118	0.3	19.2	236
14	Mr. Javed Ali , Pouli	6.4	63	215	21	16	0.108	0.6	21.12	230
15	Ukuria Bazar	6.5	35	246	19	14	0.162	0.5	21.12	174

Samples were collected into 1 litre polyethylene containers with caps . The collected samples were transported to the laboratory with minimum time lag between collection and analysis , so that no significant change occurred in the quality of the sample and kept at room temperature.

After each collection , the quality of water samples were determined. Some of the water quality data are summarised in Table:5.1.

Out of total 15 water samples four samples were selected for detailed study considering iron concentration , pH, alkalinity, CO_2 content etc. Selected samples with characteristic quality are presented in Table:5.2.

Table: 5.2 Characteristics quality of selected natural ground water samples

Sample No (ID)	Tubewell location & identification	pH	CO_2	Alkalinity as $CaCO_3$	Chlorine Cl	Iron	PO_4	NO_3	SO_4	Hardness as $CaCO_3$
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1 (A)	STW water , Bachelor Mess, Joyra , Manikgonj.	6.9	96	310	21	24	0.155	0.1	44.16	194
7 (B)	Mr. Minhazuddin , Dhighi , Manikgonj.	6.5	66	274	31	13.5	0.253	0.2	62.4	226
12 (C)	Mr.Milon, Bandutia, Manikgonj .	6.3	145	449	31	20	0.116	0.4	14.4	264
14 (D)	Mr. Javed Ali, Pouli, Manikgonj.	6.4	63	215	21	16	0.108	0.6	21.12	230

5.3 VARIATION OF IRON REMOVAL WITH SEDIMENTATION TIME

In this section four selected natural ground water samples were used. Residual iron concentration of the samples was determined at different sedimentation time after aeration with and without filtration.

5.3.1 Experimental Set-Up

The four natural ground water samples of ID no A, B, C and D have initial iron concentration 24, 13.5 , 20 and 16 mg/L respectively. The samples were aerated and then allowed to settle. A portion of the supernatant was drawn off after different sedimentation time interval of 0 ,30, 60 and 120 minute and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2). Samples remaining in the jars after 2 hr sedimentation were filtered and a portion of the filtered sample was then drawn off and transferred to the tubes again for the determination of iron concentration (as described in Art. 4.3.2)

The results are presented in tabular form in Appendix- "C" , Table: C_1 and residual iron concentration in four different natural ground water samples at different sedimentation time after aeration is presented in Figure:5.1. Residual iron concentration after aeration, 2 hr sedimentation and filtration is presented in Table: 5.3.

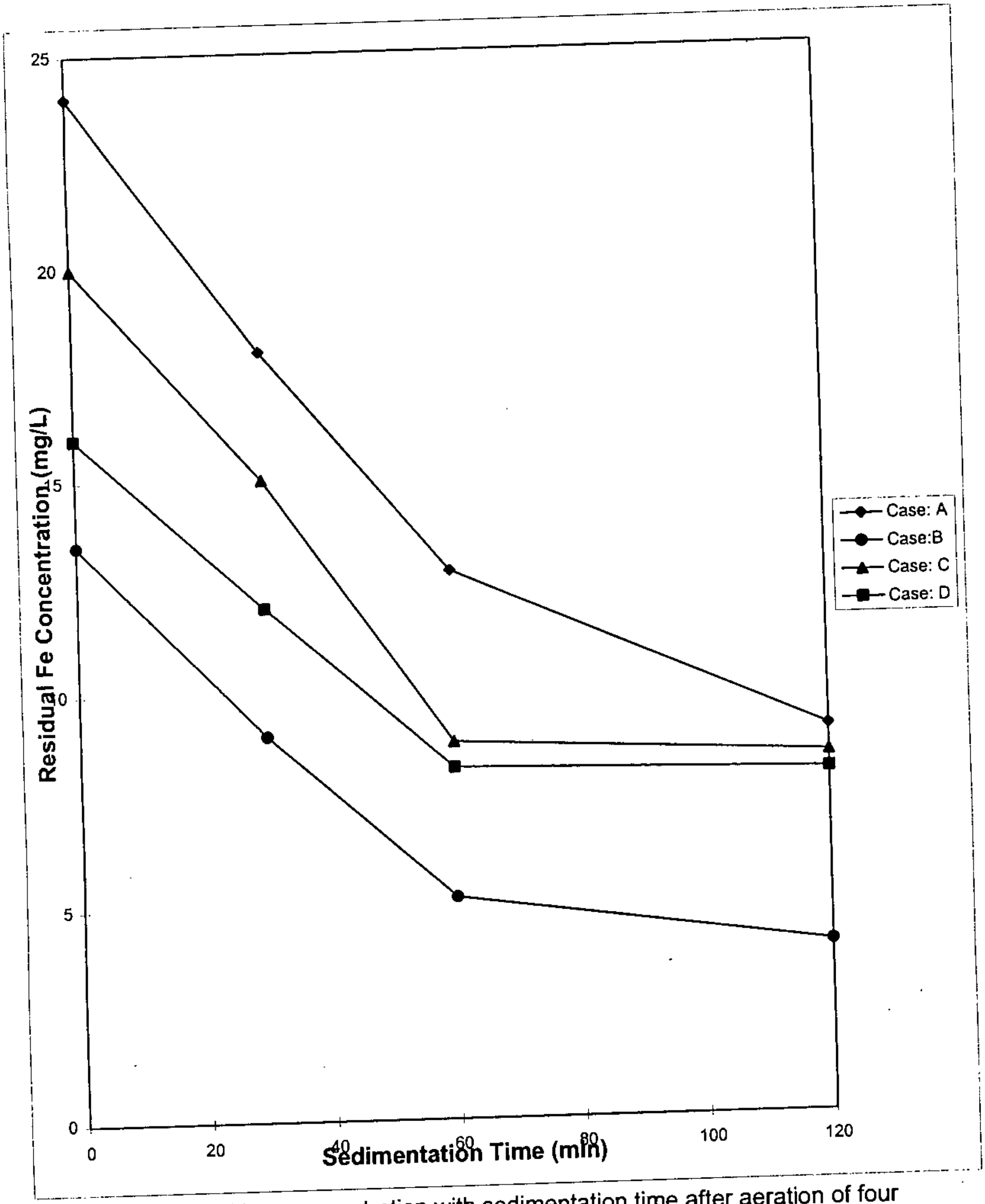

Figure:5.1 Residual iron concentration with sedimentation time after aeration of four natural ground water samples (i) Case A: Sample with ID no A, (ii) Case B: Sample with ID no B, (iii) Case C: Sample ID no C and (iv) Case D: Sample with ID no D

5.3.2 Results And Discussions

It is observed from Figure : 5.1 that for all natural ground water samples with different quality, removal of iron increases with the increase of sedimentation time. In other words residual iron concentration decreases with the increase in sedimentation time. But the rate of increase of iron removal diminishes with the increase in sedimentation time. With an increase in sedimentation time from 0 to 60 min iron removal of samples with ID no : A, B, C and D increases by 46.66% , 61.48%, 56.00% and 48.75% respectively. While with an increase in sedimentation time from 60 to 120 min iron removal from the above mentioned samples increases by only 15.84%, 8.89%, 2.00% and 1.25% respectively. Allowing 2 hr. settling after aeration , residual Fe concentration of 9 mg/L, 4 mg/L, 8.4 mg/L and 8 mg/L is obtained for water samples with ID no: A, B, C and D respectively.

It is clear from literature review that on aeration soluble ferrous iron oxidizes to insoluble ferric iron. The insoluble precipitates gradually settle leading to a decrease in iron concentration. As more time is allowed in the sedimentation basin then smaller precipitates will also settle leading to further decrease in residual iron in the supernatant liquid. However, the submicron size range of the precipitates limit effective removal by sedimentation.

It is observed from Figure: 5.1 that after only aeration and 2 hr. sedimentation iron removal of sample with ID no : A, B, C and D are 62.5% , 70.37%, 58% and 50 % respectively . Residual Fe concentration varies from 4.00 to 9.00 mg/L . However , Table 5.3 presented iron removal status of the four selected samples (as described in Table: 5.2) after aeration and 2 hr sedimentation and filtration. It indicates that in all the cases iron removal is more than 99 percent. Residual iron concentration varies from 0.02 to 0.03 mg/L i.e. filtration can reduce iron concentration much below the allowable limit. However, clogging and cleaning difficulties of filtration needs further attention.

Table :5.3 Fe removal from four selected natural ground water samples after aeration , 2 hr. sedimentation and filtration.

Sample ID no	Initial Fe concentration	Residual Fe concentration	Fe removal
	(mg/ L)	(mg/L)	(%)
A	24.00	0.02	99.92
B	13.50	0.03	99.78
C	20.00	0.03	99.85
D	16.00	0.03	99.81

Figure 5.2 represents percent iron removal with alkalinity after aeration and 30, 60 , 120 minute sedimentation of different natural ground water samples. It is observed that iron removal of the natural water samples are independent of the alkalinity when concentration of alkalinity is above 130 mg/L as $CaCO_3$. This is in line with the fact (as explained in Literature Review) that when concentration of alkalinity reaches 130 mg/L as $CaCO_3$ then oxidation becomes complete and all of the ferrous iron oxidizes almost immediately to

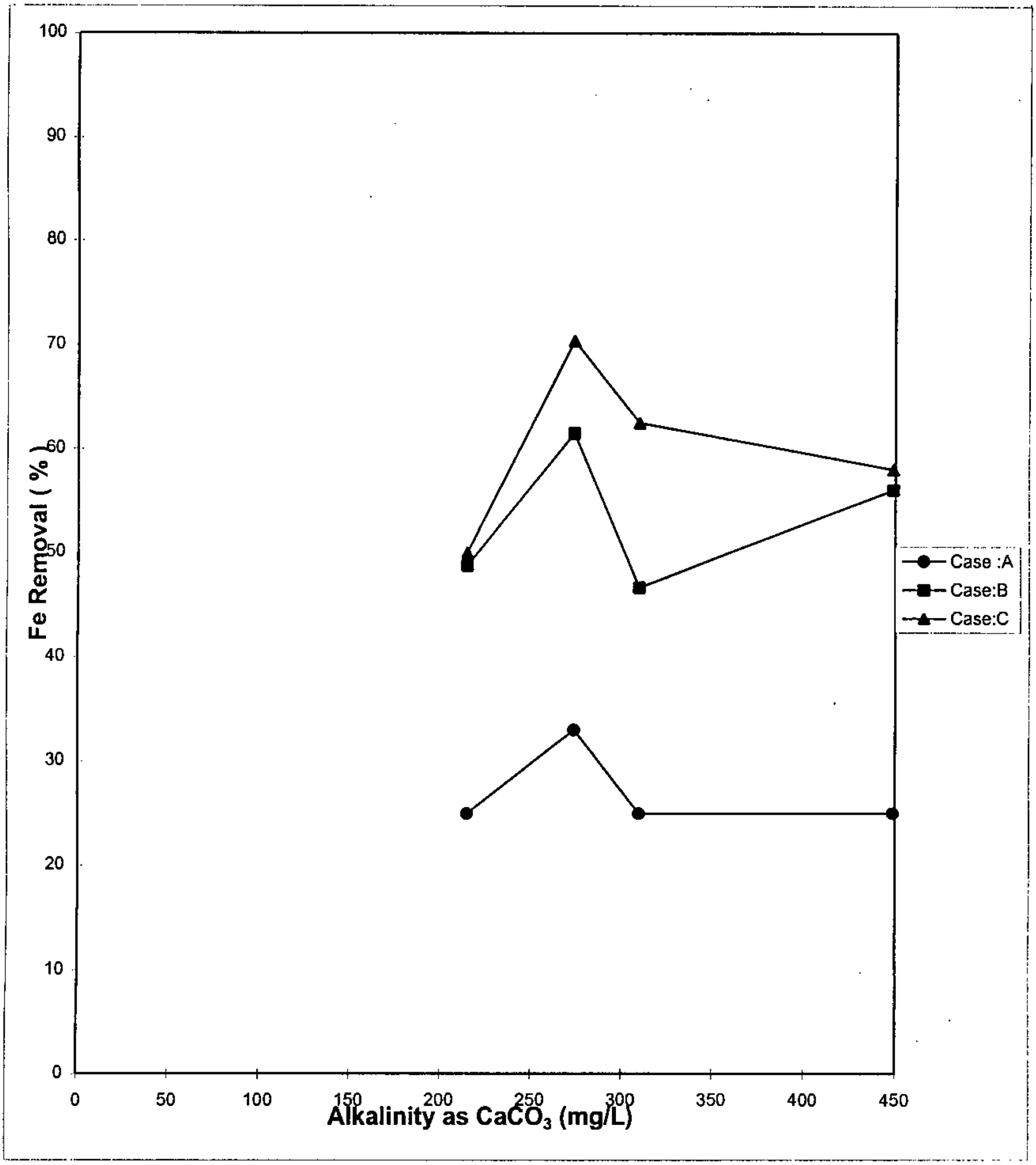

Figure:5.2 Influence of alkalinity on removal of iron from different natural ground water samples after aeration and (i) Case A : 30 min. sedimentation , (ii) Case B : 60 min. sedimentation (iii) Case C: 120 min. sedimentation.

produce insoluble ferric iron. So that alkalinity above 130 mg/L does not effect iron removal.

5.4 EFFECT OF COAGULATION AND FILTRATION ON IRON REMOVAL

In this section all the four natural ground water samples were used but each sample at a time. For coagulation lime and alum were used as coagulant at different doses. Residual iron concentration of all the samples were measured with filtration and without filtration.

5.4.1 Experimental Set-Up

The four natural ground water samples i.e. samples with ID no: A, B, C and D (as described in Table:5.2) were aerated at first. Then 500 ml. of sample with ID no: A was taken in each of four different jars. Lime was added as coagulant at different doses of 60, 100, 150 and 200 mg/L in different jars and were then coagulated (as described in Art. 4.3.1). The stirred water samples were allowed to settle for 30 min. A portion of the supernatant was drawn off from all the four jars and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2). Samples remaining in the jars after sedimentation were filtered and a portion of the filtered sample was then drawn off and transferred to the tubes again for determination of iron concentration (as described in Art. 4.3.2).

Again 500ml. of sample with ID no: A was taken in each of the six jars and alum was added to all the six jars as coagulant at different doses of 10, 17.5, 20, 40 , 60 and 100 mg/L. The water samples were then coagulated (as described in Art. 4.3.1) and the stirred water samples were then allowed to settle for 30 min. A portion of the supernatant was drawn off from all the six jars and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2). Samples remaining in the jars after sedimentation were filtered and a portion of the filtered sample was then drawn off and transferred to the tubes again for determination of iron concentration (as described in Art. 4.3.2).

This whole process as mentioned above was repeated for all the rest three water samples i.e. samples with ID no: B, C and D.

The difference of iron concentration between original samples and coagulated one gives a measure of iron removal. The difference of iron concentration between original samples and filtered one is a measure of filter performance. The results are given in tabular form in Appendix-"C" , Table: C_2, C_3, C_4, C_5 and residual iron concentration with coagulant dose with and without filtration for all the four samples are shown in Figure: 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9 and 5.10.

5.4.2 Results And Discussions

It is clear from Figure: 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9 and 5.10 that residual iron concentration decreases with the increase in coagulant dose. In other words iron removal increases with the increase in coagulant dose. In all the cases if filtration is performed after aeration, coagulation and sedimentation then iron removal increases to much more higher level.

It is also clear that in all the cases after aeration, coagulation and 30 min sedimentation rate of increase of iron removal with coagulant

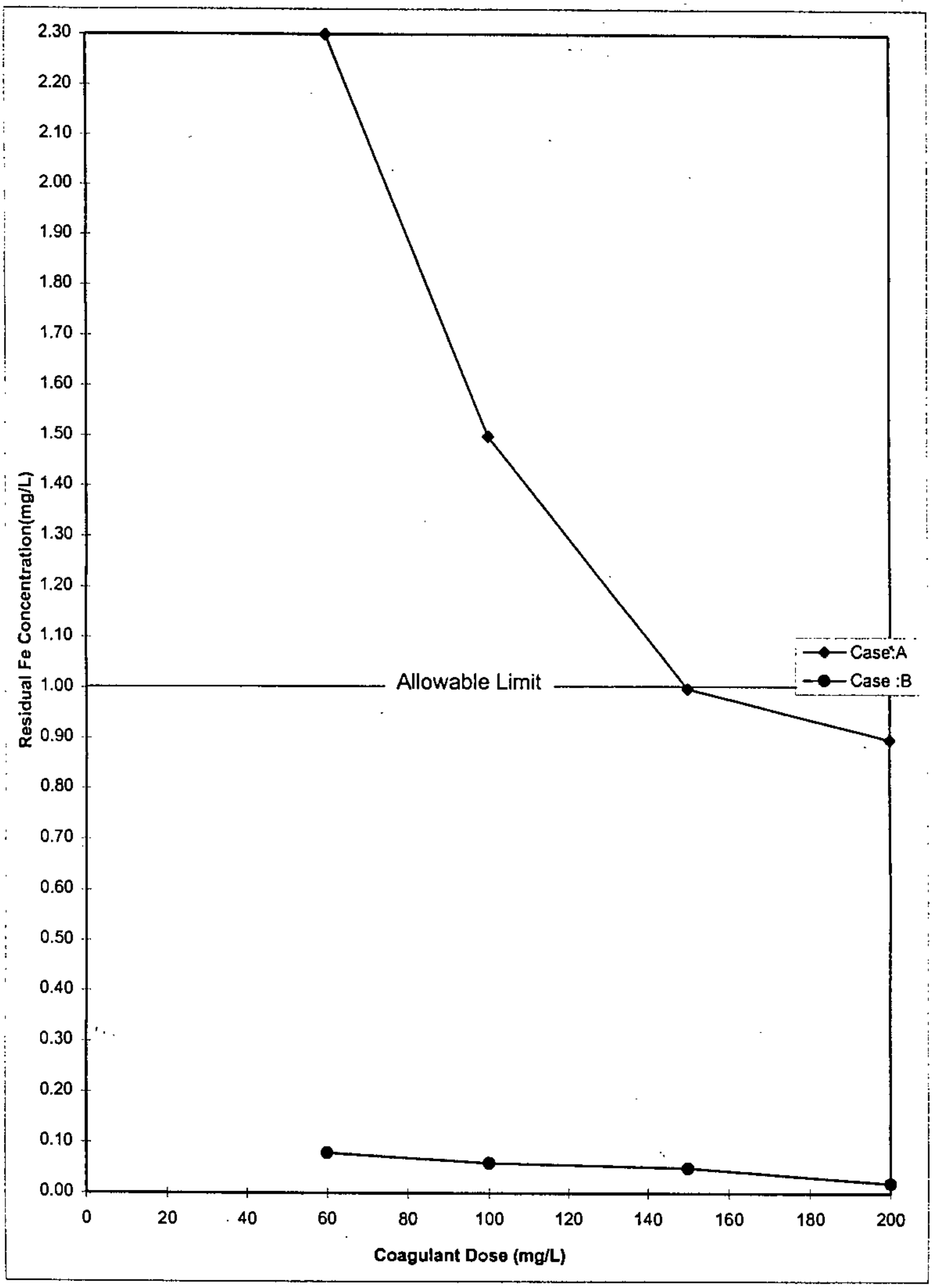

Figure: 5.3 Residual iron concentration of natural ground water sample (sample with ID no:A) with coagulant dose after aeration ,coagulation using lime as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration .

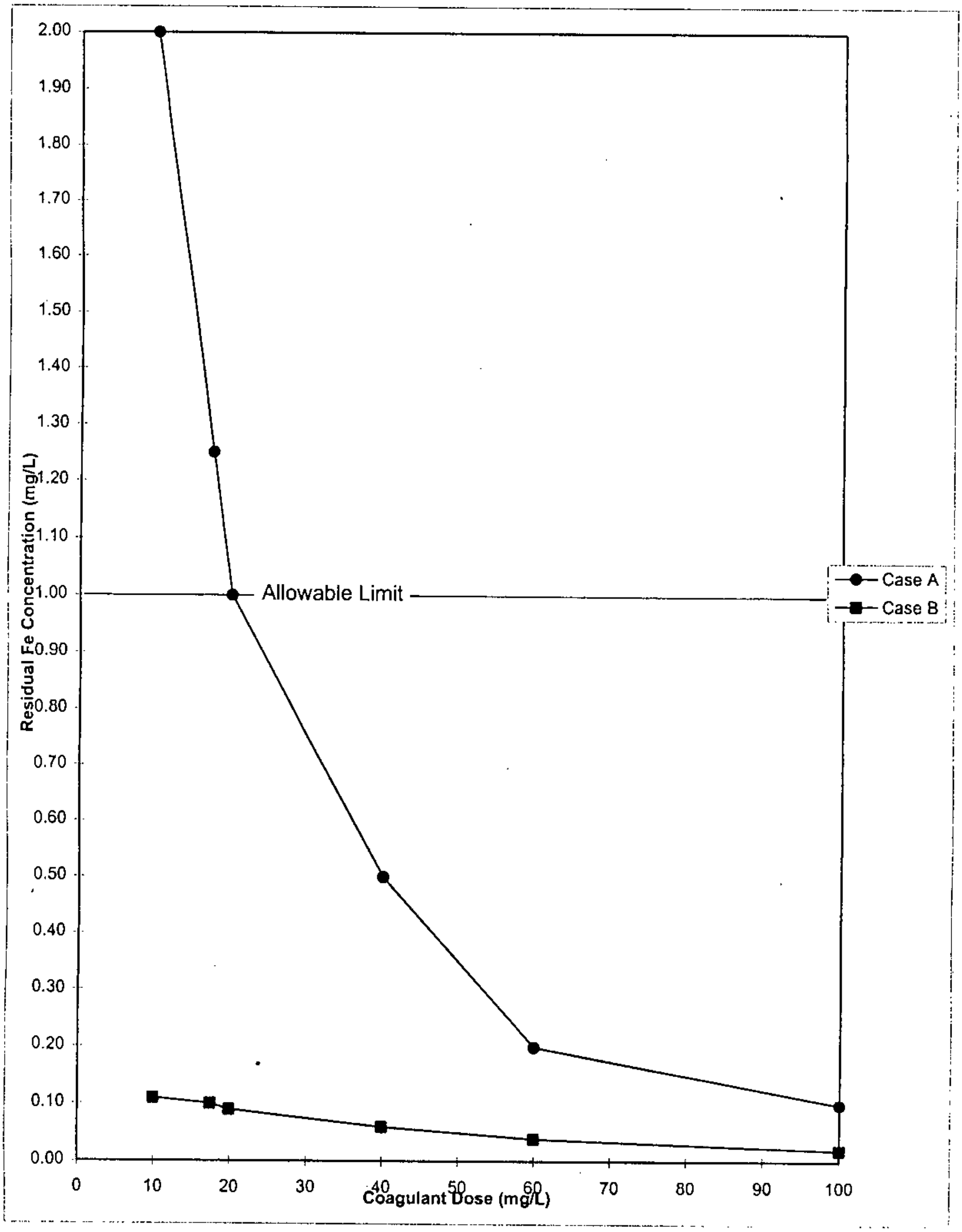

Figure: 5.4 Residual iron concentration of natural ground water sample (sample with ID no: A) with coagulant dose after aeration ,coagulation using alum as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration

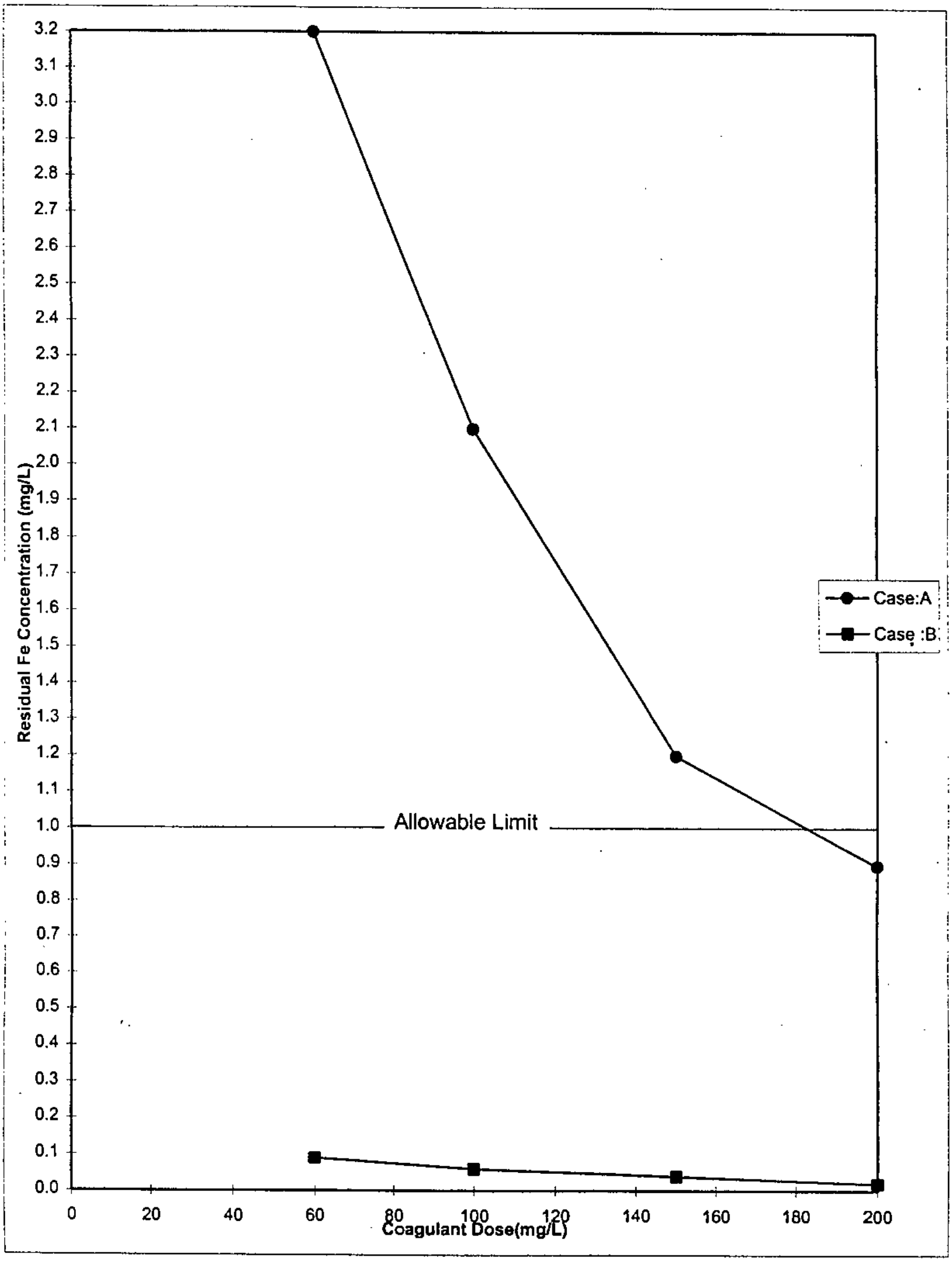

Figure: 5.5 Residual iron concentration of natural ground water sample (sample with ID no: B) with coagulant dose after aeration ,coagulation using lime as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration

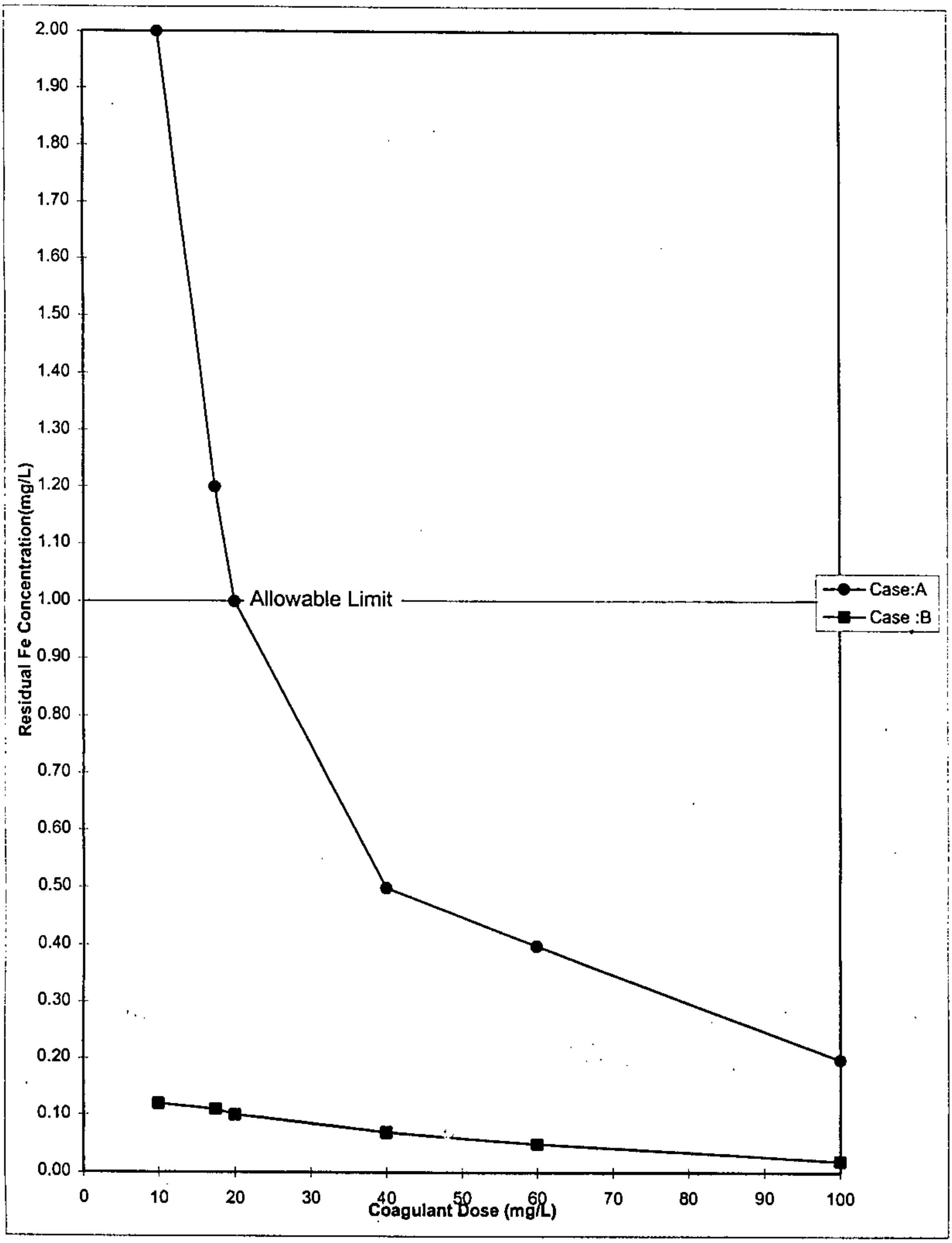

Figure: 5.6 Residual iron concentration of natural ground water sample (sample with ID no:B) with coagulant dose after aeration ,coagulation using alum as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration

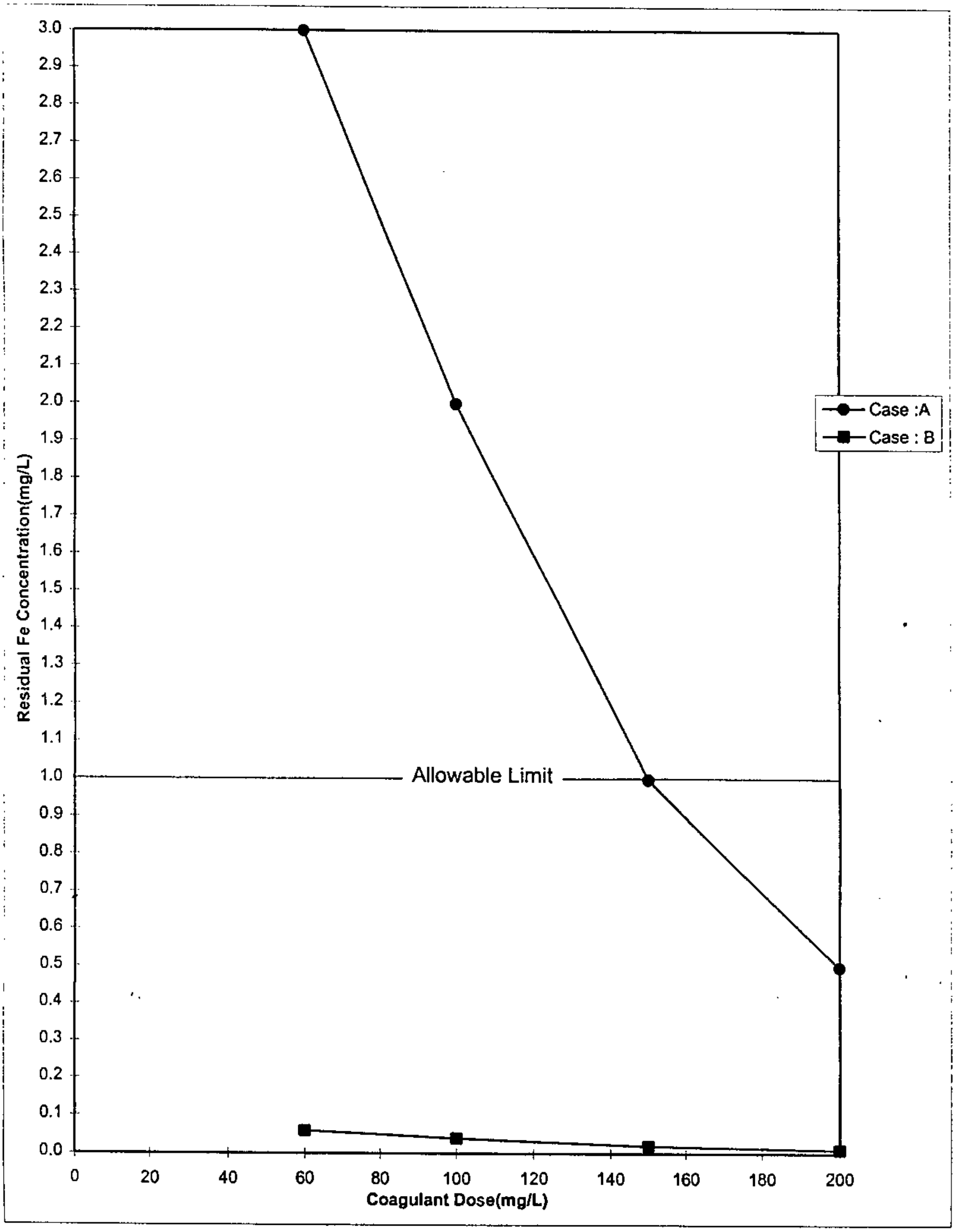

Figure: 5.7 Residual iron concentration of natural ground water sample (sample with ID no: C) with coagulant dose after aeration ,coagulation using lime as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration

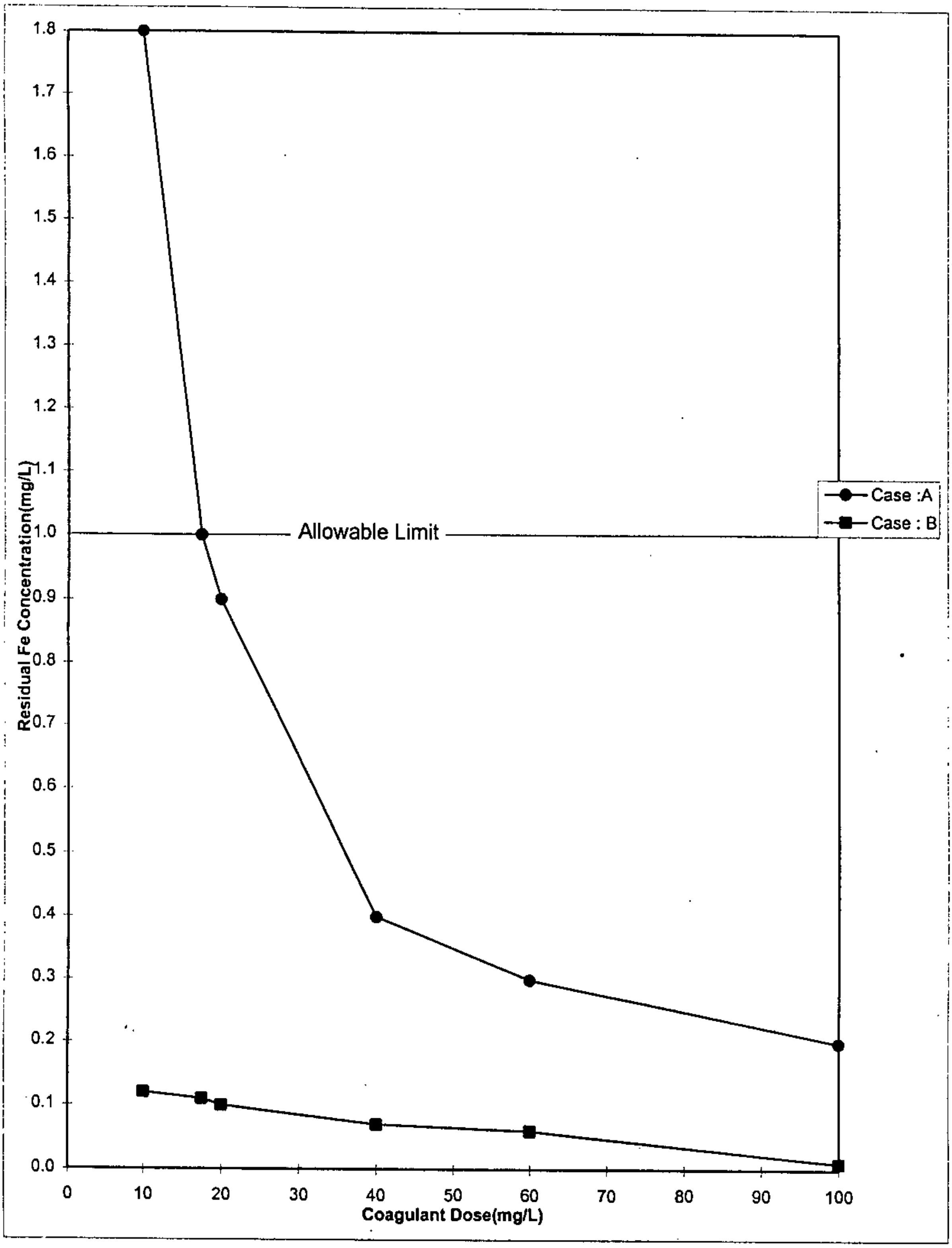

Figure: 5.8 Residual iron concentration of natural ground water sample (sample with ID no: C) with coagulant dose after aeration ,coagulation using alum as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration

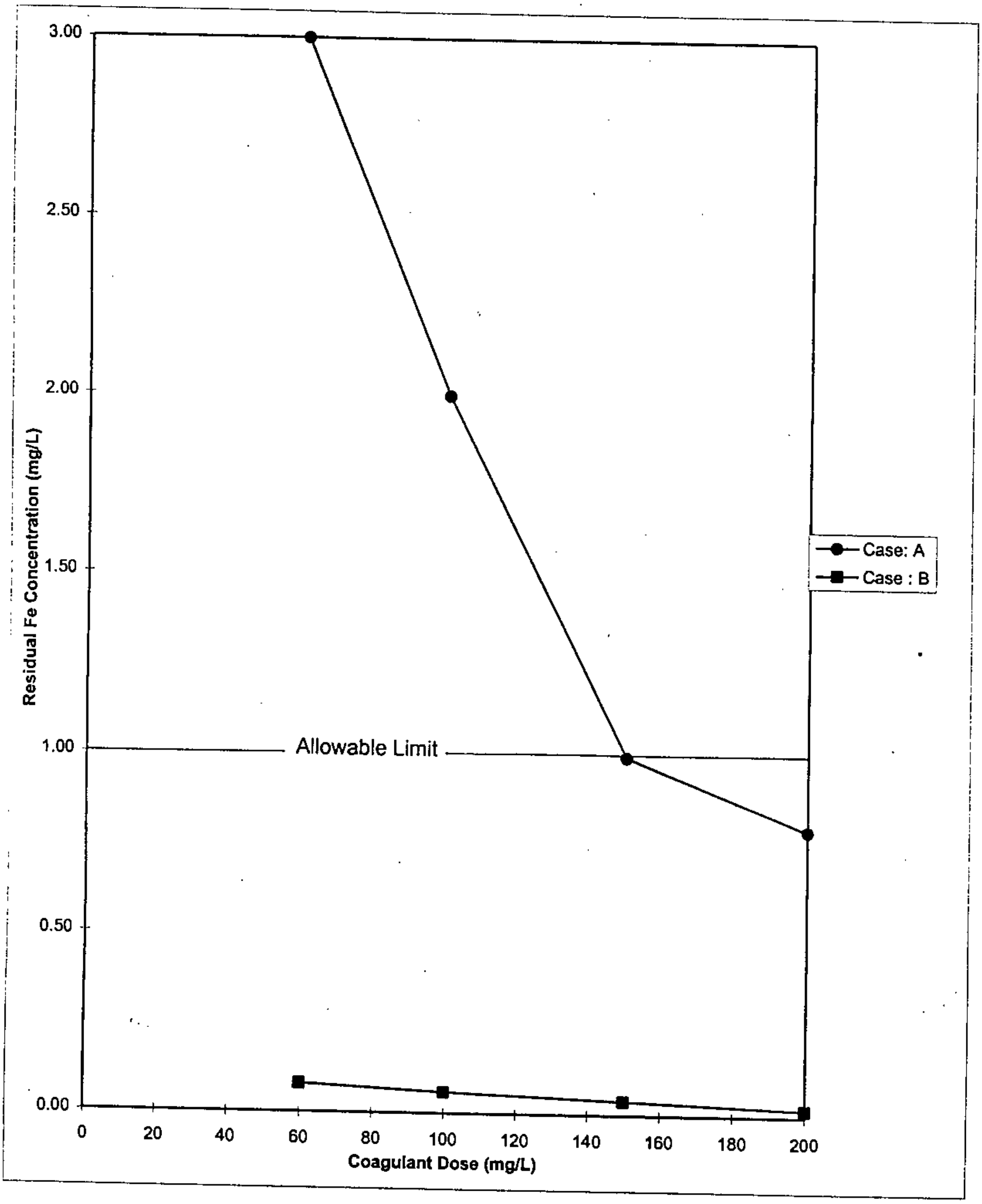

Figure: 5.9 Residual iron concentration of natural ground water sample (sample with ID no : D) with coagulant dose after aeration ,coagulation using lime as coagulant , 30 min. sedimentation and (I) Case A: Without filtration (ii) Case B: With filtration

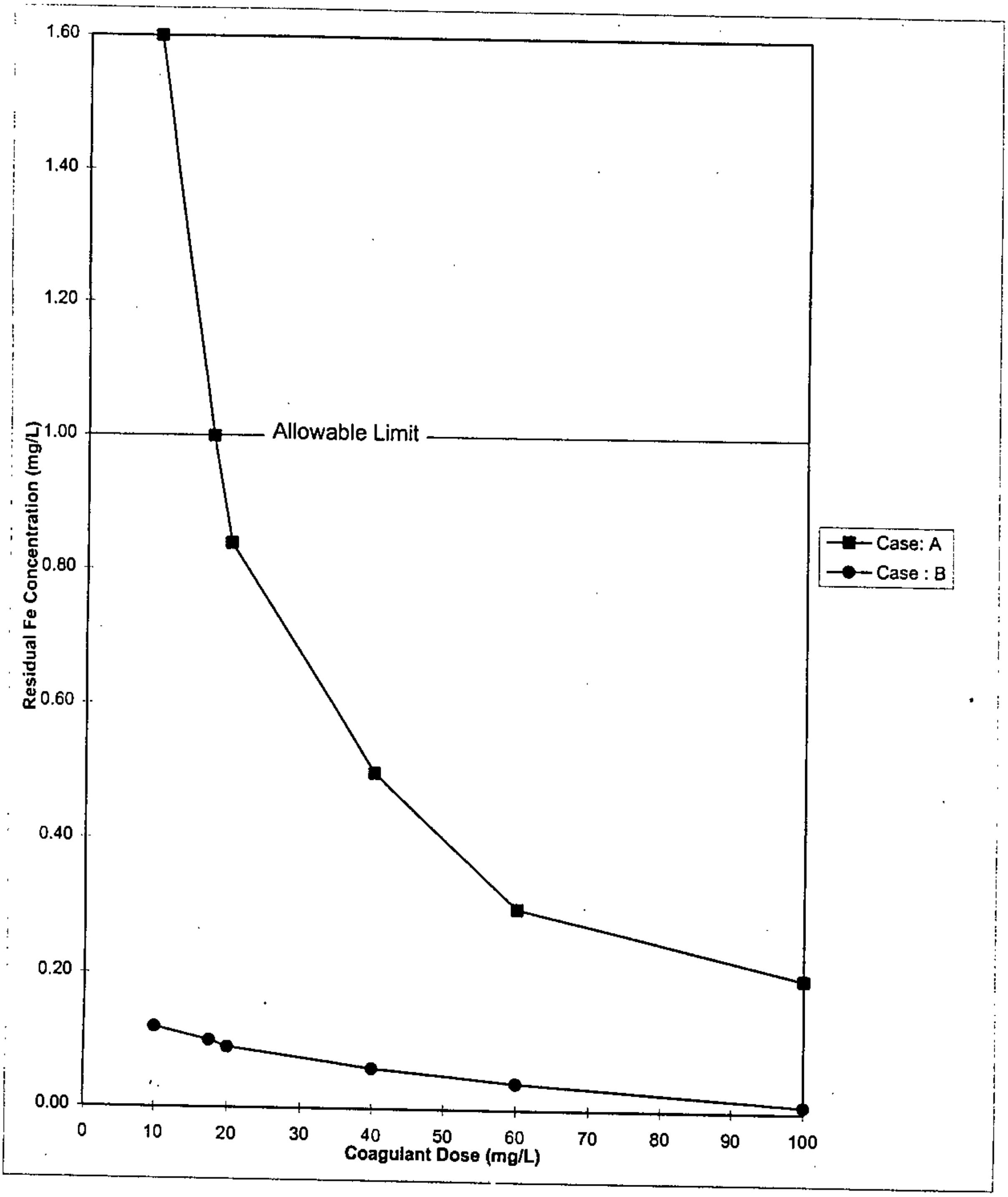

Figure: 5.10 Residual iron concentration of natural ground water sample (sample with ID no :D) with coagulant dose after aeration ,coagulation using alum as coagulant , 30 min. sedimentation and (i) Case A: Without filtration (ii) Case B: With filtration dose for either lime or alum is high. However, if filtration is performed after aeration, coagulation and 30 min sedimentation then the effect of increase of coagulant dose on iron removal is not too much significant.

As it is observed from Figure:5.1 that after only aeration and 30 min sedimentation iron removal of sample with ID no: A , B, C and D are 25%, 33%, 25% and 25% respectively. Residual Fe concentration varies from 9 to 18 mg/L. But when coagulation is performed before sedimentation, iron removal increases to more than 90% in all the cases and residual Fe concentration varies from 0.5 to 3.2 mg/L when lime is used as coaguant and 0.1 to 2.0 mg/L when alum is used as coagulant at different doses. However, the removal of iron after aeration , coagulation , 30 min. sedimentation and filtration become more than 99% in all the cases. In this stage residual iron varies from 0.01 to 0.12 mg/L.

Aeration oxidizes the soluble iron to insoluble iron. But the oxidized and precipitated iron particles are too small in size. So only sedimentation can not effectively remove these insoluble particle. But when coagulation is done after aeration these small particles will flocculate and increase the effective size , thereby the settling velocity and thus increases removal by sedimentation. Most of the rest insoluble particles will be removed when filtration is done in addition to it.

Allowable limit of iron in drinking water for Bangladesh is 1mg/L as recommended by the Department of Environment. From figures it is observed that this limit can be attained by aeration , coagulation either by lime or alum and 30 min. sedimentation without filtration in all the cases. The required coagulant doses are 150 mg/L, 183 mg/L, 150 mg/L and 150 mg/L for sample with ID no: A, B, C and D respectively when lime is used as coagulant. Whereas, the required coagulant doses are 20 mg/L, 20 mg/L, 17.5 mg/L and 17.5 mg/L for sample with ID no: A, B, C and D respectively when alum is used as coagulant. If filtration is performed in addition to these then it brings iron level to much more lower than the allowable one in all the cases.

It is clear that aeration , sedimentation and filtration can reduce iron content in ground water to allowable limit. However, frequent cleaning difficulties of the filter bed and low yield needs further attention.

5.5 EFFECT OF COAGULANT DOSE ON IRON REMOVAL

In this section all the four selected water samples were used. Lime and alum each at a time were used as coagulant for the coagulation of the water samples. Residual iron concentration were measured each time after aeration , coagulation and 30 min. sedimentation.

5.5.1 Experimental Set-Up

The four natural ground water samples with ID no: A, B, C and D of different quality (as described in Table:5.2) were at first aerated. Then 500 ml. of sample with ID no: A was taken in each of four different jars. Lime was added as coagulant at different doses of 60, 100, 150 and 200 mg/L in different jars and were then coagulated (as described in Art. 4.3.1). The stirred water samples were allowed to settle for 30 min. A portion of the supernatant was drawn off from all the jars and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2).

Again 500ml. of sample with ID no: A was taken in each of the six jars and alum was added to all the six jars as coagulant at different doses of 10, 17.5, 20, 40 , 60 and 100 mg/L. The water samples were then coagulated (as described in Art. 4.3.1) and the stirred water samples were then allowed to settle for 30 min. A portion of the supernatant was drawn off from all the six jars and transferred to tubes for the determination of iron concentration (as described in Art. 4.3.2).

This whole process as mentioned above was repeated for all the rest three water samples i.e. sample with ID no: B, C and D.

The difference of iron concentration between original samples and coagulated one gives a measure of iron removal . The results are given in tabular form in Appendix- "C" , Table:C_6 and residual iron concentration with coagulant dose for all the four natural water samples are presented in Figure:5.11, 5.12, 5.13 and 5.14 respectively.

5.5.2 Results And Discussions

It is observed from Figure: 5.11, 5.12, 5.13 and 5.14 that for all the samples iron removal increases with increase in coagulant dose. But the rate of increase of iron removal diminishes with the increase in coagulant dose in all the cases . Further it is observed that alum used as coagulant is more effective than lime in iron removal i.e. same amount of alum as coagulant is more effective than lime.

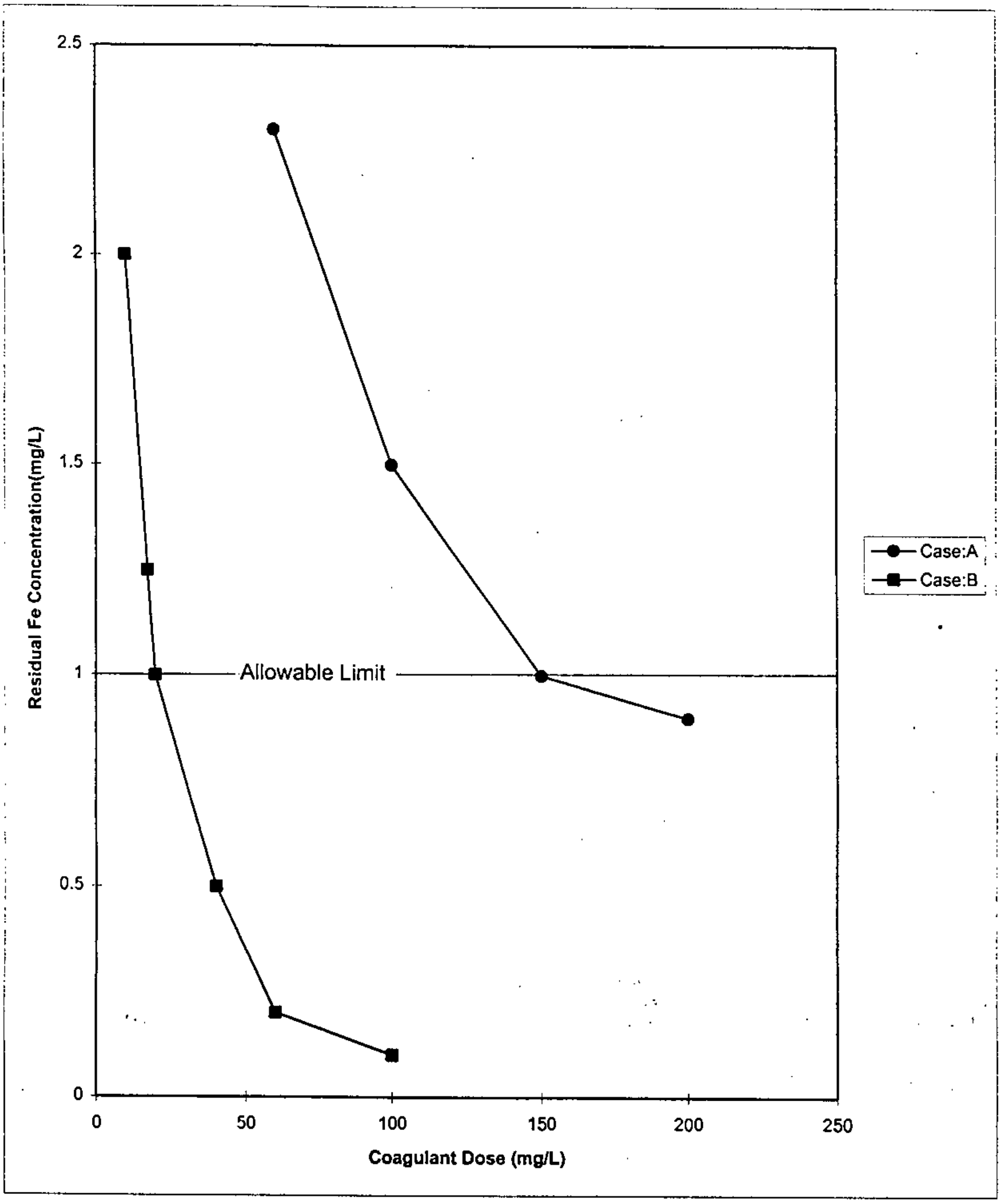

Figure: 5.11 Residual iron concentration of natural ground water sample (sample with ID no:A, with initial Fe conc. 24 mg/L) with coagulant dose after aeration ,coagulation and 30 min sedimentation ,using (I) Case A: Lime as coagulant (ii) Case B: Alum as coagulant

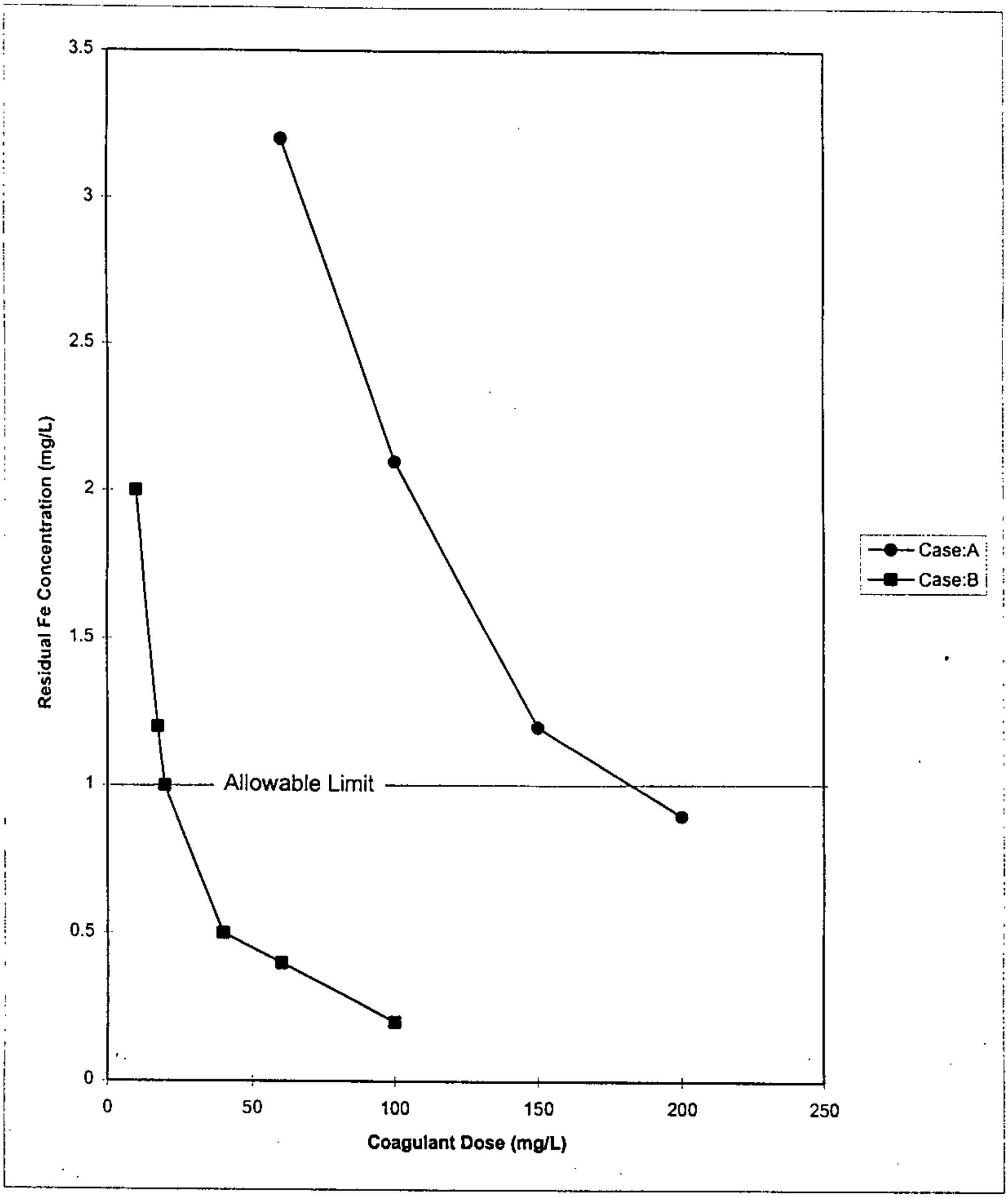

Figure: 5.12 Residual iron concentration of natural ground water sample (sample with ID no: B, with initial Fe conc. 13.5 mg/L) with coagulant dose after aeration , coagulation and 30 min sedimentation using (I) Case A: Lime as coagulant (ii) Case B: Alum as coagulant .

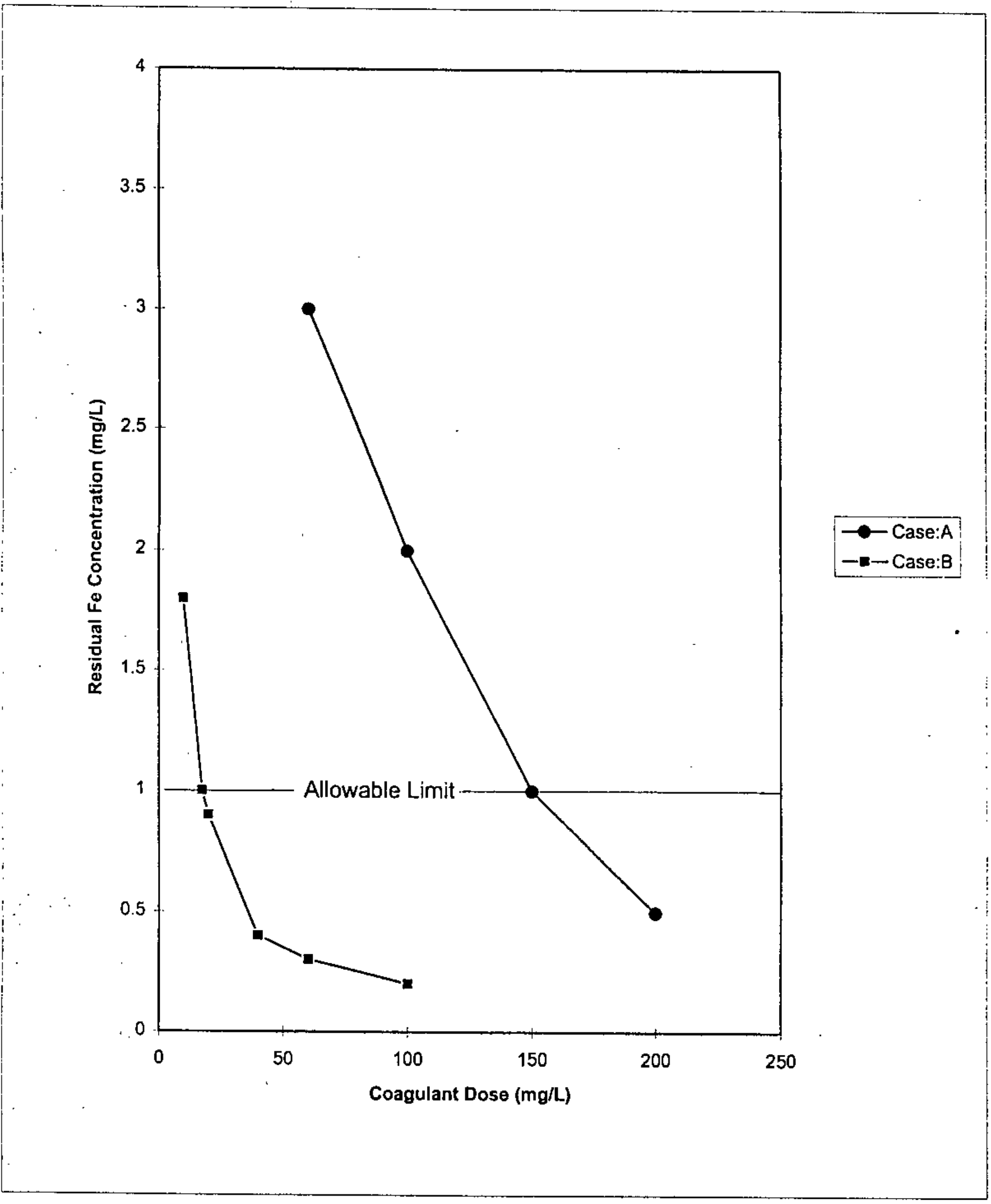

Figure:5.13 Residual iron concentration of natural ground water sample (sample with ID no: C, with initial Fe conc. 20 mg/L) with coagulant dose after aeration ,coagulation and 30 min. sedimentation, using (I) Case A: Lime as coagulant (ii) Case B: Alum as coagulant

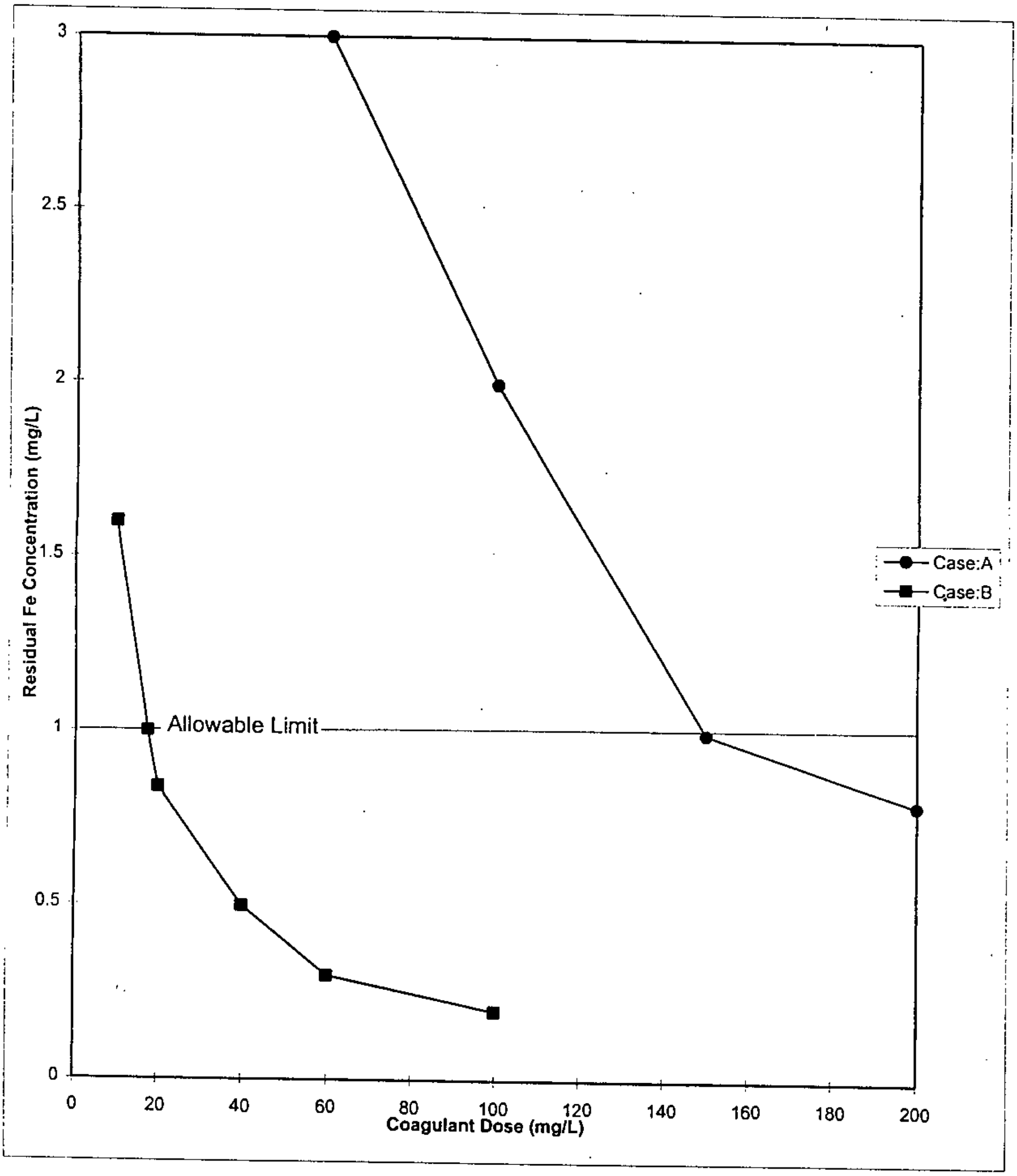

Figure: 5.14 Residual iron concentration of natural ground water sample (sample with ID no:D, with initial Fe conc. 16 mg/L) with coagulant dose after aeration ,coagulation and 30 min sedimentation using (i) Case A: Lime as coagulant (ii) Case B: Alum as coagulant

It is also clear from the figures that for a coagulant dose of 60 mg/L iron removal from the four natural ground water samples with ID no: A, B, C and D are 90.42%, 76.3%, 85% and 81.25% respectively when lime is used as coagulant. Residual Fe concentration varies from 3.2 mg/L to 2.3 mg/L. However, for the same dose when alum is used as coagulant iron removal is 99.17%, 97.04%, 98.50% and 98.13% respectively. Residual Fe concentration varies from 0.2mg/L to 0.4 mg/L. Similarly, for a coagulant dose of 100 mg/L iron removal from the four natural ground water samples with ID no: A, B, C and D are 93.75%, 84.44%, 90% and 87.50% respectively when lime is used as coagulant. Whereas, iron removal of 99.58%, 98.52%, 99% and 98.75% respectively is experienced at the same coagulant dose of 100 mg/L when alum is used as coagulant.

1 mg/L is the allowable limit of iron in drinking water for Bangladesh as recommended by the Department of Environment. From Figure: 5.11, 5.12, 5.13 and 5.14 it is clear that this limit can be attained by both of the coagulant after aeration, coagulation and 30 min. sedimentation. But required lime dose will be more than that of alum. For sample with ID no: A this allowable limit can be attained by coagulant dose of 150 mg/L for lime and 20 mg/L for alum. For sample with ID no: B this allowable limit can be attained by coagulant dose of 183 mg/L for lime and 20 mg/L for alum. For sample with ID no: C this allowable limit can be attained by coagulant dose of 150 mg/L for lime and 17.5 mg/L for alum. For sample with ID no: D this allowable limit can be attained by coagulant dose of 150.00 mg/L for lime and 17.5 mg/L for alum. The results are summarised in the following Table:5.4:

Table:5.4 Coagulant dose required to attain allowable limit of 1 mg/L of iron in water

Sample ID No.	Initial Fe Concentration (mg/L)	Coagulant Dose to Attain Allowable Limit (mg/L)	
		Lime	Alum
A	24.00	150.00	20.00
B	13.50	183.00	20.00
C	20.00	150.00	17.50
D	16.00	150.00	17.50

Cost Analysis:

In this section attempts have been made to compare coagulant cost involve in coagulation by alum and lime in iron removal Allowing similar unit processes i.e. aeration, coagulation and fixed settling time of 30 min. alum and lime dose required to attain allowable limit of 1 mg/L of iron is taken into consideration.

The market price of lime is about Tk. 30 per kg and that of alum is about Tk. 500 per kg. Ahmed (1987) mentioned that per capita water consumption is about 24 Litre/ day from hand tubewell after improving the quality. In this analysis the above mentioned factors have been considered.

From Table 5.4 , it is observed that to attain the allowable limit of 1 mg/L of residual iron concentration by aeration , coagulation and 30 min. sedimentation the average amount of coagulant doses required for natural ground water samples with ID no:A, B, C and D are 150 mg/L, 183mg/L, 150mg/L and 150 mg/L respectively when lime is used as coagulant. The required coagulant doses are 20 mg/L, 20 mg/L, 17.5 mg/L and 17.5 mg/L respectively when alum is used as coagulant. Cost comparison is presented briefly in the following Table:5.5 :

Table:5.5 Comparison of coagulant cost involved with alum and lime used as coagulant in iron removal by aeration , coagulation and 30 min sedimentation

Sample ID No	Initial Fe Concentration	Type of Coagulant	Per capita Water Consumption	Coagulant Dose	Total Coagulant Required	Cost of Coagulant	Total Cost of Coagulant per capita per day	Avg. Cost of Coagulant per capita per day
	mg/L		Lpcd	mg/L	mg /d	Tk.per kg	Tk	Tk
A	24	Lime	24.00	150.00	3600	30.00	0.11	0.12
B	13.5	Lime	24.00	183.00	4392	30.00	0.13	
C	20	Lime	24.00	150.00	3600	30.00	0.11	
D	16	Lime	24.00	150.00	3600	30.00	0.11	
A	24	Alum	24.00	20.00	480	500.00	0.24	0.23
B	13.5	Alum	24.00	20.00	480	500.00	0.24	
C	20	Alum	24.00	17.50	420	500.00	0.21	
D	16	Alum	24.00	17.50	420	500.00	0.21	

From the analysis given in Table: 5.5 it is observed that the coagulant cost of alum is higher than lime.On an average lime used as coagulant will cost Tk.0.12 per capita per day and alum used as coagulant will cost Tk.0.23 per capita per day. Performing aeration, coagulation and allowing same settling time in both the cases , alum used as coagulant will cost 191.7% higher than when lime is used as coagulant to get water with residual iron concentration of 1 mg/L.

It is clear that lime will be more cost effective than alum used as coagulant. However, the pH value of the effluent water needs further attention.

Comparison Between Natural And Artificial Iron Containing Water.

Figure 5.15 represents the effects of lime dose on iron removal from natural and artificial iron containing water samples. In both the cases residual iron concentration decreases with an increase in lime dose following the same trend. However, iron removal is more in case of natural ground water samples than artificial iron containing water sample. For a lime dose of 60 mg/L, iron removal from natural water sample is 85%. Whereas, at the same lime dose iron removal from artificial water sample is 70%. Similarly, at a lime dose of 200 mg/L, iron removal from natural and artificial water samples are 97.5% and 87.5% respectively. This variation occurs mainly due to the fact that in case of natural water samples aeration was performed in addition to coagulation and filtration. As such due to additional aeration , oxidation of soluble ferrous iron to insoluble

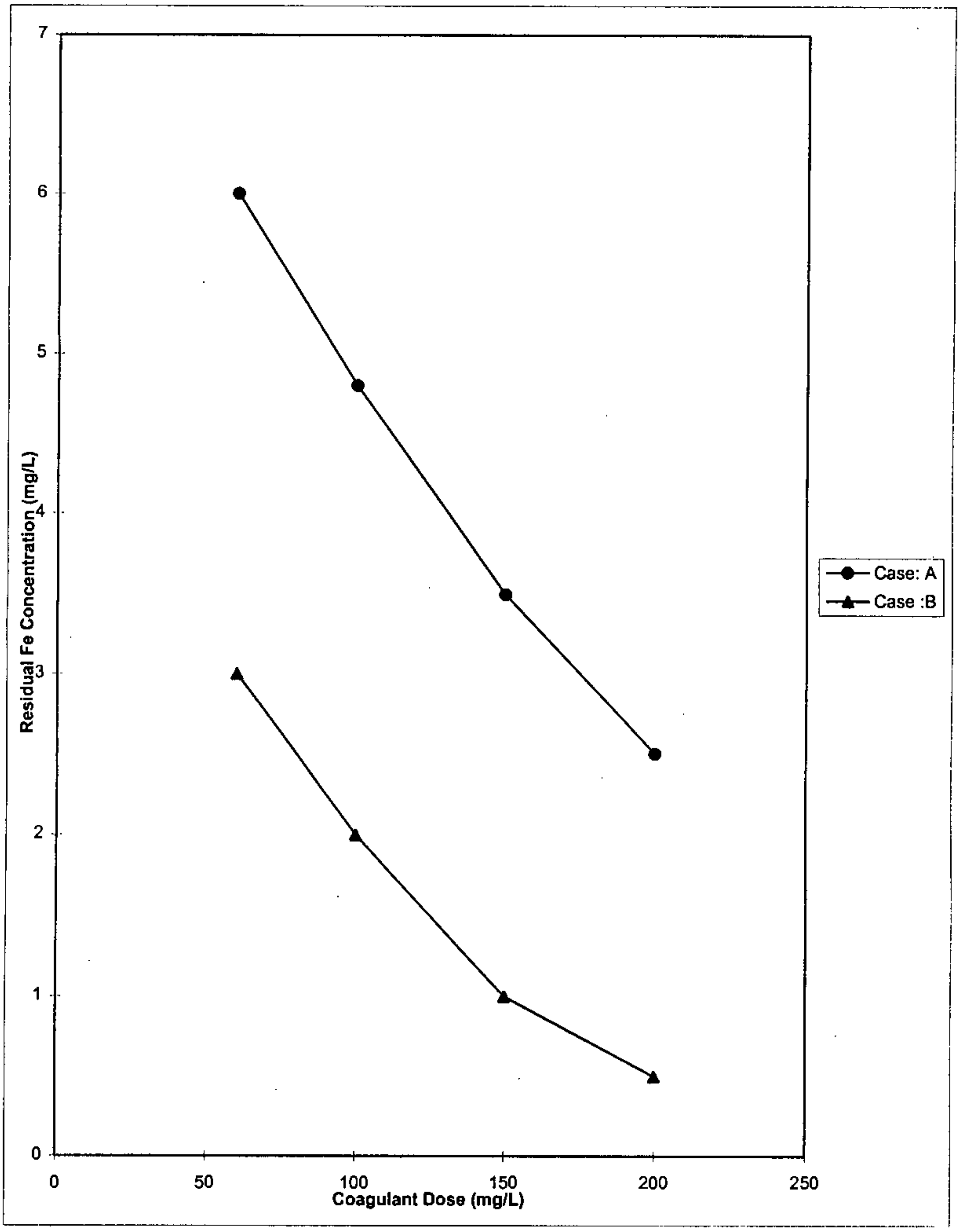

Figure:5.15 Residual iron concentration of water samples (initial Fe concentration: 20 mg/L) with coagulant dose (i) Case A: After coagulation with lime and 30 min. sedimentation of artificial water sample (ii) Case B: After aeration , coagulation with lime and 30 min sedimentation of natural ground water sample

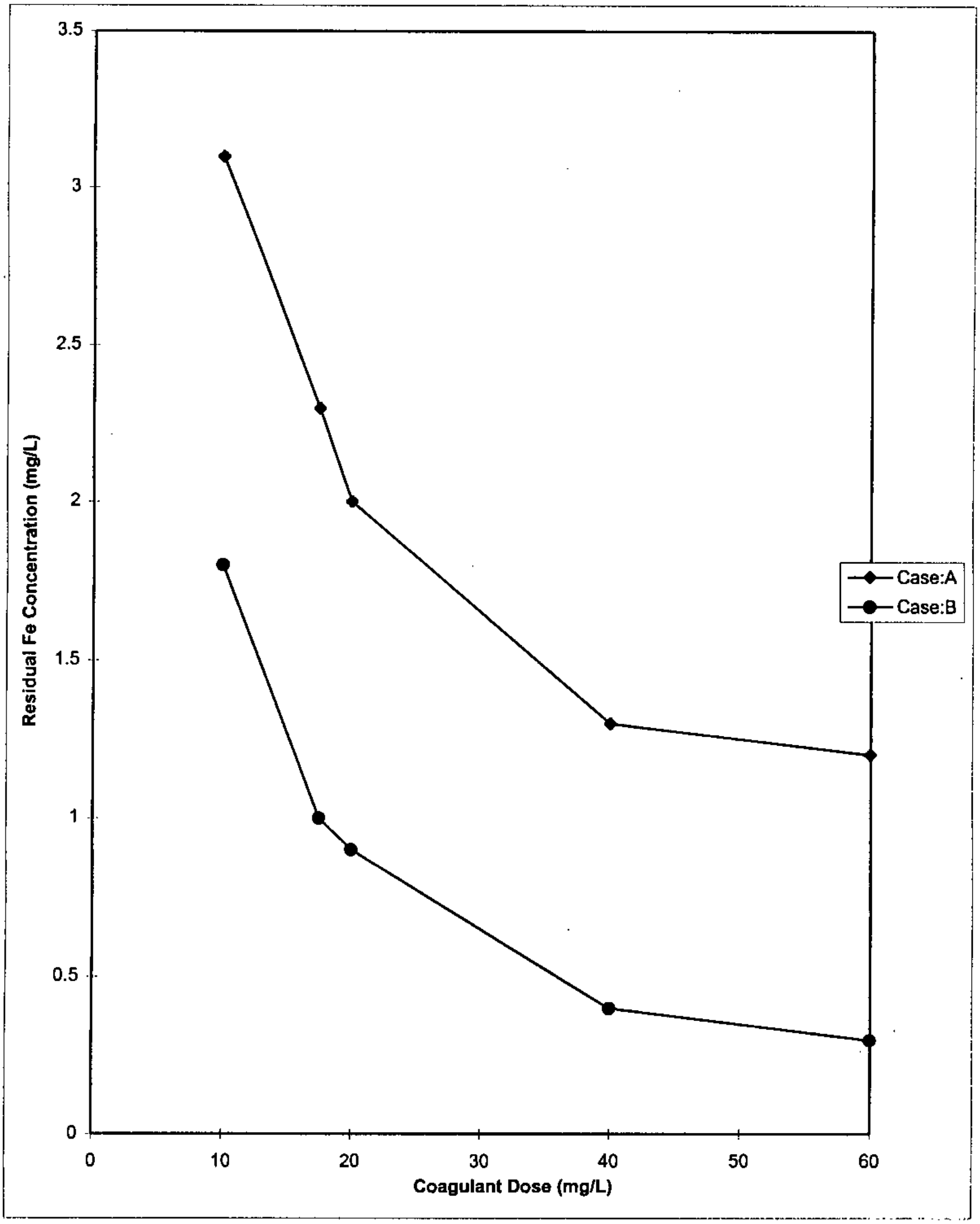

Figure:5.16 Residual iron concentration of water samples (initial Fe concentration: 20 mg/L) with coagulant dose (i) Case A: After coagulation with alum and 30 min. sedimentation of artificial water sample (ii) Case B: After aeration , coagulation with alum and 30 min sedimentation of natural ground water sample ferric iron was more which in turn increases removal of iron from natural water.

Figure 5.16 represents the effects of alum dose on iron removal from natural and artificial iron containing water samples. In both the cases residual iron concentration decreases with an increase in alum dose. For a alum dose of 10 mg/L, iron removal from natural water sample is 91%. Whereas at the same lime dose iron removal from artificial water sample is 84.5%. Residual iron concentrations for artificial and natural iron containing water samples being 3.1 mg/L and 1.8 mg/L respectively. Similarly, at a alum dose of 60 mg/L, iron removal from natural and artificial water samples are 98.5% and 94% respectively. This indicates that iron removal is more in case of natural ground water samples than artificial iron containing water sample. This variation occurs mainly due to the fact that in case of natural water samples aeration was performed in addition to coagulation and filtration. As such oxidation of soluble ferrous iron to insoluble ferric iron was more which in turn increases removal of iron in case of natural water sample i.e. aeration plays an important role in iron removal.

It is also clear from Figures: 5.15 and 5.16 that allowable limit of 1 mg/L of residual iron concentration can be attained in natural iron containing water sample at coagulant doses of 17.5 mg/L and 150 mg/L for alum and lime respectively used as coagulant. Corresponding values are presented in Tabular form in Appendix-"C", Table: C_7 and C_8.

5.6 SUMMARY OF FINDINGS

The study results obtained can be summarised as follows :

- Aeration and 2 hr. sedimentation results in iron removal upto 70%. But when filtration is performed after aeration and 2hr. sedimentation iron removal from natural water increases to more than 99%.

- Iron removal increases with an increase in sedimentation time. But the rate of increase of iron removal diminishes with the increase in sedimentation time.

- Iron removal from both artificial and natural iron containing water increases with an increase in coagulant dose for both of the coagulants, alum and lime .

- After aeration and 30 min. sedimentation iron removal of upto 33% was observed. But when coagulation is done in addition to aeration and 30 min. sedimentation then iron removal increases to more than 90%. However , iron removal increases to more than 99% if filtration is performed after aeration , coagulation and 30 min. sedimentation.

- Allowable limit of iron in drinking water i.e. 1 mg/L can be attained by aeration , coagulation with either lime or alum and 30 min. sedimentation. If filtration if performed in addition to these then the value of residual Fe concentration become much lower than the allowable limit.

- Alum used as coagulant is more effective than lime in iron removal from natural ground water resulting residual iron concentration to 1 mg/L.

- The amount of coagulant dose required to attain the allowable limit of 1 mg/L of iron in drinking water after aeration, coagulation and 30 min sedimentation in naturall ground water samples with initial Fe concentration of 24 mg/L, 13.5 mg/L, 20 mg/L and 16 mg/L are 150 mg/L, 183 mg/L, 150 mg/L and 150 mg/L respectively when lime is used as coagulant and 20 mg/L, 20 mg/L, 17.5 mg/L and 17.5 mg/L respectively when alum is used as coagulant. Average cost of coagulant involved is Tk. 0.12 per capita per day when lime is used as coagulant and Tk 0.23 per capita per day when alum is used as coagulant

- Alum as coagulant will cost 191.7% higher than lime to coagulate same quantity of water resulting residual Fe concentration of 1 mg/L.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

6.1 CONCLUSIONS

The following conclusions are drawn on the basis of the results obtained from the research work :

- Iron removal increases with an increase in pH value. However, after a certain pH value iron removal exhibit a decreasing trend. After coagulation and 15 min sedimentation of artificial water sample with initial Fe concentration 20 mg/L, this pH value is observed to be 9.3 when lime is used as coagulant and 9.6 when sodium hydroxide is used as coagulant.

- Increase in sedimentation time results in an increase in iron removal. The rate of increase of iron removal diminishes with the increase of settling time. However, sedimentation time required to attain allowable limit of 1 mg/L of residual iron concentration for the three artificial water samples having initial iron concentration of 20 mg/L, 15 mg/L and 10 mg/L are 240 min., 110 min. and 10 min. respectively after coagulation with lime at pH 7.4. Whereas, this limit can be attained after settling time of 50 min and 10 min at pH 8.3 and 9.6 respectively for artificial water sample with 20 mg/L of initial Fe concentration after coagulation with NaOH. Within the same pH range lime is more effective than sodium hydroxide as coagulant in iron removal.

- Aeration and 30 min. sedimentation results in iron removal of upto 33% from natural ground water samples. But when coagulation is done in addition to aeration and 30 min. sedimentation then iron removal of more than 90% is observed. However , iron removal increases to more than 99% if filtration is performed after aeration , coagulation and 30 min. sedimentation. Whereas, filtration after aeration and 2 hr. sedimentation also results in iron removal of more than 99%.

- Alum used as coagulant is more effective than lime in iron removal from natural ground water. The amount of coagulant dose required for natural ground water samples with initial iron concentration of 24 mg/L, 13.5 mg/L, 20mg/L and 16 mg/L to attain the allowable limit of 1 mg/L of residual iron concentration after aeration, coagulation and 30 min sedimentation are 150 mg/L, 183 mg/L, 150 mg/L and 150 mg/L respectively when lime is used as coagulant. Whereas, required coagulant doses are 20 mg/L, 20 mg/L, 17.5 mg/L and 17.5 mg/L respectively when alum is used as coagulant. However, average cost of coagulant involved is Tk. 0.12 per capita per day when lime is used as coagulant and Tk. 0.23 per capita per day when alum is used as coagulant. Alum as coagulant will cost 191.7% higher than lime to coagulate same quantity of water.

- Iron removal increases with an increase in OH^- ion (NaOH) concentration . However, after a certain limit iron removal exhibit a decreasing trend. For artificial iron content water with initial Fe concentration of 20 mg/L, this value of OH^- ion concentration is observed to be 25.5 mg/L and the corresponding pH value is 9.6.

- Residual iron concentration decreases with an increase in anion (Cl^- and SO_4^{-2}) concentration . However, if the added anion is common to the anion in solution then more pronounced effect is observed due to the common ion effect.

6.2 RECOMMENDATIONS FOR FURTHER STUDIES

This research was carried out in the laboratory. Further studies are needed to find out its practical application.

In this study artificial iron containing water was prepared by using distilled water. However, in further studies tap water can be used in place of distilled water.

Study reveals that OH^- ion concentration effects the iron removal . However, change in alkalinity can be further related in this respect.

A more detailed study is necessary to find out a relationship between the anion concentration and iron removal and common ion effect.

Study reveals that filtration is an effective mode in iron removal . Further study is needed to evaluate cost effectiveness of filtration process taking into consideration all the associated problems of filtration i.e. frequent cleaning , low yield etc.

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Appendix-"A"

Measurement Of Iron Concentration

The water samples were tested in the laboratory according to the following procedure:

Reagents used:

- Dilute hydrochloric acid
- Potasium permanganate solution
- Potasium thiocyanate solution
- Standard iron solution

Procedure:

- Firstly each sample was stirred very well to disperse the iron precipitates uniformly throughout the sample.
- 100 ml of each sample was taken in a Nessler tube.
- 5ml of dilute hydrochloric acid was added to each tube.
- Then 2 drops of potasium permanganate were added . A pink color was formed after the addition of potasium permanganate . If pink color disappeared after 5 minutes , then more permanganate was added.
- 5 ml of potasium thiocyanate solution was added to the sample. A brown color was formed after the addition.
- Then the brown color formed was compared with the " standard " prepared as follows:

⇒ Added 100 ml of distilled water in a Nessler tube.

⇒ Added 5 ml of the dilute hydrochloric acid in the tube.

⇒ Added 5 ml of potasium thiocyanate solution in the tube .

⇒ Added 0.2 ml of standard iron solution at a time until the color of the "standard" and sample matched.

Calculation:

Amount of iron present in the sample (mg/L) = ml of the standard iron solution used

APPENDIX - " B"

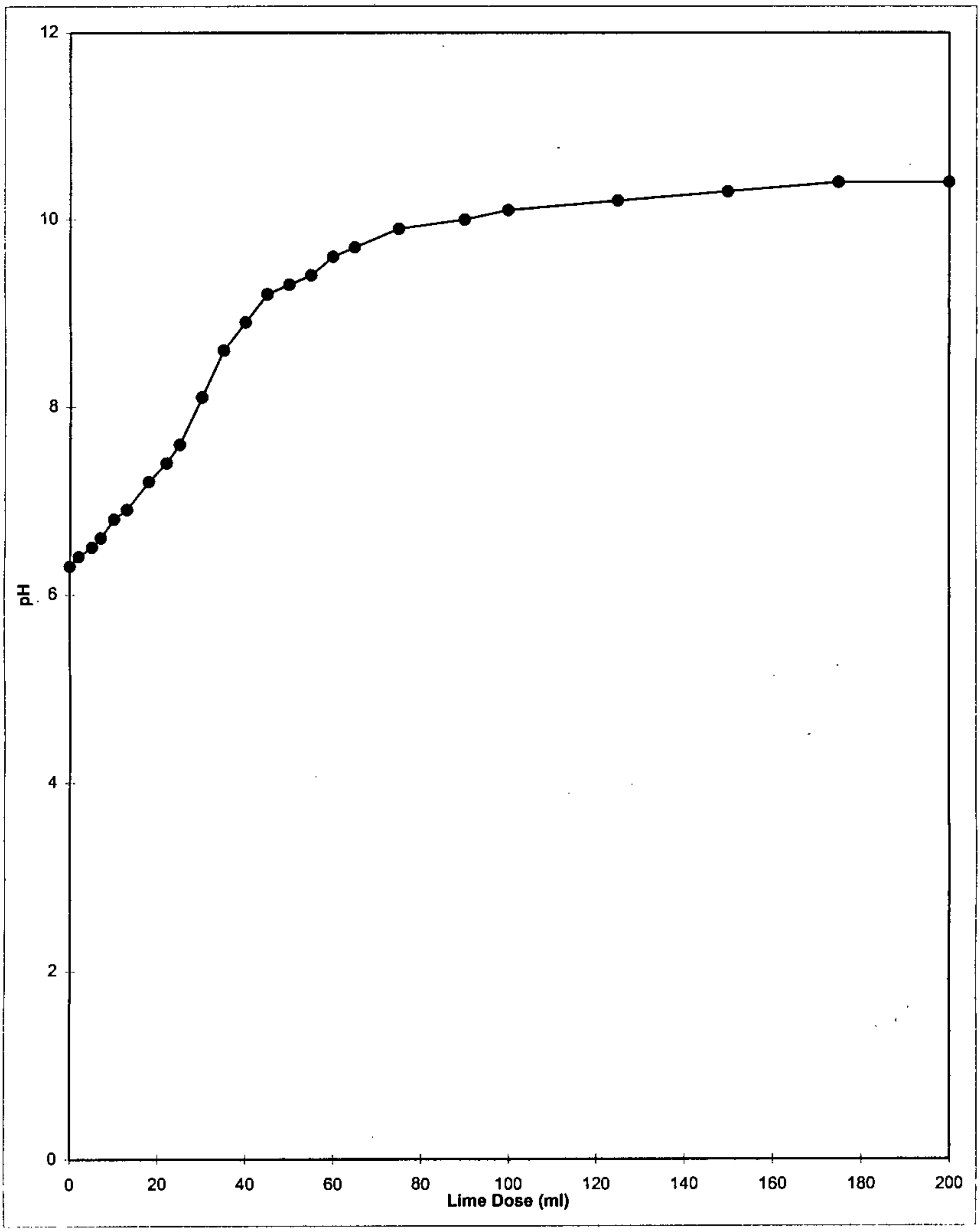

Figure: B_1 Variation of pH with lime (4mg/L) dose added to 500ml of artificial water sample having initial Fe concentration of 20 mg/L.

Table: B_1 Effect of pH on iron removal from artificial iron containing water after coagulation with lime and 15 min. sedimentation.

Sl No	Initial Fe Concentration	pH	Residual Fe Concentration	Fe Removal
	(mg/L)		(mg/L)	(%)
1	20.00	7	5	75
2	20.00	7.4	3.5	82.5
3	20.00	7.7	3	85
4	20.00	8.16	2.8	86
5	20.00	8.5	2.5	87.5
6	20.00	8.9	2.3	88.5
7	20.00	9.3	2.0	90
8	20.00	11.68	2.8	86

Table : B_2 Iron removal from artificial water sample containing 20 mg/L of iron at different pH after coagulation with sodium hydroxide and 15 min. sedimentation .

Sl. No.	Initial Fe Concentration	pH	Residual Fe Concentration	Fe Removal
	(mg/L)		(mg/L)	(%)
1	20	7.0	14	30
2	20	7.4	10	50
3	20	8.3	2.5	87.5
4	20	9.6	0.5	97.5
5	20	9.9	0.6	97
6	20	10.4	18.5	7.5

Table:B_3 Effect of sedimentation time on iron removal from artificial iron containing water samples after coagulation with lime at pH 7.4

Sl. No.	Sedimentation Time	Case:A Initial iron Conc: 20mg/L		Case :B Initial iron Conc: 15mg/L		Case:C Initial iron Conc: 10mg/L	
		Residual Fe Concentration	Fe Removal	Residual Fe Concentration	Fe Removal	Residual Fe Concentration	Fe Removal
	(min)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)
1	15	3.50	82.50	2.25	85.00	1.00	90.00
2	30	3.00	85.00	1.50	90.00	0.80	92.00
3	60	2.00	90.00	1.28	91.47	0.55	94.50
4	120	1.50	92.50	0.95	93.67	0.45	95.50
5	240	1.00	95.00	0.65	95.67	0.35	96.50
6	720	0.50	97.50	0.35	97.67	0.25	97.50
7	1440	0.35	98.25	0.30	98.00	0.20	98.00

Table:B_4 Iron removal from artificial water sample having initial iron concentration of 20 mg/L at different sedimentation time after coagulation with NaOH at different pH

Sl No	Initial Fe Concentration	Sedimentation Time	Residual Fe Concentration	Fe Removal
	(mg / L)	(min)	(mg / L)	(%)
	Case: A pH 7.4			
1	20.00	5	13.50	32.50
2	20.00	10	11.00	45.00
3	20.00	15	10.00	50.00
4	20.00	45	7.90	60.50
5	20.00	90	6.00	70.00
	Case :B pH 8.3			
1	20.00	5	6.60	67.00
2	20.00	10	3.50	82.50
3	20.00	15	2.50	87.50
4	20.00	45	0.90	95.50
5	20.00	90	0.70	96.50
	Case :C pH 9.6			
1	20.00	5	2.50	87.50
2	20.00	10	1.00	95.00
3	20.00	15	0.50	97.50
4	20.00	45	0.30	98.50
5	20.00	90	0.20	99.00
	Case :B pH 10.4			
1	20.00	5	19.00	5.00
2	20.00	10	18.70	6.50
3	20.00	15	18.50	7.50
4	20.00	45	18.20	9.00
5	20.00	90	18.00	10.00

Table:B_5 Effect of added OH^- ion (NaOH) concentration on iron removal from artificial water sample with initial iron concentration 20 mg/L after coagulation and sedimentation

Initial Fe conc.	pH	Added OH^- ion conc.	Case A: Coagulation + 5 min sedimentation		Case B: Coagulation + 10 min sedimentation		Case C: Coagulation + 15 min sedimentation		Case D: Coagulation + 45 min sedimentation		Case E: Coagulation + 90 min sedimentation	
			Residual Fe conc.	Fe removal	Residual Fe conc.	Fe removal	Residual Fe conc.	Fe removal	Residual Fe conc.	Fe removal	Residual Fe conc.	Fe removal
(mg/L)		(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)
20.00	7.4	6.8	13.5	32.5	11	45	10	50	7.9	60.5	6.0	70
	8.3	13.6	6.6	67	3.5	82.5	2.5	87.5	0.9	95.5	0.7	96.5
	9.6	25.5	2.5	87.5	1.0	95	0.5	97.5	0.3	98.5	0.2	99
	10.4	34	19	5	18.7	7.5	18.5	7.5	18.2	9	18	10

Table: B_6 Iron removal from artificial iron containing water with alkalinity and pH after coagulation with Na_2CO_3 and 30 min sedimentation.

Sl No	Initial Fe Concentration	pH	Alkalinity	Residual Fe Concentration	Fe Removal
	(mg/L)		(mg/L as $CaCO_3$)	(mg/L)	(%)
1	20	4.8	8	12	40.0
2	20	6.0	32	9.0	55.0
3	20	6.7	100	3.2	84.0
4	20	6.8	120	2.3	88.5
5	20	6.9	130	1.8	91.0
6	20	7.5	226	0.8	96.0
7	20	8.2	267	0.7	96.5

Table: B_7 Effect of alkalinity (varied using Na_2CO_3) on turbidity and colour of artificial iron containing water sample .

Sl. No.	Initial Fe Concentration	pH	Turbidity	Colour	Alkalinity
	(mg/L)		(NTU)	(TCU)	(mg/L as $CaCO_3$)
1	10.00	4.5	1.14	19.0	6.0
2	10.00	5.7	2.1	73.0	16.0
3	10.00	6.0	4.3	118.0	32.0
4	10.00	6.7	5.1	131.0	100.0
5	10.00	6.8	5.25	133.0	120.0
6	10.00	6.9	5.35	135.0	130.0
7	10.00	7.5	4.9	98.0	226.0
8	10.00	8.2	4.4	84.0	267.0

Table: B_8 Variation of turbidity of artificial iron containing water samples with alkalinity using NaOH to increase alkalinity.

Sl. No.	Initial Fe Concentration	pH	Turbidity	Alkalinity
	(mg/L)		(NTU)	(mg/L as $CaCO_3$)
1	10.00	9.1	5.2	56.92
2	10.00	7.3	4.8	49.04
3	10.00	6.3	3.3	21.69
4	10.00	5.8	3.15	19.51
5	10.00	4.8	2.70	12.62
6	10.00	4.4	1.97	4.85
7	10.00	3.7	1.76	0.0

Table: B_9 Effect of alum dose on iron removal from artificial iron containing water after coagulation with alum and 30 min sedimentation at pH 6.2.

Sl. No.	Initial Fe Concentration	Alum Dose	Residual Fe Concentration	Fe Removal
	(mg/L)	(mg/L)	(mg/L)	(%)
1	20.00	10.0	3.1	84.5
2	20.00	17.5	2.3	88.5
3	20.00	20.0	2.0	90.0
4	20.00	40.0	1.3	93.5
5	20.00	60.0	1.2	94.0

Table : B_{10} Effect of added anion concentration on iron removal from artificial iron containing water sample after coagulation with lime and 15 min. sedimentation.

Sl .No.	Initial Fe Concentration	Added Anion Concentration	Residual Fe Concentration	Fe Removal
	(mg/L)	(mg/L)	(mg / L)	(%)
		Case A: Cl^-		
1	20.00	0	3.5	82.5
2	20.00	25	3.4	83.0
3	20.00	50	3.3	83.5
4	20.00	100	3.1	84.5
5	20.00	200	2.8	86.0
6	20.00	500	2.7	86.5
		Case B: SO_4^{-2}		
1	20.00	0	3.5	82.5
2	20.00	25	3.0	85.0
3	20.00	50	2.75	86.0
4	20.00	100	2.5	87.5
5	20.00	200	2.0	90.0
6	20.00	500	1.75	91.25

APPENDIX - " C "

Table: C_1 Iron removal from four different natural ground water sample after aeration and sedimentation allowing different sedimentation time

Sample ID	Sample Location	Initial Fe Concentration (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Sedimentation Time (min)	Residual Fe Concentration (mg/L)	Fe Removal (%)
A	Bachelor Mess , Joyra, Manikgonj	24.00	310.00	0	24.00	0.00
				30	18.00	25.00
				60	12.80	46.66
				120	9.00	62.50
B	House of Mr. Minhazuddin , Dhighi, Manikgonj.	13.50	274.00	0	13.50	0.00
				30	9.00	33.00
				60	5.20	61.48
				120	4.00	70.37
C	House of Mr. Milon , Bandutia, Manikgonj.	20.00	449.00	0	20.00	0.00
				30	15.00	25.00
				60	8.80	56.00
				120	8.40	58.00
D	House of Mr. Javed Ali, Pouli , Manikgonj.	16.00	215.00	0	16.00	0.00
				30	12.00	25.00
				60	8.20	48.75
				120	8.00	50.00

Table: C_2 Iron removal from natural ground water sample with ID no: A after aeration, coagulation with different type and doses of coagulant , 30 minute sedimentation , with and without filtration.

Location	Sample ID No	Initial Iron Conc. (mg/L)	Coagulant Dose (mg/L)	Aeration+Coagulation +30min Sedimentation		Aeration+Coagulation +30min Sedimentation +Filtration	
				Residual Fe Concentration (mg/L)	Fe Removal (%)	Residual Fe Concentration (mg/L)	Fe Removal (%)
Case A: Lime as coagulant							
Bachelor Mess , Joyra , Manikgonj	A	24	60	2.30	90.42	0.08	99.67
		24	100	1.50	93.75	0.06	99.75
		24	150	1.00	95.83	0.05	99.79
		24	200	0.90	96.25	0.02	99.92
		Case B: Alum as coagulant					
		24	10	2.00	91.67	0.11	99.54
		24	17.5	1.25	94.83	0.10	99.58
		24	20	1.00	95.83	0.09	99.63
		24	40	0.50	97.92	0.06	99.75
		24	60	0.20	99.17	0.04	99.83
		24	100	0.10	99.58	0.02	99.92

Table: C_3 Iron removal from natural ground water sample with ID no: B after aeration, coagulation with different type and doses of coagulant , 30 minute sedimentation , with and without filtration.

Location	Sample ID no	Initial Iron Conc. (mg/L)	Coagulant Dose (mg/L)	Aeration+Coagulation +30min Sedimentation		Aeration+Coagulation +30min Sedimentation +Filtration	
				Residual Fe Concentration (mg/L)	Fe Removal (%)	Residual Fe Concentration (mg/L)	Fe Removal (%)
Case A : Lime as coagulant							
Dhighi , Manikgonj	B	13.5	60	3.2	76.30	0.09	99.33
		13.5	100	2.1	84.44	0.06	99.55
		13.5	150	1.2	91.11	0.04	99.70
		13.5	200	0.9	93.33	0.02	99.85
		Case B : Alum as coagulant					
		13.5	10	2.0	85.16	0.12	99.11
		13.5	17.5	1.2	91.11	0.11	99.19
		13.5	20	1.0	92.59	0.10	99.26
		13.5	40	0.5	96.30	0.07	99.48
		13.5	60	0.4	97.04	0.05	99.63
		13.5	100	0.2	98.52	0.02	99.85

Table: C_4 Iron removal from natural ground water sample with ID no: C after aeration, coagulation with different type and doses of coagulant , 30 minute sedimentation , with and without filtration.

Location	Sample ID no	Initial Iron Conc. (mg/L)	Coagulant Dose (mg/L)	Aeration+Coagulation +30min Sedimentation		Aeration+Coagulation +30min Sedimentation +Filtration	
				Residual Fe Concentration (mg/L)	Fe Removal (%)	Residual Fe Concentration (mg/L)	Fe Removal (%)
Case A :Lime as coagulant							
Bandutia , Manikgonj	C	20	60	3.0	85.00	0.06	99.70
		20	100	2.0	90.00	0.04	99.80
		20	150	1.0	95.00	0.02	99.90
		20	200	0.5	97.50	0.01	99.95
		Case B :Alum as coagulant					
		20	10	1.8	91.00	0.12	99.40
		20	17.5	1.0	95.00	0.11	99.45
		20	20	0.9	95.50	0.10	99.50
		20	40	0.4	98.00	0.07	99.65
		20	60	0.3	98.50	0.06	99.70
		20	100	0.2	99.00	0.01	99.95

Table: C_5. Iron removal from natural ground water sample with ID no: D after aeration, coagulation with different type and doses of coagulant , 30 minute sedimentation , with and without filtration.

Location	Sample ID no	Initial Iron Conc. (mg/L)	Coagulant Dose (mg/L)	Aeration+Coagulation +30min Sedimentation		Aeration+Coagulation +30min Sedimentation +Filtration	
				Residual Fe Concentration (mg/L)	Fe Removal (%)	Residual Fe Concentration (mg/L)	Fe Removal (%)
Case A :Lime as coagulant							
Mr. Javed Ali, Pouli , Manikgonj	D	16	60	3.0	81.25	0.08	99.50
		16	100	2.0	87.50	0.06	99.62
		16	150	1.0	93.75	0.04	99.75
		16	200	0.8	95.00	0.02	99.88
		Case B :Alum as coagulant					
		16	10	1.60	90.00	0.12	99.25
		16	17.5	1.00	93.75	0.10	99.37
		16	20	0.84	94.75	0.09	99.44
		16	40	0.50	96.88	0.06	99.62
		16	60	0.30	98.13	0.04	99.75
		16	100	0.20	98.75	0.01	99.94

Table:C_6 Effect of coagulant dose on iron removal after aeration , coagulation and 30 min. sedimentation of four natural ground water samples

Sample ID No	Location	Initial Fe Concentration	Coagulant Dose	Residual Fe Concentration	Fe Removal
		(mg/L)	(mg/L)	(mg/L)	(%)
A	Bachelor Mess, Joyra, Manikgonj	24.00			
			Case:A; Lime as coagulant		
			60	2.30	90.42
			100	1.50	93.75
			150	1.00	95.83
			200	0.90	96.25
			Case:B ; Alum as coagulant		
			10	2.00	91.67
			17.5	1.25	94.83
			20	1.00	95.83
			40	0.50	97.17
			60	0.20	99.17
			100	0.10	99.58
B	Dhighi, Manikgonj	13.50			
			Case:A ; Lime as coagulant		
			60	3.20	76.3
			100	2.10	84.44
			150	1.20	91.11
			200	0.90	93.33
			Case:B ; Alum as coagulant		
			10	2.00	85.16
			17.5	1.20	91.11
			20	1.00	92.59
			40	0.50	96.3
			60	0.40	97.04
			100	0.20	98.52

Sample ID No	Location	Initial Fe Concentration	Coagulant Dose	Residual Fe Concentration	Fe Removal
		(mg/L)	(mg/L)	(mg/L)	(%)
C	Mr. Milon, Bandutia , Manikgonj	20.00			
			Case:A ; Lime as coagulant		
			60	3.00	85.00
			100	2.00	90.00
			150	1.00	95.00
			200	0.50	97.50
			Case:B ; Alum as coagulant		
			10	1.80	91.00
			17.5	1.00	95.00
			20	0.90	95.50
			40	0.40	98.00
			60	0.30	98.50
			100	0.20	99.00
D	Mr. Javed Ali, Pouli, Manikgonj	16.00			
			Case:A; Lime as coagulant		
			60	3.00	81.25
			100	2.00	87.50
			150	1.00	93.75
			200	0.80	95.00
			Case:B ; Alum as coagulant		
			10	1.60	90.00
			17.5	1.00	93.75
			20	0.84	94.75
			40	0.50	96.88
			60	0.30	98.13
			100	0.20	98.75

Table:C_7 Iron removal from natural and artificial iron containing water after coagulation with lime and 30 min. sedimentation.

Sl. No.	Initial Fe Concentration	Lime Dose	Case A: Artificial Iron Containing Water		*Case B: Iron Containing Natural Ground Water	
			Residual Fe Concentration	Fe Removal	Residual Fe Concentration	Fe Removal
	(mg/L)	(mg/L)	(mg/L)	(%)	(mg/L)	(%)
1	20.00	60.0	6.0	70.0	3.0	85.0
2	20.00	100.0	4.8	76.0	2.0	90.0
3	20.00	150.0	3.5	82.5	1.0	95.0
4	20.00	200.0	2.5	87.5	0.5	97.5

* Aeration performed in addition to coagulation and 30 min. sedimentation.

Table:C_8 Iron removal from natural and artificial iron containing water after coagulation with alum and 30 min. sedimentation at pH 6.2.

Sl. No.	Initial Fe Concentration	Alum Dose	Case A: Artificial Iron Containing Water.		*Case B: Iron Containing Natural Ground Water	
			Residual Fe Concentration	Fe Removal	Residual Fe Concentration	Fe Removal
	(mg/L)	(mg/L)	(mg/L)	(%)	(mg/L)	(%)
1	20.00	10.0	3.1	84.5	1.8	91.0
2	20.00	17.5	2.3	88.5	1.0	95.0
3	20.00	20.0	2.0	90.0	0.9	95.50
4	20.00	40.0	1.3	93.5	0.4	98.0
5	20.00	60.0	1.2	94.0	0.3	98.5

*Aeration performed in addition to coagulation and 30 min. sedimentation.