VA-teknik
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CHALMERS TEKNISKA HÖGSKOLA
Institutionen för Vattenförsörjnings- och Avloppsteknik

EXAMENSARBETE / Diploma work

Optimization of the Chemical Treatment at Xinkaihe Water Treatment Plant

A Minor Field Study in Tianjin, China

MARTIN LEIDENHED AND CHRISTIAN WIELAND

Examensarbete 1997:1

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Keywords: **flocculation**
jar test
China
MFS
water treatment

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Preface

This study has been carried out within the framework of the Minor Field Studies (MFS) Scholarship Programme, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a Third World country on a basis of a Master's dissertation or a similar in-depth study. These studies are primarily conducted within areas that are important for development and in a country supported by the Swedish programme for international development assistance.

The main purpose of the MFS programme is to increase interest in developing countries and to enhance Swedish university students' knowledge and understanding of these countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the Swedish personnel resources for recruitment into international cooperation.

The Centre for International Technical and Educational Cooperation, CITEC, at the Royal Institute of Technology, KTH, Stockholm, administers the MFS programme for all faculties of engineering and natural sciences in Sweden.

Sigrun Santesson
Programme Officer
MFS Programme

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1. 总结及建议

本研究描述了含铝和铁的絮凝投加剂的效果以及混凝剂条件如：剂量和 pH 的最优化方案。另外本研究还包括有关新开河水厂水力条件和消毒步骤。此研究是于 1996 年 9 月 18 日至 1996 年 11 月 23 日与天津市自来水集团有限公司合作以小型现场试验进行的。

新开河水厂（ XWTP ）源水取自天津以北 230 公里的滦河。水厂设计总能力为每日 100 万立方米，目前使用含铁絮凝剂，不调节 pH 值。

源水中的 pH 值通常在 8.0 左右，影响絮凝剂的性能。 pH 值对于消毒步骤同样重要，它可以决定由 HClO 还是 ClO^- 占主要成分。 HClO 比 ClO^- 更有效，当 pH 值在 5.0 左右时为主要成分，调节 pH 值利于消毒步骤的进行。因而，此次研究中应用了 pH 调节。但是，为了找到最适合新开河水厂的絮凝剂，也对不调节 pH 值水进行了试验。

将瑞典 Kemira Kemi AB 生产的六种含铝絮凝剂（ ALG, PAX10, PAX16, PAX XL-1, PAX XL-60, PAX XL-61 ）和两种含铁絮凝剂（ PIX 111, PIX 115 ）以及中国首都钢铁公司生产的一种含铁絮凝剂进行了对比。使用的是一种台式自动絮凝器进行常规烧杯试验。对絮凝剂的几个方面指标：净水中的浊度，余铝，余铁，色度及 COD_{Mn} 作了比较。

不调节 pH 值水絮凝试验结果

在所有的含铝絮凝剂中，全部性能看来均好的是 PAX XL-61, PAX XL-60, PAX XL-1, PAX 10 也不错。所有含铁絮凝剂中全部性能看来都好的是 PIX 111 。

调节 pH 值水絮凝试验结果

在所有的含铝絮凝剂全部性能看来均好的是 PAX XL-61, PAX 10 也不错。所有含铁絮凝剂中全部性能看来都好的是 PIX 115 。

结论

总的说来，含铝絮凝剂比含铁絮凝剂的效果好。含铁絮凝剂中瑞典 Kemira Kemi AB 生产的比北京首都钢铁公司生产的要好。对所有的絮凝剂来说， pH 值对效果都是最重要的。只有 PAX XL-1 和 PAX XL-61 不需要较低的 pH 值也可得到最佳效果。

近期建议

为了得到最佳投资收益，不调节 pH 值处理源水时，建议使用 PAX XL-60 。

远期建议

长远看来一旦新开河水厂重建，增加 pH 调节，建议使用 PIX 115 。

1. SUMMARY AND RECOMMENDATIONS

This research describes the effect of aluminum- and iron based coagulant additions and optimization of coagulant conditions such as dose and pH. Furthermore the research contains information about the hydraulic conditions and the disinfection step at Xinkaihe Water Treatment Plant. The research was carried out as a Minor Field Study in Tianjin, P.R.China in cooperation with Tianjin Waterworks Co. between September 18th and November 23rd, 1996.

The Xinkaihe Water Treatment Plant (XWTP) receives raw water from Luanhe river, situated 230 km north of Tianjin. The designed total plant flow is one million m^3 per day and today an iron based coagulant is used without pH-adjustment.

The pH in raw water, normally around 8.0, affects the performance of the coagulant chemicals. For the disinfection step, pH is also of great importance as to determine whether HClO or ClO^- is dominant. HClO, which is more effective than ClO^-, is dominant at pH-values around 5.0 and the disinfection step would benefit from a pH-adjustment. In this study pH adjustment was therefore applied. However, in order to find the most suitable coagulant for XWTP, experiments using unadjusted water, as to pH, were carried out.

Six aluminum based (ALG, PAX 10, PAX 16, PAX XL-1, PAX XL-60, PAX XL-61) and two iron based coagulants (PIX 111, PIX 115) manufactured by Kemira Kemi AB, Sweden were compared with one iron based coagulant manufactured by Beijing Steel Company, P.R.China. An automated bench scale flocculator was used to perform conventional laboratory Jar-tests. The performance of the coagulants were compared in terms of final turbidity, residual aluminum or residual iron, color and COD_{Mn} of the treated water.

Water without pH-adjustment, results from flocculation experiments

Among the aluminum based coagulants the best overall performance was seen with PAX XL-61. PAX XL-60, PAX XL-1 and PAX 10 also worked well.
Among the iron based coagulants the best overall performance was seen with PIX 111.

Water with pH-adjustment, results from flocculation experiments

Among the aluminum based coagulants the best overall performance was seen with PAX XL-60. PAX 10 also worked very well.
Among the iron based coagulants the best overall performance was seen with PIX 115.

Conclusion

In general the aluminum based coagulants performed better than the iron based coagulants. Among the iron based coagulants the ones produced by Kemira Kemi AB, Sweden performed better than the one produced by Beijing Steel Company, China. For all of the coagulants the pH is essential for the performance. Only PAX XL-1 and PAX XL-61 did not need a lowered pH in order to obtain optimum performance.

Recommendation for the near future

In order to get the best return for the investment, when treating raw water without pH-adjustment, the usage of PAX XL-60 is recommended.

Recommendation for the long run

In the long run the usage of PIX 115 is recommended along with a reconstruction of the XWTP which would provide pH-adjustment.

2. ACKNOWLEDGMENTS

This Minor Field Study has been performed at Xinkaihe water treatment plant in cooperation with Tianjin Waterworks Co. between September 18th and November 23rd 1996.

We know that this research could not have been completed without the help of many people. First of all we thank the Swedish International Development Cooperation Agency for the financial support of this project and also Lars Gillberg (Kemira Kemi AB, Helsingborg, Sweden) who provided the coagulants used in the study and for his technical advice.

Our supervisors throughout this research have been professor Torsten Hedberg (Department of Sanitary Engineering, Chalmers University of Technology, Göteborg, Sweden) and chief engineer Mr Xu Jing Yi (Tianjin Waterworks Co., Tianjin P.R.China).
We wish to thank Torsten Hedberg for initiating this project. His contact with Tianjin Waterworks Co. and his technical advice have been invaluable for the performance of our study. We are grateful to Mr Xu Jing Yi and the staff of the chief engineers office for all assistance throughout the project, especially in making arrangement on location such as accommodation and transportation. Among the staff there are two persons whose help are especially appreciated, Mrs Jia Xia Zhen for being our contact person during the preparations in Sweden and "Ellen" for guiding us through the Chinese language and the Chinese customs.

This work required the cooperation of many employees at Xinkaihe water treatment plant. We thank Mr Leo and Mrs Jia for providing laboratory assistance and furthermore we extend our appreciation to Mrs Han for her technical support and for showing such great enthusiasm on the performance of our experiments.

During the preparatory studies in Sweden we appreciate the assistance of Evy Axén (Chalmers University of Technology). She also provided us with chemicals and equipment necessary for the research in China.

Finally, we thank Mr Fu Li (Tianjin Waterworks Co.) for sharing his knowledge in Chinese culture and Chinese history which enabled us to fully learn from the time we spent in Tianjin, both in and away from the factory.

3. BACKGROUND

3.1 Origin of the project

In September 1995 the Department of Sanitary Engineering at Chalmers University of Technology arranged a conference in Management of Urban Water Supply and Wastewater Systems in Göteborg, Sweden. During this conference Mrs Jia Xia Zhen, as a representative of Tianjin Waterworks Co., discussed problems at the water treatment plants in Tianjin with the Department of Sanitary Engineering. Professor Torsten Hedberg visited Tianjin in 1992 and was therefore familiar with the situation. At the end of the conference we met with Mrs Jia and together with Professor Torsten Hedberg a preliminary description of this project was set up to be carried out in autumn of 1996 at the Xinkaihe water treatment plant in Tianjin, P.R.China.

3.2 General description of Xinkaihe water treatment plant

Tianjin Waterworks Co. supplies over four million people with daily water. Xinkaihe is the largest of three major water treatment plants in Tianjin with a designed total plant flow of one million m^3 per day. The treatment process is divided into two separate phases - the second phase was completed in 1996, while the first phase has been used since 1986.

The raw water source is Luanhe River, located about 230 km north of Tianjin. All three major water treatment plants in Tianjin use the same raw water source.

Luanhe River has a high quality water most of the year with high turbidity only in the summer period. Stable and high water quality is normally prevailing in spring (March-May) and autumn (September-November), with water temperatures around 20°C. In winter the major problems are the low water temperature, causing ice formations on the surface in the sedimentation tank, and also low turbidity which makes the flocculation step more difficult, while in summer there is sometimes a problem with algae's in the raw water.

pH in the raw water is normally around 8.0 and the alkalinity is high, 100-200 mg HCO_3^-/l. The content of organic matters, measured as COD_{Mn}, is normally 2-4 mg/l O_2, however in summertime it can be above 5 mg/l O_2.

The water treatment plant has got three reservoirs were raw water is stored. Iron salt ($FeCl_3$) is used as coagulant chemical and the flocculation step is designed with hydraulic mixing. In phase one the separation step is carried out with so called tube settlers, while the second phase has traditional horizontal sedimentation tanks. In the final separation step there are twentyfour dual-media filters per phase. All filters are rapid filters with anthracite and sand.

For both phases chlorine gas is used as disinfectant. In the first phase the chlorine gas is dosed only in the distribution valve before flocculation, while in the second phase it is dosed at three places; before flocculation, after sedimentation and after filtration.

A detailed description of the operation is to be found in Appendix A in the end of this report.

3.3 Research objectives

One of the two primary goals was to optimize the chemical conditions of the treatment. Eight Swedish coagulants were compared with the coagulant used today at the treatment plant. The other goal was to evaluate the operation at Xinkaihe water treatment plant as to the hydraulic conditions and the addition of disinfection chemicals.

Specific objectives follow:

1. To compare the effects of various coagulant chemical additions as to turbidity, organic matters, color and residual aluminum or iron of the treated water.
2. To determine the optimum pH values for each of the nine coagulants.
3. To look into the treatment performance at Xinkaihe water treatment plant and to study the complete process, with special attention paid to the flocculation step and the separation step.
4. To examine the disinfection step as to the addition of chlorine and chlorine gas and to measure total chlorine and free chlorine in the water leaving the factory.

3.4 Scope of the project

The research was initiated by looking through the treatment operation at Xinkaihe water plant. Flocculation and separation was studied more elaborately in order to procure specific information necessary for the bench scale analysis. The quality data from the raw water source together with the detention times for coagulation, flocculation and separation were of great interest.

The knowledge about the operation was then the basis of the performance of the laboratory experiments, aiming to imitate the actual operation but in a smaller scale. In the bench scale experiments various chemical coagulants were compared in terms of turbidity, organic matters and residual coagulant.

The research was now divided into two groups depending on whether pH-adjustment was applied or not. Different doses were tested for each of the nine coagulants. Throughout the experiments the iron based coagulant presently used at XWTP worked as a frame of reference. Table 3-1 is a list of coagulants and doses that were studied during this work.

Aluminum Based Coagulants	Density (g/cm^3)	Al-content (%)	Dose (mg/l)
ALG		9.1	0.69, 1.04, 1.73
PAX 10	1.19	4.8	0.69, 1.04, 1.73
PAX 16	1.33	8.0	1.04, 1.73
PAX XL-1	1.23	5.0	0.69, 1.04, 1.73, 2.76
PAX XL-60	1.30	7.0	0.69, 1.04, 1.73, 2.76
PAX XL-61	1.24	5.3	1.04, 1.73
Iron Based Coagulants	**Density (g/cm^3)**	**Fe-content (%)**	**Dose (mg/l)**
PIX 111	1.40	13.7	1.04, 1.38, 1.73, 2.76
PIX 115	1.49	11.5	1.73
$FeCl_3$		6.6	1.38, 1.76, 2.76, 3.45

Table 3-1 List of coagulant chemicals used

Once all nine coagulants had been investigated one at a time, comparative experiments were carried out with a number of coagulants using the same sample of raw water.

In the end of the research at Xinkaihe water treatment plant a more circumstantial examination was carried out on the technical process. Constructional drawings were studied and the theoretically designed plant was compared with the actual performance. Finally, free and total chlorine was measured in the water leaving the factory, as well as at one point along the distribution net.

4. INTRODUCTION TO TREATMENT PROCESSES

Many impurities in water and wastewater are present as colloidal solids which will not settle. Their removal can be achieved by promoting agglomeration of such particles by coagulation and flocculation with the use of a coagulant followed by sedimentation. In this introduction the unit processes coagulation, flocculation, sedimentation and disinfection are explained in general.

4.1 Coagulation process

A coagulation process has two separate and distinct components or steps. First, particles in the water must be treated chemically to make them unstable. This involves the addition of one or more chemicals in rapid mixing tanks where vigorous mixing takes place for a short time, normally one minute or less. Second, these destabilized particles must be brought into contact with each other so that aggregation can occur. This is done by gentle stirring of the water in flocculation tanks. A schematic flow diagram of a coagulant process is shown in Figure (Sanks 1978).

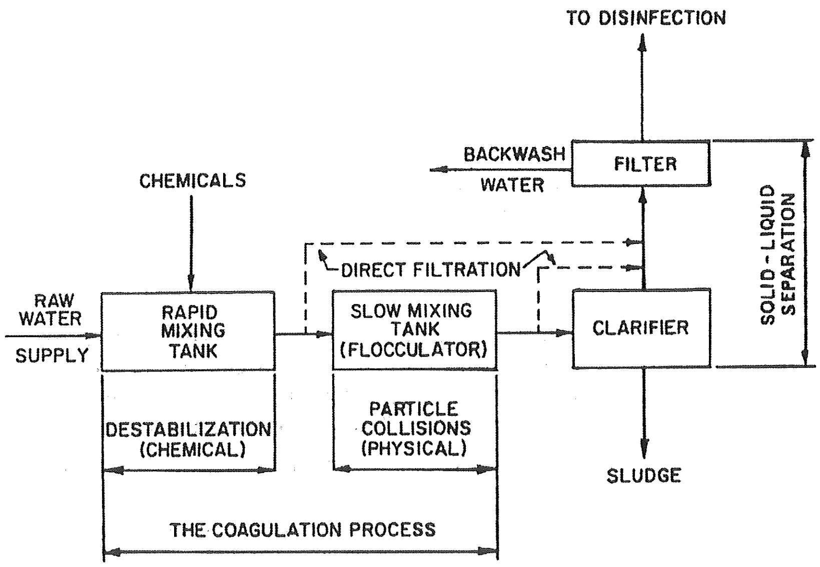

Figure 4:1 Schematic diagram of a coagulation process in a water treatment plant

4.2 Coagulation

Coagulation consists of adding, into the water, a product which can discharge the generally electro-negative colloids, present in water, and give rise to a precipitate.

This product is called a chemical coagulant. With low concentrations of colloids, a coagulant is added to produce bulky floc particles which enmesh the colloidal solids.

The coagulant is a metal salt, which reacts with alkalinity in the water to produce an insoluble metal hydroxide floc, which incorporates the colloidal particles. This fine precipitate is then flocculated to produce settleable solids.

Chemicals added to bring about or assist in destabilizing suspended particles includes salt of hydrolyzing metal ions such as aluminum sulfate and ferric chloride, polyelectrolytes, activated silica and various clays.

In many countries aluminum sulfate is the most used coagulant for water treatment, although there are some concerns about health hazards from aluminum residuals from its use. The manufactures claim that when the value of residual aluminum is as low as 0.05 mg/l there is no reason to worry about any health consequences (Tebbutt 1992).

Iron based coagulants such as ferric sulfate and ferric chloride are now again becoming popular because of the, probably unjustified, public concern about aluminum in water. Iron salts are cheaper than aluminum salts but unless precipitation is complete residual iron in solution can be troublesome, particularly due to its corrosive properties in the distribution system.

A first surmise of requisite coagulant dose for water treatment can be calculated using formula 4.1 compiled for Swedish waters on empirical basis. According to the formula the dose of trivalent metal ions are calculated, i.e. Al^{3+} and Fe^{3+}. Color and turbidity are representing the raw water quality (Compendium (1996), Department of Sanitary Engineering Chalmers University of Technology).

$$[Me^{3+}] = (\text{Color (mg Pt/l)} + \text{Turbidity (NTU)} + 50) \cdot 10^{-3} \text{ mmol/l} \quad (4.1)$$

With very low concentrations of colloidal matter floc formation is difficult and coagulant aids may be required. A coagulant aid, activated silica for example, may improve the possibility of collisions between particles. Added before the coagulant in treating low turbidity waters, activated silica can provide additional targets for flocculation permitting a reduction in coagulant dose. Added after the coagulant, activated silica can help to bind small flocs together into larger and denser aggregates (Sanks 1978).

4.3 Flocculation

Flocculation is an important part of the process used in many water treatment processes. The sedimentation step and the filtration step works more effective when the size of the particles in the water is increased. If the size of the particles in the raw water is too small to be removed by separation, increasing the size can be achieved by aggregation. This aggregation process is known as coagulation and flocculation.

The efficiency of the flocculation is affected by the probability of two particles colliding with each other as well as the ability of these particles to adhere after they were brought together by collision (Pieterse and Cloot 1996).

In the flocculation the volume of the water is mixed by hydraulic or mechanical mixing devices in order to improve the possibility of a collision between particles, which increases the size of the aggregate. It is important that the mixing energy is enough so that the particles collide, but not too high because then the flocs can not adhere.

In the flocculation tank, differences in velocity gradients occurs from point to point which entails particles, suspended in the water, to have different velocities, and hence can come into contact. A mean velocity gradient (G) can be determined, preliminary depending on the power input into the water.

As mentioned above velocity gradients are inducted by mechanical or hydraulic mixing. Hydraulic mixing is accomplished using baffled flocculation tanks that can be horizontal or vertical. Typical mechanical mixing installations, which nowadays are more common, use horizontal rotation paddles mounted either perpendicular to or along the axis of flow.

At Xinkaihe water treatment plant a baffled channel flocculator is used for both first and second phase and this flocculation design is accordingly described in detail in Chapter 4.3.1. Mechanical flocculators are discussed in detail in Chapter 4.3.2.

4.3.1 Baffled Channel Flocculators - hydraulic mixing

Baffled channel flocculators provide plug-flow mixing conditions and are an effective flocculation system. Baffled channel flocculators have some disadvantages, such as inflexible mixing and large head loss across the basin. Still they are capable of producing good floc, without any serious flow short circuiting, if the plant flow rate is fairly constant.

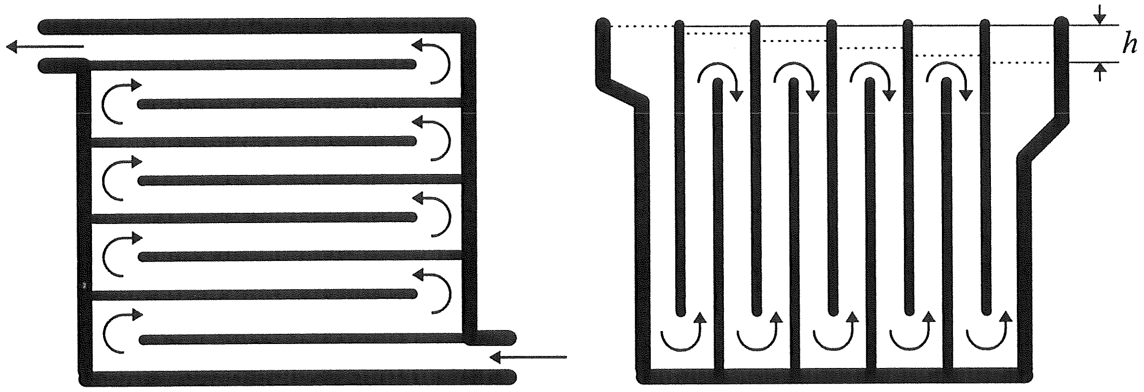

Figure 4:2 Horisontal and vertical baffles

Since tapered mixing is effective in forming large settleable flocs, the baffles should be properly arranged, to reduce the mixing intensity and floc shearing force in the latter stages of the tank. For a construction with hydraulic mixing the recommended water velocity should decrease from 0.65 m/s to 0.25m/s (Compendium (1996), Department of Sanitary Engineering Chalmers University of Technology). Because of inflow variations within a single day good mixing in the entire flow range may be difficult.

For baffled channel flocculation, the arrangement of the baffles can be computed based on an average velocity gradient (G value) of 20 or 30 sec^{-1} using the following formula 4.2 (Montgomery, Consulting Engineers, Inc. 1985):

$$G = \sqrt{\frac{g \cdot h \cdot \rho}{t \cdot \mu}} \qquad (4.2)$$

where g is the gravity constant [9.8 m/sec^2], h is the head loss [m], ρ is the mass density [1000 kg/m^3], t is the retention time [sec] and μ is the absolute viscosity [10^{-3} kg/m, sec at 20°C].

The head loss in a baffles mixing channel from turbulence and friction on the insides of the channel can be calculated using formula 4.3 (Montgomery, Consulting Engineers, Inc. 1985):

$$h = \frac{Lv^2}{C^2 R} \qquad (4.3)$$

where L is the length of the mixing channel, v is a mean flow velocity, C is the Chezy coefficient and R is the hydraulic radius.

4.3.2 Mechanical flocculators - mechanical mixing

Two basic types of mechanical flocculators are frequently used in water treatment facilities designed with horizontal rotating paddles mounted either perpendicular to or along the axis of flow. In Figure different facilities for mechanical flocculation are shown (Compendium (1996), Department of Sanitary Engineering Chalmers University of Technology). During the latter decades, vertical-shaft flocculators have reached a dominant position.

The rotating blades are turning relatively slow but sufficiently fast to prevent the deposition of sediment on the tank bottom. Mechanical flocculators provide more control over the process than the hydraulic flocculators but require more maintenance.

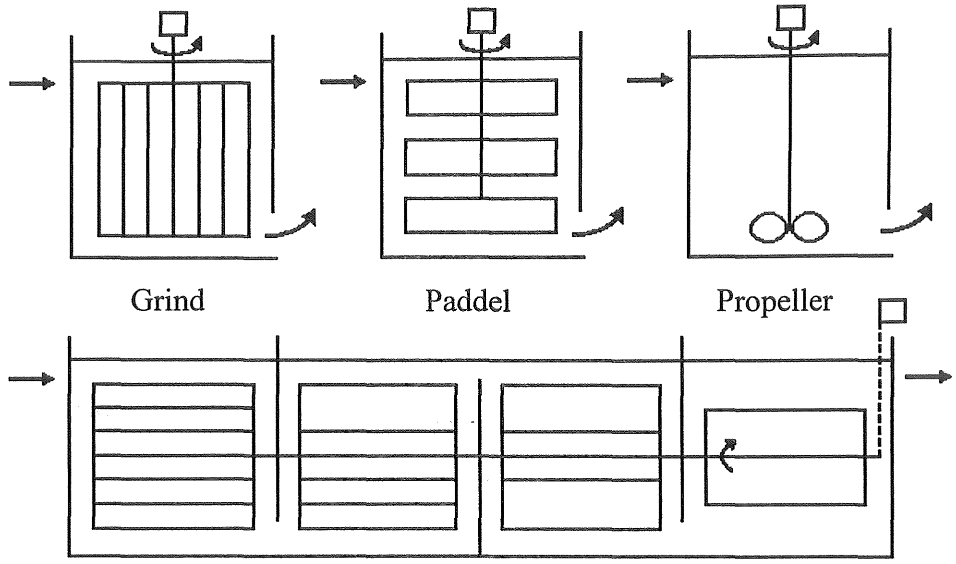

Figure 4:2 Different facilities for mechanical flocculation

Representative velocity gradient for horizontal-shaft paddle flocculator and vertical-shaft, high energy flocculator designs are 30 and 80 sec^{-1} respectively. Preferably, a decreasing velocity gradient should be used in order to obtain maximum size of the flocs. This requires three to six flocculation tanks with an abatement of the mixing velocity. For mechanical flocculation the G value can be calculated with the following formula 4.4 (O'Melia 1990):

$$\overline{G} = \sqrt{\frac{W}{\mu}} \qquad (4.4)$$

where $\overline{G}$ = mean velocity gradient [sec^{-1}]
W = power input per volume unit [$g/ms^3 = W/m^3$]
μ = absolute viscosity [$g/ms = Ns/m^2$]

W can be calculated in different ways depending on the performance of the power input. If paddles are designed mounted perpendicular to the axis of flow formula 4.5 can be used (O'Melia 1990).

$$W = \frac{C_D \rho}{2V}(2\pi)^3 \cdot \alpha^2 \cdot n^3 \cdot \Sigma A_{pi} \cdot r_i^3 \qquad (4.5)$$

where C_D = constant depending on the shape of the paddles
ρ = density [g/m^3]
V = volume [m^3]
α = constant depending on the movement of the paddles in relation to the water
n = number of revolutions [sec^{-1}]
A_p = area of one paddle [m^2]
r = radius of the paddle [m]

C_D has been determined on experimental basis. If the paddle has a cylindrical shape $C_D = 1.2$ can be used, and $C_D = 2.0$ for flat modeling. α is difficult to calculate and if measurements are not available the constant must be estimated. α is often stated to 0.6 - 0.75.

4.4 Sedimentation

Many of the impurities in water and wastewater occur as suspended matter, which remains in suspension in flowing liquids, but which will move vertically under the influence of gravity in quiescent conditions. Usually the particles are denser than the surrounding liquid so that sedimentation takes place. In the treatment of potable water, sedimentation is a common unit operation step used after coagulation-flocculation and ahead of filtration.

Sedimentation units have a dual role; the removal of settleable solids and the concentration of the removed solids into a smaller volume of sludge. The choice of design depends a great deal on the size of the plant throughput. The main types of sedimentation tanks are:

- long rectangular basins with or without sludge scrapes
- small square (or round) hopper-bottomed tanks
- tube settlers or lamella separators

At Xinkaihe water treatment plant tube settlers are used in the first phase while rectangular horizontal sedimentation basins with sludge scrapes are used in the second phase.

4.4.1 Rectangular Horizontal Sedimentation Basins

The behavior of a horizontal sedimentation tank, operating on a continuous flow basis with a discrete suspension of particles, can be examined by reference to an ideal sedimentation basin (Figure 4:3) which assumes:

1. Quiescent conditions in the settling zone.
2. Uniform flow across the settling zone.
3. Uniform solids concentration as flow enters settling zone.
4. Solids entering the sludge zone are not resuspended.

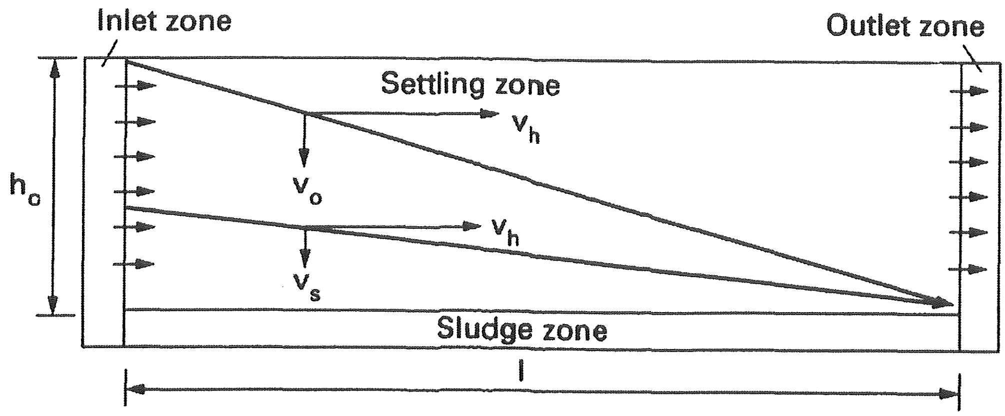

Figure 4:3 Ideal sedimentation basin (Tebbutt 1992)

Consider a discrete particle with a settling velocity v_0 which just enters the sludge zone at the end of the tank. This particle falls through a depth h_0 in the retention time t_0:

$$v_0 = \frac{h_0}{t_0} \tag{4.6}$$

But since

$$t_0 = \frac{Volume(V)}{Flow\,/\,unit\ time(Q)} \tag{4.7}$$

$$v_0 = \frac{h_0 \cdot Q}{V} = \frac{h_0 \cdot Q}{A \cdot h_0} \tag{4.8}$$

where A = surface area of sedimentation tank

Finally, the settling velocity of the particle, v_0 can be calculated as:

$$v_0 = \frac{Q}{A} \tag{4.9}$$

This shows that the surface overflow rate *(Q/A)* is of great significance for the settling performance. If a particle with the settling velocity v_f, entering the basin at the surface, reaches the sludge zone before the outlet zone, all other particles with the same settling velocity, entering the tank at a distance from the surface, will also settle. I.e. if the condition $v_f \geq (Q/A)$ is accomplished all particles with a settling velocity $\geq v_f$ will settle before the outlet zone (Tebbutt 1992).

4.4.2 Tube Settlers

In the mid-1960s, rapid rate settling devices made of plastic were introduced to the water market. These devices, called tube settlers, were of great interest in order to increase the flow rate through existing structures and reduce the detention time for the sedimentation step.

There are several configurations of tube shapes and sizes. The most common variety of settling tube is the upflow tube, shown in Figure 9:1, which can be placed in a conventional rectangular horizontal sedimentation basin. A typical commercial form is a system of square tubes inclined at 60° to the horizontal. In most applications the water flows upward and the sludge flows counter to the water (Sanks 1978).

Because time is shortened when tube settlers are used, velocities increase, creating a danger of hydraulic disturbance which can interfere with settling. The ideal distribution system is a baffle wall between the flocculator and the tube settlers, providing a stilling zone to decrease the velocity of the water. For a functional separation the same water flow should pass through each tube.

4.5 Disinfection step

Disinfection is a method where an essential reduction of microorganisms (bacteria's and virus), injurious to one's health, can be achieved.

The small size of microorganisms means that complete removal of them from water by processes such as coagulation and filtration can not be guaranteed. Because of the public health significance of water-borne microorganisms, it is essential to ensure the elimination of potentially harmful microorganisms from potable water, by the use of a suitable disinfection process.

4.5.1 Process Alternatives

Alternative disinfection systems available for the disinfection step are numerous. Generally, they can be divided into two groups:

1. chemical agents
2. non chemical agents

Chemical agents include an array of compounds with oxidation potential including chlorine, chlorine dioxide and ozone. Non chemical, or energy-related, means of disinfection include ultraviolet (UV) radiation.

In Table 4-1 (Compendium (1996), Department of Sanitary Engineering Chalmers University of Technology), a comparison between some of the most common disinfectants are shown.

	Efficiency	*Operation*	*Distribution system*
Chlorine	+ Excellent as HClO - Efficiency decreases with increasing in pH	+ Reliable + Cheap + Long experience - Accident hazard	+ Residual in distribution system - Increasing corrosion
Chlorine Dioxide	+ Excellent	+ Reliable + Relatively cheap + Advantageous to flocculation - Maximized dose	+ Residual in distribution system - Increasing corrosion - Difficulties in analyzing
Ozone	+ Excellent	+ Simple operation without chemicals + Advantageous to flocculation - Expensive	+ Decreasing corrosion - No residual in distribution system
UV	+ Good	+ Reliable + Simple operation without chemicals + Relatively cheap - Only clear water can be treated	- No residual in distribution system

Table 4-1 Disinfection alternatives, advantages and disadvantages

5. EXPERIMENTAL METHODS - THE JAR TEST PROCEDURE

This chapter describes the experimental approach and procedures used in the research studies at Xinkaihe water treatment plant.

5.1 Experimental design

In this section the components used in conducting the flocculation experiments are described.

5.1.1 Coagulants and Natural Waters

The nine coagulants used in the experiments are listed in Table 3-1. All of the coagulants were stored as liquids except ALG which was in form of granules. Six aluminum based (ALG, PAX 10, PAX 16, PAX XL-1, PAX XL-60, PAX XL-61) and two iron based coagulants (PIX 111, PIX 115) manufactured by Kemira Kemi AB, Sweden were compared with one iron based coagulant manufactured by Beijing Steel Company, P.R.China.

The natural raw water came from Luanhe River, a high quality water supply, most of the year, with algae problems and high turbidity in the summer. Table 5-1 shows the average quality values of the raw water during the time of experiments.

Quality parameter	Average value
pH	8.1
Turbidity (NTU)	6.9
Color	10 to 15
COD mg/l O_2	2.6
Temperature (°C)	17.4 (Max.: 22.6 in Sept., Min.: 12.1 in Nov.)
$[HCO_3^-]$ (mg/l)	156

Table 5-1 Raw water quality of Luanhe River Sept.-Nov. 1996

5.1.2 Flocculation equipment

Flocculation experiments were conducted using a bench scale automated Kemira flocculator system designed and produced by Kemira Kemi AB. The bench scale system consisted of six 1 liter Plexiglas jars and six vertical paddles operated by a control unit.

5.2 Experimental procedures

This section describes the experimental procedures used during work at the Xinkaihe water treatment plant.

5.2.1 Flocculation experiments - Jar tests

Water samples were collected from a raw water tap at the XWTP in a 7 liter plastic container. Most experiments were performed immediately after the collection and all experiments were done within 5 hours.
The water quality was measured for all raw waters which included measuring turbidity, pH, color, temperature and COD_{Mn}.
$[HCO_3^-]$ was measured in order to calculate preliminary pH-value for certain acid adjustments.
One liter of the raw water was added to each of the six jars. The proper amount of acid (0.1 M H_2SO_4) needed to obtain the desired pH after coagulant addition was then added to the water and mixed with fast rotation speed during 3 minutes. In order to decide the proper amount of acid, numerical analysis using a computer were performed. The first formula used for this was:

$$10^{-pH} = 10^{-pKa} \cdot \frac{[H_2CO_3]}{[HCO_3^-]} \qquad (5.1)$$

where	pH	=	The desired flocculation pH
	pKa	=	6.4 at 20°C
	$[HCO_3^-]$	=	Hydrogencarbonate concentration, mol/l
	$[H_2CO_3]$	=	Carbonic acid, mol/l

From formula 5.1 $[H_2CO_3]$ was calculated. From the formula (5.2), $[H_2SO_4]$ was then calculated.

$$10^{-pH} = 10^{-pKa} \frac{([H_2CO_3]+3[Me^{3+}]+2[H_2SO_4])}{([HCO_3^-]+3[Me^{3+}]-2[H_2SO_4])} \qquad (5.2)$$

where	$[Me^{3+}]$	=	The iron or aluminum ions at various doses

After the acid was added and mixed, a coagulant of the desired dose was added. The mixing condition was 5 minutes at 350 rpm followed by 15 minutes at 20 rpm and 10 minutes at 10 rpm. Every five minutes the size of the flocs was estimated.

As for the size of the floc, the mixing speed 20 rpm prevented optimum performance for some of the coagulants. Slow mixing at 10 rpm was therefore used to maximise flocsize without sedimentation occuring.

Mixing conditions with 5 minutes at 350 rpm, followed by 25 minutes at 20 rpm was also used in order to imitate the hydraulic conditions of the full scale treatment plant as closely as possible.

The recommended G-value for the slow mixing step, the flocculation step, at XWTP was $15s^{-1}$. With a mixing speed at 20 rpm and a water temperature of 15°C a G-value of $13s^{-1}$ was obtained for the Jar-test. Formula 4.4 and 4.5 were used to calculate the G-value.

After the flocculation step a settling period (sedimentation) of 40 minutes was used for most of the experiments. This period could have been reduced in some cases but was kept to 40 minutes to make sure that this part of the process would not effect the results. A shorter settling period of 10 minutes was used for some of the comparative experiments where different coagulants were added to the same raw water.

After the settling period samples of approximately 100 ml was gently withdrawn from 3 cm below the water surface which prevented getting sludge, formed on the surface of the water, into the sample bottle. The samples were used for measuring pH and turbidity.

For measuring color, residual aluminum or iron and COD_{Mn} 200 ml samples were filtered with Munktell filterpaper, quality 3. Before filtration the filter papers were washed with 50 ml distillated water and 50 ml of the samples in order to clean them from loose fibers which could affect the results.
Aluminum analysis were performed on the aluminum-based coagulants while iron analysis were performed on iron-based coagulants.

5.3 Analythical parameters

This section describes the chemical analyses used during work at the Xinkaihe water treatment plant.

5.3.1 Turbidity

A Hach Model 43900 ratio/XR turbidimeter was used to measure turbidity. Before each measurement, the instrument was calibrated, and the glass tubes containing the sample were cleaned with silicone oil produced by Hach CO. Turbidity was measured after approximately 10 seconds, as an average value of the values displayed.

5.3.2 pH

A pH-meter type PHS-2, with range pH 0-14 and accuracy pH 0.02 made by Shanghai 2nd Analytical Instruments Factory China was used to measure pH. The meter was calibrated daily and pH was measured after the reading had stabilized.

5.3.3 Temperature

The temperature of the water was measured with a temperature-meter SWL 1-1, model 88 after the reaction tank, before sedimentation, at a depth of two meters.

5.3.4 Aluminum

The Aluminum-method from SKTF Vattenundersökningar (1952) was used to measure dissolved aluminum:

The samples were filtered through Munktell filterpaper, quality 3, before the dissolved aluminum was measured.
Seven 50 ml distillated water samples mixed with known quantities (0-1.0 mg/l) of an aluminum standard solution was used as a reference measuring dissolved aluminum. 2 ml buffer-solution (Acetate buffer) was added both to the samples with known content of aluminum and to the samples with filtered water. The samples were mixed well and 1 ml Aluminon was added in each sample and mixed carefully.
After 15 minutes a color-comparison was made between the filtered samples and the samples with known content of aluminum.

5.3.5 Iron

Following method was used to measure dissolved iron:

4 ml HCl (1:1, density = 1.19 g/cm^3, concentration = 36%), was added to a 50 ml sample. The sample was mixed and 1 ml $HONH_3Cl$ (concentration = 10%) was added and mixed.
In order to improve the boiling conditions two small glassballs with a diameter of approximately 4 mm were added. The sample was heated up and boiled until 20-30 ml remained and was then cooled to room temperature and poured into a glass tube.
2 ml Phemanthroline, $C_{12}H_8N_2*H_2O$ (Concentration = 0.1%) was added together with 10 ml $HAc+NH_4Ac$ (700 ml HAc + 250 g NH_4Ac +150 ml H_2O). Pure water was added until the sample contained 50 ml. After mixing the sample rest for 10-15 minutes.
The sample was then poured into a glass-container (1cm*1cm*4cm) and put into a Fen Guang Du Ji colorimeter, model 721 made in Shanghai at no 3 analysis instrument factory. Light with a wavelength of 510 nm was used and the residual iron was measured after the reading had stabilized.

5.3.6 COD

The method described in this section was used to measure COD_{Mn}.

5 ml H_2SO_4 (1:3) and 10 ml $KMnO_4$ (0.0625 M) was added to a 50 ml sample.

In order to improve the boiling conditions two small glassballs with a diameter of approximately 4 mm were added. The sample was heated up to 80-100°C during 10 minutes and then 10 ml $H_2C_2O_4$ (0.0250 M) was added while the sample was still hot. After mixing $KMnO_4$ was added until the sample switched color from clear white to purple.The amount $KMnO_4$ needed was measured in ml which corresponded to the COD_{Mn} in mg/l.

5.3.7 Color

The method described in this section was used to prepare seven color standards which then were used as a reference when measuring the treated, filtrated water samples.

To 50 ml water 1.246 g K_2PtCl_6 (500 mg Pt), 1.00g $CoCl_2*6H_2O$ (250 mg Co) and 100 ml HCl (density = 1.19 g/cm^3, concentration = 36%) was added.
After mixing H_2O was added until the sample contained 1000 ml.
From this solution seven samples containing 0, 1, 2, 3, 4, 5, 6 and 8 ml were withdrawn and 100 ml purewater was added until the sample contained 100 ml.
The following table was created:

Solution [ml]	0	1	2	3	4	5	6	8
H_2O [ml]	100	99	98	97	96	95	94	92
Color [mg Pt/l]	0	5	10	15	20	25	30	40

Table 5-2 Color scale for different solutions

6. JAR TEST EXPERIMENTS FOR MODELING FULL SCALE OPERATION

6.1 Imitating the actual treatment process

Bench scale experiments were performed, in order to compare the effect of different coagulant chemicals. To get reliable results it is important that the experiments imitate the actual operation at the plant. In the research an automated bench scale flocculator was used with mechanical mixing during both the coagulation and the flocculation step. At Xinkaihe water treatment plant mechanical mixing is only used in the coagulation step, while in the flocculation step hydraulic mixing is carried out in a baffled channel. The difference will make each result impossible to directly convert into the actual operation. The various coagulants can only be compared relatively to each other.

6.2 Variations in raw water quality

In the beginning of each experiment raw water was taken from a tap at the treatment plant connected with the Luanhe river. The raw water quality had variations from day to day regarding turbidity, COD_{Mn}, color, pH and alkalinity. The most reliable results are therefore those from the comparative experiments with a number of coagulant chemicals using the same sample of raw water. The results of these experiments can be seen in Appendix B18-19, B22-23, B24, B25-26 and B27 or in Figure 7.19 to 7.23.

6.3 Low doses of coagulant chemicals

The raw water quality was high during the time of the year when this project was carried out. Therefore small doses of coagulant chemicals were used. The small variation in the raw water quality was advantageous when making comparative experiments.

7. RESULTS FROM THE JAR TEST EXPERIMENTS

7.1 Analytical parameters

The results of the analytical parameters were collected in tables in Appendix B. Some of the most interesting results were then transformed into graphs and charts. This section describes the results of the investigations showing the effects of different coagulants at various doses and pH's.

The criteria's used for determining applicable dose and successful sedimentation were the Chinese requirements for water leaving the treatment plant. The requirements concern water which is fully treated. In the bench scale experiments the turbidity is measured before filtration. Therefore the criteria, as to residual turbidity, is in a sense set too strict.

Chinese requirements for water leaving the treatment plant

1) Residual turbidity less than 1 NTU
2) Residual iron less than 0.2 mg/l
3) Residual aluminum less than 0.2 mg/l
4) COD less than 2.0 mg/l O_2
5) Color less than 5

7.1.1 Size of the flocs

The most rapid growing of flocs, after adding the coagulant, was seen with PAX XL-60 and PAX XL-61 followed by PAX 10, PAX XL-1 and $FeCl_3$.

7.1.2 Turbidity

In Appendix C, Figures C:1-9 present data on the effect of adding the coagulants in different doses at different pH. The data shows that the performances of the coagulants are depending on the pH. In general the iron based coagulants need a lower pH than the aluminum based coagulants, in order to get optimum performance.

Table 7.1 shows the optimum pH for each coagulant, based on evaluation of the results from the turbidity experiments.

Aluminum-based Coagulant	Optimum pH	Iron-based Coagulant	Optimum pH
ALG	6.2-6.5	PIX 111	5.3-5.5
PAX 10	6.3-6.7	PIX 115	5.2-5.5
PAX 16	6.3-6.7	$FeCl_3$	5.3-5.5
PAX XL-1	7.9		
PAX XL-60	6.7-6.9		
PAX XL-61	7.9		

Table 7-1 Optimum pH for each coagulant chemical

In Appendix C, Figures C:10-18 present data on turbidity with the dose 1.73 mg Al^{3+}/l or 1.73 mg Fe^{tot}/l at either optimum pH or at unadjusted raw water. The data shows that low turbidity is achieved, with the same coagulant and the same dose, using different samples of raw water.

Water without pH-adjustment

Experiments using unadjusted water, as to pH, were carried out in order to find the most suitable coagulant for Xinkaihe Water Treatment Plant today.
Figure 7:1 and 7:2 present data comparing different coagulants added at the same dose, 1.73 mg Al^{3+}/l. Figure 7:2 includes ALG and PAX 16 at optimum pH because those two coagulants gave unsatisfying results for unadjusted water. To make a fair comparison between the different coagulants each figure is based on a specific raw water.

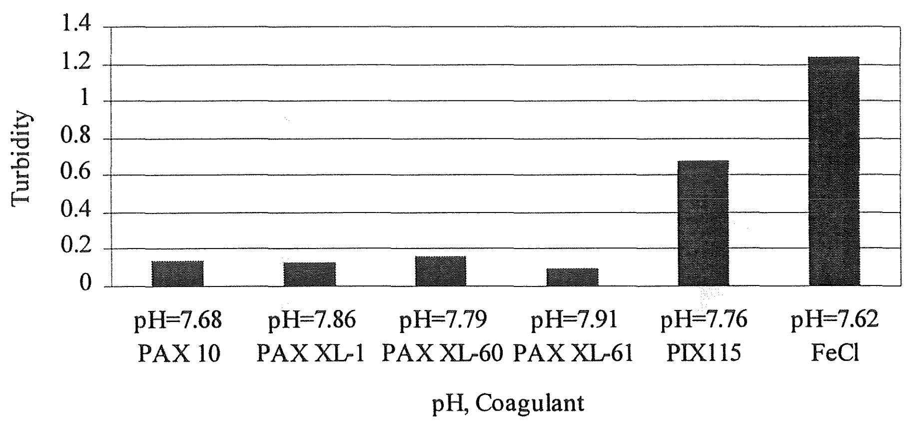

Figure 7:1 Turbidity without pH-adjustment, both Al- and Fe-based coagulants are added using the same sample of raw water at the dose 1.73 mg Al^{3+}/l or 1.73 mg Fe^{tot}/l

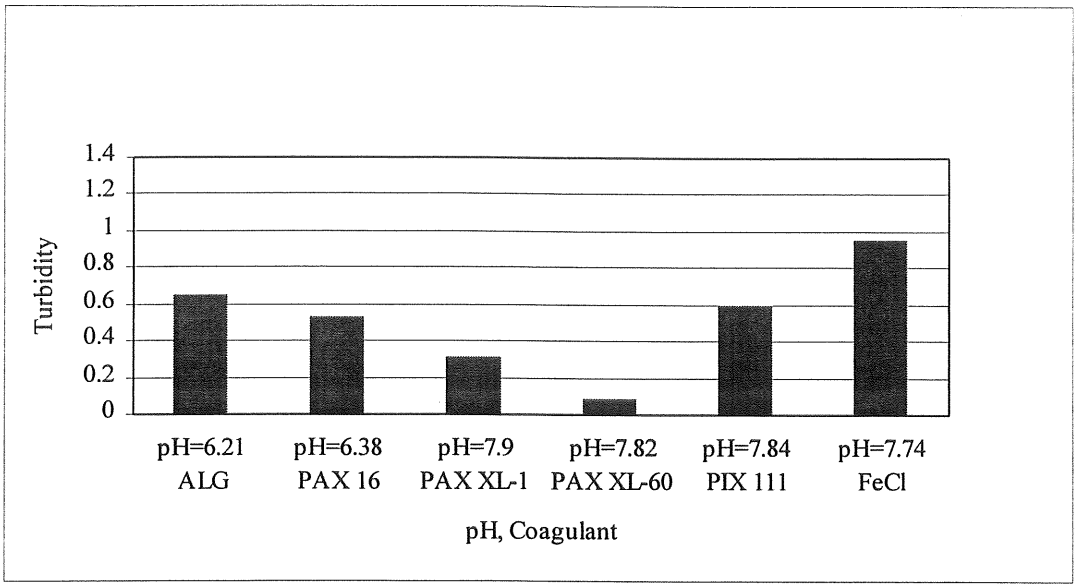

Figure 7:2 *Fe-based coagulants compared with PAX XL-1 and PAX XL-60 for unadjusted water. ALG and PAX 16 were added at optimum pH. All coagulants were added at the dose 1.73 mg Al^{3+}/l or 1.73 mg Fe^{tot}/l and raw water was taken from the same water sample.*

The results in Figure 7:1 and Figure 7:2 shows that, among the aluminum based coagulants, the best performance is seen with PAX XL-61. PAX XL-60, PAX XL-1 and PAX 10 also works well. Furthermore the best performance among the iron based coagulants is seen with PIX 111.

Figure 7:3 presents data comparing the aluminum based coagulants at the dose 0.69 mg Al^{3+}/l with the iron based coagulants at the dose 1.38 mg Fe^{tot}/l.

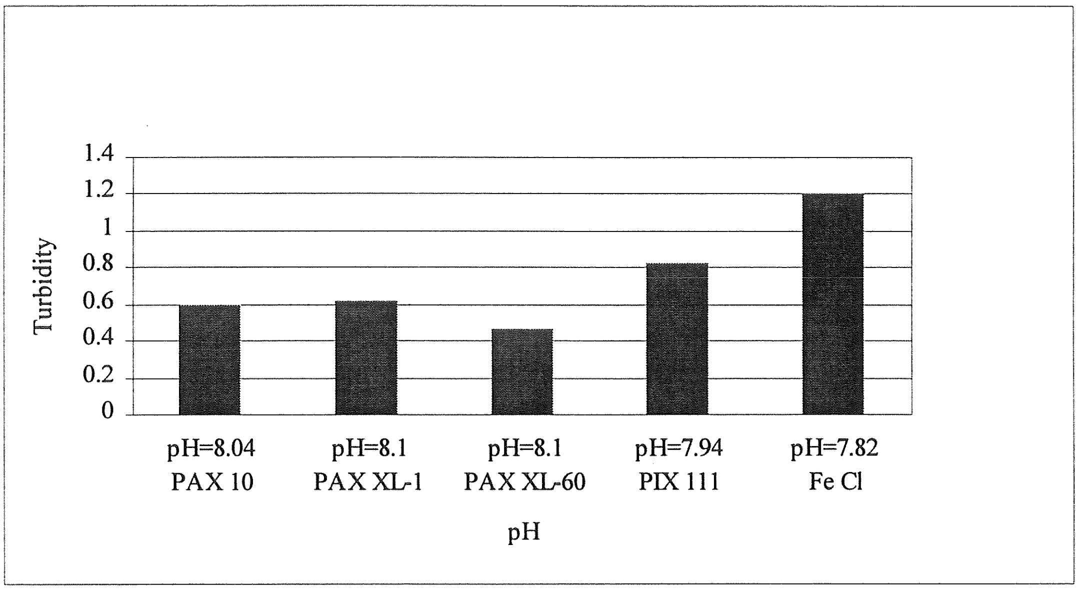

Figure 7:3 *Turbidity without pH-adjustment, dose 0.69 mg Al^{3+}/l and 1.38 mg Fe^{tot}/l*

The data in Figure 7:3 indicates that the aluminum based coagulants perform well at a lower dose than the iron based coagulants. All of the nine coagulants, except $FeCl_3$, manage to get the turbidity before filtration below the Chinese requirement of turbidity after filtration, which is 1 NTU. The optimum coagulant dose is varying from day to day but is usually about 1.04 mg Al^{3+}/l (except for ALG), 1.04 mg Fe^{tot}/l for the Swedish, iron-based coagulants and 1.73 mg Fe^{tot}/l for the Chinese, iron-based coagulant.

Water with pH-adjustment

The pH in raw water affects the performance of the coagulant. Adjustment of the pH was therefore applied in order to find the optimum treatment condition for each coagulant.

Figure 7:4 presents data comparing the aluminum based coagulants at optimum pH, at the dose 1.73 mg Al^{3+}/l, with the iron based coagulants, at the dose 1.73 mg Fe^{tot}/l.

In Figure 7:5 the dose is 1.04 mg Al^{3+}/l for the aluminum based coagulants and 1.04 mg Fe^{tot}/l for the iron based coagulants.

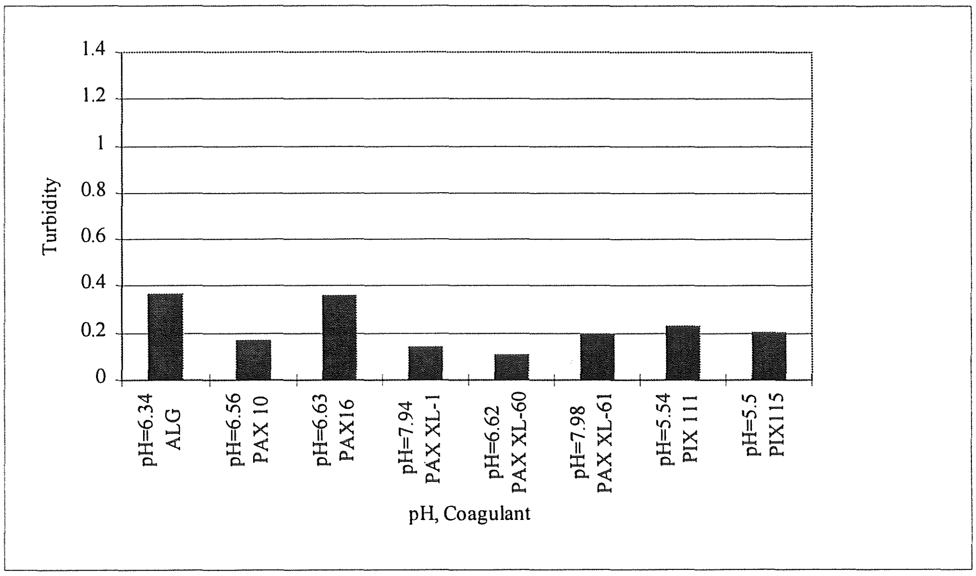

Figure 7:4 Turbidity at around optimum pH for various coagulants using the same raw water, dose 1.73 mg Al^{3+}/l or 1.73 mg Fe^{tot}/l

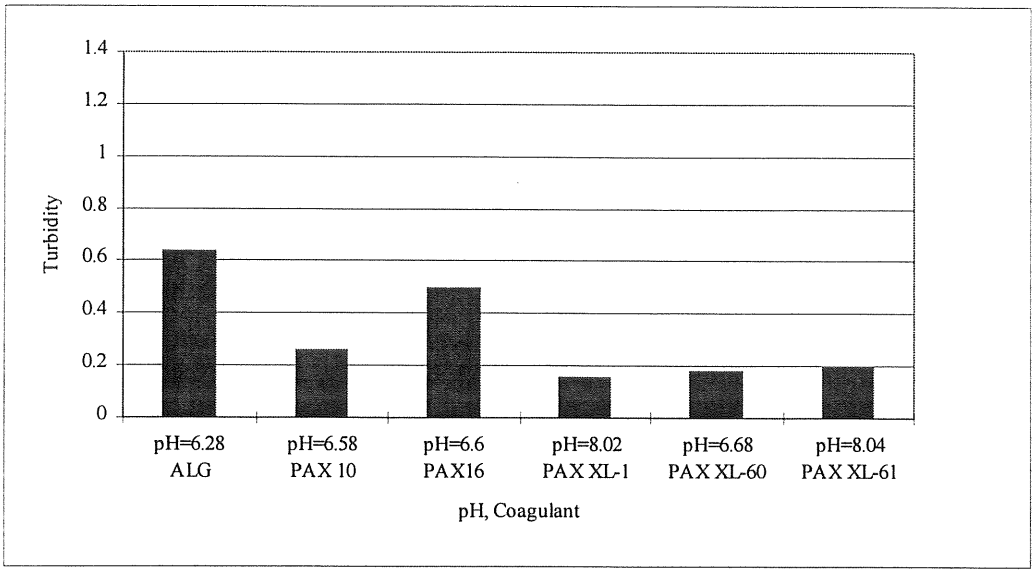

Figure 7:5 *Turbidity at around optimum pH for various coagulants using the same raw water, dose 1.04 mgAl^{3+}/l*

The data in Figure 7:4 shows that among the aluminum based coagulants the best performance is seen with PAX XL-60. PAX 10 also works very well.
Among the iron based coagulants the best performance is seen with PIX 115.
In Figure 7:5 relatively poor performance is seen using ALG at the doses 1.04 mg Al^{3+}/l. Further details can be found in Appendix B, page B12 and B27.

7.1.3 Residual Aluminum and Residual Iron

When using aluminum based coagulants, pH-adjustment is needed in order to get low residual aluminum in the treated water. This is showed in Table 7-2, which compares residual aluminum in pH- and not pH-adjusted water. The coagulants have been added using the same dose but different waters.

Aluminum Based Coagulants	**Residual Aluminum, without pH-adjustment (mg/l)**	**Residual Aluminum, with pH-adjustment (mg/l)**
ALG	0.15	0.05
PAX 10	0.15	0.05
PAX 16	0.175	<0.05
PAX XL-1	0.1	
PAX XL-60	0.15	<0.05
PAX XL-61	<0.05	

Table 7-2 *Residual Aluminum in pH-adjusted or unadjusted water, dose 1.73 mg Al^{3+}/l*

All of the coagulants pass the Chinese requirement of 0.2 mg residual aluminum/l.

Table 7-3 present residual iron after using an iron based coagulant in pH- and not pH-adjusted water. The data shows that pH-adjustment does not have a positive effect in order to get lower residual iron.

Iron Based Coagulants	Residual Iron, without pH-adjustment (mg/l)	Residual Iron, with pH-adjustment (mg/l)
PIX 111	0.07	0.125
PIX 115	0.10	0.10
$FeCl_3$	0.175	0.85

Table 7-3 Residual Iron in pH- or not pH-adjusted water, dose 1.73 mg Fe^{tot}/l

All of the coagulants pass the Chinese requirement of 0.2 mg residual Iron/l.

7.1.4 COD

All of the coagulants, which improve the performance as to turbidity by pH-adjustment, except $FeCl_3$, also improve the performance as to COD by pH-adjustment.

7.1.5 Color

All of the coagulants performs satisfying, with or without pH-adjustment, as to the color of the treated water.

7.2 Chlorine

Chlorine was measured as free residuals and total residuals. Water samples were taken from a tap located immediately after the completed treatment process and from another tap at Water Hotel located along the distribution net. Free residual chlorine (ClO^-, HClO, Cl_2, ClO_2) and combined residual chlorine (NH2Cl, $NHCl_2$, $NHCl_3$) together are equivalent to total residuals. The results in Table 7-4 are mean values from a number of experiments.

	Total residual	Free residual	Combined residual
At the treatment plant	1.6-1.7	0.6-0.7	1.0
At Water Hotel	0.5-0.8	0.3-0.5	0.2-0.3

Table 7-4 Residual Chlorine, mean values (mg/l)

When the reaction time for combined residuals are comparatively slow, they have an advantage for the distribution net, where a long-term acting disinfection is desirably. Free residuals are much more effective and are therefore wanted during the treatment process.

7.3 Discussion of Experimental Results

One of the aims was to determine the optimum pH for each of the nine coagulants. Table 7-1, showing optimum pH for each coagulant chemical, is mostly based upon the results from the turbidity experiments due to lack of trustworthy data of the other parameters. The optimum pH is slightly different for each one of the analytical parameters which has not fully been taken into consideration determining the optimum pH for each coagulant.

7.3.1 Turbidity

Among the analytical parameters turbidity gave the most reliable results as to the determination of optimum pH and optimum dose. The turbidity was measured on water after sedimentation, before filtration. Measuring the turbidity before filtration indicated whether the coagulant worked well or not more clearly than if measuring the turbidity after filtration.

The fact that all of the coagulants, except $FeCl_3$, gave a turbidity of the treated water before filtration (not using optimum pH) below the Chinese requirement, implicates a good performance among the coagulants produced in Sweden. $FeCl_3$ probably also performs good enough to pass the requirements, since the requirements do not concern water before filtration.

The iron based coagulant $FeCl_3$, will not be used in a future process at XWTP where a pH-adjustment can be carried out. Therefore $FeCl_3$ is not presented in a comparative Figure 7:4. Nevertheless the performance of the coagulant, as to turbidity, is improved by pH-adjustment.

7.3.2 Residual Aluminum and Residual Iron

The order of precedence among the aluminum based coagulants, as to minimize residual aluminum in the treated water, can not be established. Further experiments have to be performed in order to determine this since the results, showed in Appendix B, page B24 and B25, point in different directions - in Appendix B25 PAX XL-60 performs better than the other coagulants but in B24 it performs poorer than the other coagulants.
Among the iron based coagulants pH-adjustment did not have a positive effect in order to get low residual iron. $FeCl_3$, the coagulant produced in China, showed bad results at optimum pH as to turbidity. One theory is that the coagulant contains both

Fe^{2+} and Fe^{3+}. Turbidity only indicates whether there is Fe^{3+} in the treated water or not. Therefore a high value of residual iron is possible even when the turbidity is low.

7.3.3 COD

Some of the results from the COD-measurements are misleading. For an example, it is hard to believe that COD of the treated water should be higher than COD in the not treated raw water when using PIX 111 without pH-adjustment (Appendix B, page B13). If the filter-papers are not pre-washed properly before filtration of the samples, the results can be effected and have to be looked upon with some skepticism.
Even though the method can not be fully trusted, as to determine the exact COD of the filtrated water, it is still useful since a relative comparation of the results gives the order of precedence among the coagulants.

7.3.4 Color

Since the raw water had a rather low color value, never above 15, it is difficult to determine whether some of the coagulants performed better than others. Comparing the results from the color-test, the main deviation is little: from five to zero.

8. ECONOMICAL ASPECT OF THE TREATMENT PROCESS

Looking at the wide price range for different coagulants, one realize that making a proper choice of coagulant includes not only the treatment performance of the coagulant but also the cost of using it. In order to determine the cost, the dose needed to get acceptable treatment has to be determined for each of the coagulants. Generally the dose of 1.73 mg Fe/l was needed for the iron based coagulants whereas the dose of 1.04 mg Al/l was needed for the aluminum based coagulants.
Comparing USD/ton of the coagulant, the aluminum based coagulants are more expensive than the iron based coagulants. Table 8-1 is a list of the coagulants used and a rough estimate of their market-price in China.

Coagulant	Price (USD/ton)
PAX XL-61	525
PAX XL-1	455
PAX XL-60	455
PAX 16	350
PAX 10	350
ALG	210-255
PIX 111	150-180
PIX 115	150-180
$FeCl_3$	50

Table 8-1 Rough estimation of the Chinese market-price of coagulant chemicals used

A fair comparison between the prices of the coagulants has to take the doses of the coagulants used into consideration. To simplify, a high concentration and a high specific weight of the coagulant involves using a small dose of the coagulant. The comparison between the different coagulants is based on the amount of metal ions (Al^{3+} or Fe^{tot}) added. Table 8-2 presents the actual ranking among the coagulants, as to the cheapest price. The concentrations and the specific weights of the coagulants has been taken into consideration and the doses are as follow:

1.73 mg Fe^{tot}/l for $FeCl_3$
1.35 mg Fe^{tot}/l for PIX 111 and PIX 115
1.04 mg Al^{3+}/l for the aluminum based coagulants

Ranking	Price index	Turbidity index
5. $FeCl_3$	1.0	5.3
2. PIX 111	1.0	4.2
3. PIX 115	1.1	3.8
4. PAX 16	3.1	2.5
5. PAX XL-60	5.0	1.1
6. PAX 10	6.4	1.4
7. PAX XL-1	7.5	1.1
8. PAX XL-61	8.0	1.0

Table 8-2 *Ranking of most economic coagulant considering expenses and performances*

9. DISCUSSION OF XINKAIHE WATER TREATMENT PLANT

9.1 Flocculation step in phase two

At Xinkaihe water treatment plant mechanical mixing is used in the coagulation step while hydraulic mixing is used in the flocculation step. The hydraulic mixing is designed for a total plant flow of half a million m^3 per day. The inflow from the distribution valve is not regulated which causes a variation of the water flow. This leads to lack of control over this part of the treatment process which can cause quality problems in the water. Since the total capacity is not fully used there is a difference between the designed and the actual flocculation time and energy input. A fluctuating energy input, caused by the varying water flow, involves a varying floc-building intensity.

9.2 Sedimentation step in phase one

The sedimentation step for phase one is designed with a kind of lamella units called tube settlers, with cross sections shaped as a hexagon. The schematic design is shown in Figure 9:1. For a functional separation an equal water flow should pass through each tube.
Owing to their weight, flocs will slide down on the inside surface of the tubes. The water going on to filtration then contains less particles. It is of vital importance that all tubes are utilized.

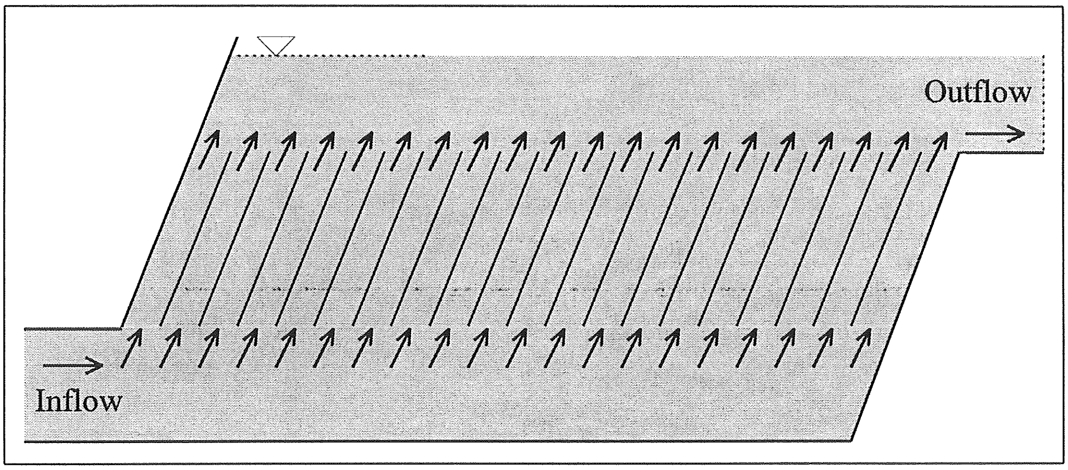

Figure 9:1 Functional separation in tube settler

Research work carried out indicates that the use of tube settlers can result in sedimentation problems. Investigations in Swedish water treatment plants show that the water-flow sometimes only passes through the last few tubes, resulting in a reaction flow on the top of the tubes. This course of events is shown in Figure 9:2.

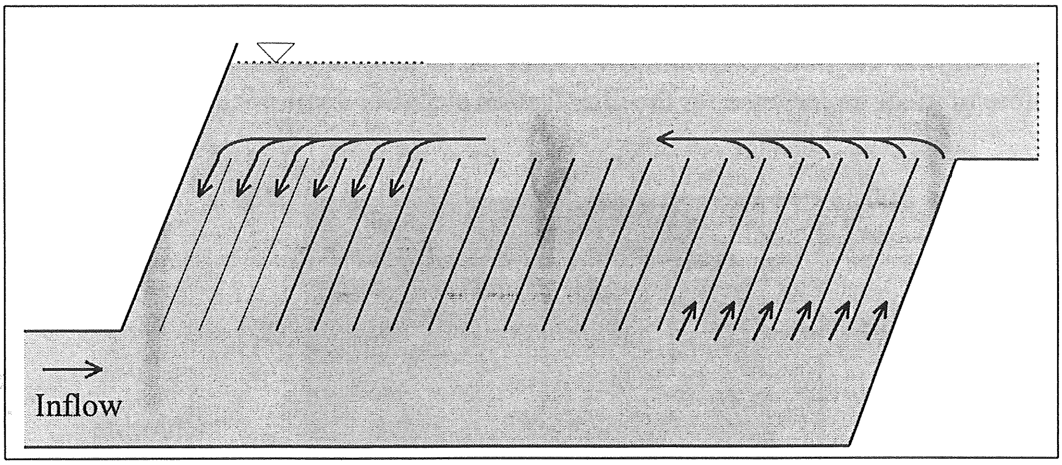

Figure 9:2 Not functional separation in tube settler

Thick sludge can create a powerful impulse which increases the circulation in the tube settler leading to a reduced performance.

9.3 Disinfection step in both phase one and two

At Xinkaihe water treatment plant chlorine and chlorine gas is used as a disinfectant in both phases. Chlorine (and its compounds) is widely used for the disinfection of water because:

1. It is readily available as gas, liquid or powder.
2. It is cheap.
3. It is easy to apply due to relatively high solubility (7000 mg/l)
4. It leaves a residual in solution which while not harmful to man provides protection in the distribution system.
5. It is very toxic to most microorganisms, stopping metabolic activities.

In phase two chlorine is dosed on three places; at the distribution valve, after sedimentation and after filtration. Total residual chlorine is measured and when the water reaches the clear water tank 1.2-1.4 mg/l is wanted. Free chlorine residuals (ClO^-, $HClO$, Cl_2, ClO_2) and combined chlorine residuals (NH_2Cl, $NHCl_2$, $NHCl_3$) together are equivalent to total residual chlorine.

Reaction when chlorine dissolves in the water in the absence of ammonia is shown below.

$$Cl_2 + 2\,H_2O \Leftrightarrow H^+ + Cl^- + HClO$$

Hypochlorous acid, HClO, hydrolyzes to chlorite ion, ClO^-:

$$HClO \Leftrightarrow H^+ + ClO^-$$

As a disinfectant hypochlorous acid HClO is more effective than the chlorite ion ClO^-. The pH value in the water determines whether HClO or ClO^- is dominant and pH is therefore of great importance for the disinfection step. See Figure 9:3.

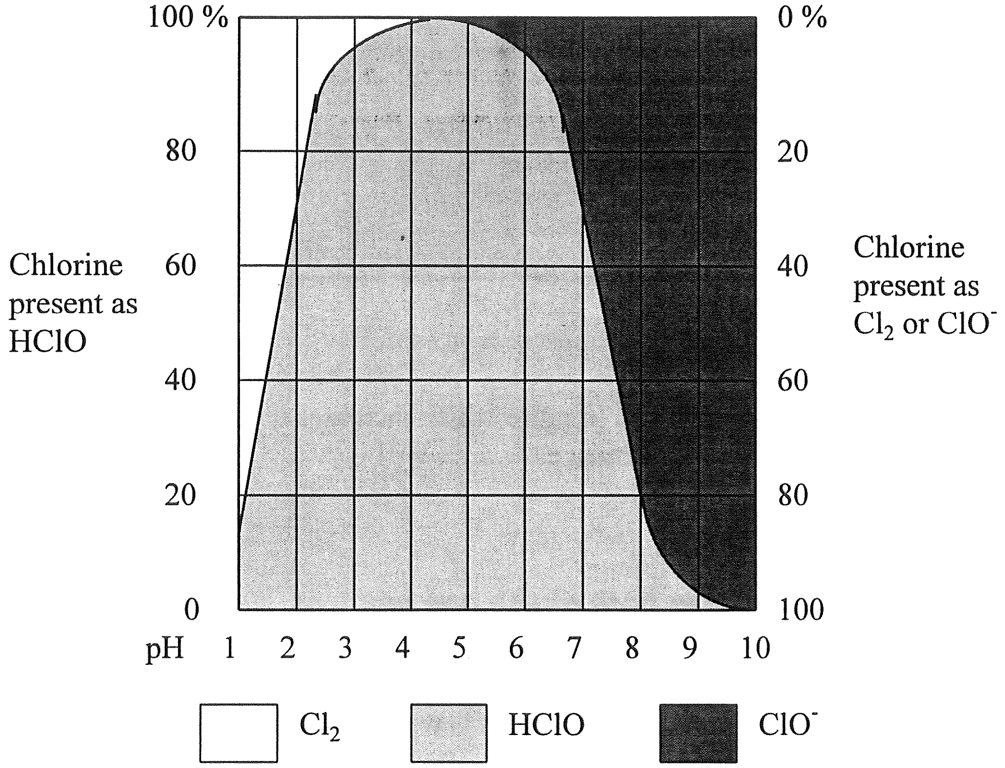

Figure 9:3 *The distribution between Cl_2, HClO and ClO^- in percentage at various pH*

At Xinkaihe water treatment plant pH-adjustment is not applied and the high pH value around 8.0 in the raw water is maintained throughout the complete process.
In Figure 9:3 it is shown in what way the high pH value will effect the disinfection, considering that HClO is a more effective disinfectant than ClO^-.

Before the clear water tank free residuals are dominant; they are a much more effective disinfectant than combined residuals. For a given kill with constant residual the combined form requires a hundred times the contact time required by the free residual. Alternatively, for a constant contact time the combined residual concentration must be twenty-five times the free residual concentration to give the desired kill.

Owing to a relatively slow reaction time, combined residuals have an advantage for the distribution net where a long-term acting disinfection is desirably. By adding ammonia to the water in the clear water tank free residuals can react and turn into combined residuals:

$NH_4^+ + HClO \Leftrightarrow NH_2Cl + H_2O + H^+$ (*monochloramine*)

$NH_2Cl + HClO \Leftrightarrow NHCl_2 + H_2O$ (*dichloramine*)

$NHCl_2 + HClO \Leftrightarrow NCl_3 + H_2O$ (*nitrogen trichloride*)

The attainment of the correct dose of chlorine is important since too low a dose will give a false sense of security and too high a dose will give a chlorine taste of the water. Furthermore, too high, a dose can be harmful to man by the by-products such as THM's that are formed. The required dose can only be determined experimentally and must be controlled to respond to fluctuating water quality.

10. RECOMMENDATIONS

This chapter deals with recommendations to improve the treatment process at the Xinkaihe Water Treatment Plant. The recommendations are based upon costs involved using different coagulants, the results of the experiments described in this report and local conditions at the XWTP in terms of available equipment and education of the employees.

10.1 In the near future

Today the Xinkaihe Water Treatment Plant does not use pH-adjustment in the treatment process. Since the proper equipment is missing and the employees have little experience in dealing with pH-adjustment, the usage of a coagulant suitable for not pH-adjusted waters is recommended.
Bench Scale Laboratory Experiments gave best results for PAX XL-61, but in order to get the best return from the investment, the usage of PAX XL-60 is recommended. Compared to Chinese requirements as to final turbidity, residual aluminum, color and COD_{Mn} of the treated water, PAX 10 worked very well.

10.2 In the long run

The low cost coagulant, PIX 115 (iron sulfate), need pH-adjustment for optimum performance. In the long run the usage of this coagulant is recommended since its performance is more than satisfying, and much better than the coagulant used at the XWTP today. According to Figure 9:3, the disinfection step would also benefit from a pH-adjustment. Therefore a reconstruction which would provide pH-adjustment at the XWTP is to prefer.

11. LITERATURE / REFERENCES

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APPENDIX A

APPENDIX A

Data of the designed First Phase of the Xin Kaihe Water Treatment plant

Schematic picture of the process:

Raw water ⇒ [1] ⇒ [2] ⇒ [3] ⇒ [4] ⇒ [5] ⇒ [6] ⇒ [7] ⇒ [8]

1. **Distribution Well**
   size = 20×8×8.6 m^3
   retention time: 4 min

2. **Mechanical Mixer (propeller mixer)**
   size = 2.2×2.2×4.4 m
   propeller: D = 1.6 m, n = 29 rpm
   mixing time: 54 sec

3. **Mechanical Reaction Tank**
   size = 3.3×3.3×4.3 m^3, reaction time: 4 min
   propeller mixer: n = 8 rpm

4. **Baffled reaction tank**
   size = 15.4×12×5 m^3, reaction time: 16 min
   inlet speed = 0.4 m/s
   outlet speed = 0.18 m/s

5. **Sedimentation Tank**
   upward speed of the water passing inclined tube settlers = 3.14 mm/s
   retention time = 30 min
   inclined tube settler: D = 35 mm

6. **Dual Media Filter**

   size = 10×8.4×3.55m^3
   running period: 8-16 h
   filter speed = 14 m/h
   media expansion rate = 40 %
   backwash time = 5 min
   washed water quantity = 360 m^3

7. **Treated Water reservoar -Clear Water Tank**
   size = 42×42×4.2 m^3

8. **Supply Water Pump Station**

Data of the designed Second Phase of the Xin Kaihe Water Treatment Plant

Schematic picture of the process:

Raw water ⇒ [1] ⇒ [2] ⇒ [3] ⇒ [4] ⇒ [5] ⇒ [6] ⇒ [7]

1. **Distribution Well**
   size = 21×6.5×8.9 m^3
   retention time: 4 min

2. **Mechanical Mixer (Axial flow impeller)**
   size = 3.0×3.0×3.5 m
   mixing time: 13 sec

3. **Baffled reaction tank**
   size = 30.4×30.4×4.8 m^3, reaction time: 36 min
   inlet speed = 0.5 m/s
   outlet speed = 0.17 m/s

4. **Horizontal Sedimentation Tank**
   retention time = 2 h
   size = 90×30.4×4.6m^2
   horzontal velosity = 12.5 mm/s

5. **Dual Media Filter**

   size = 14.8×8×3.65m^3
   running period: 12-24 h
   filter speed = 8 m/h
   media expansion rate = 40 %
   backwash time = 5 min

6. **Treated Water reservoar -Clear Water Tank**
   size = 42×34×4.2 m^3

7. **Supply Water Pump Station**

APPENDIX B

Sheet for flocculation-test

Date: Sept 27 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	$FeCl_3$		1.73	0	2	3	4	4	5	5	8	1.55		0.175	5	
2	$FeCl_3$		1.73	4	1	2	3	3	4	4	7	1.64			5	
3	$FeCl_3$		1.73	6	1	2	2	3	4	4	6.6	1.52			5 to 10	
4	$FeCl_3$		1.73	10	1	2	2	2	3	4	5.7	1.05		0.85	<5	
5	$FeCl_3$		1.73	14	0	0	0	0	1	1	3.3	4.4			5	
6	$FeCl_3$		3.45	0	3	4	4	5	6	6	7.55	1.45			10 to 15	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.57	7.4	10 to 15	3	22	134.2

Sheet for flocculation-test

Date: Sept 28 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose: Al^{3+} (mg/l)	Dose: Fe^{tot} (mg/l)	pH-adj. H_2SO_4 0.1M (ml)	Coagulation: 5 min	10 min	15 min	20 min	25 min	30 min	pH-value	Analyses: Turbidity (NTU)	Filtrated water: Residual Al (mg/l)	Residual Fe (mg/l)	Color	COD
1	$FeCl_3$		2.76	0	1	4	4	4	4	4	7.76	1.54		0.23	10	2.1
2	$FeCl_3$		2.76	10	0	3	4	4	4	4	6.18	0.72		0.18	<5	1.65
3	$FeCl_3$		2.76	12	1	4	5	5	5	5	5.42	0.39		2.45	<5	0.95
4	$FeCl_3$		2.76	14	0	1	1	2	2	2	3.74	4.47				
5	$FeCl_3$		1.04	0	0	2	3	3	3	3	8.14	3.3				
6	$FeCl_3$		1.04	12	0	1	2	2	2	2	5,76	4				
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Coagulation: 0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.4	4.4	15 to 20	2.9	22.6	161

Sheet for flocculation-test

Date: Sept 28 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	$FeCl_3$		2.76	12.3	1	3	4	5	5	5	5.64	0.652			5	1.2
2	$FeCl_3$		1.73	12.5	1	2	2^+	3	3	3	5.64	1.25			<5	
3	$FeCl_3$		1.73	12.2	1	1	1	2	2	2	5.95	1.83			5	
4	$FeCl_3$		1.73	11.2	1	1	2	2	2	2	6.14	1.94			10	
5	$FeCl_3$		3.45	11.5	1	3	3	4	4	5^+	5.82	0.4			<5	1
6																
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.32	4.3	15	2.7	22.6	

Sheet for flocculation-test

Date: Oct 3 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-60	1.04		0	1	2	4	5	6	6	7.9	0.51	0.2-0.15		<5	1.9
2	PAX XL-60	1.04		1	1	2	4	5	6	6	7.48	0.452			<5	
3	PAX XL-60	1.04		2	1	3	4	5	6	6	7.18	0.57			<5	
4	PAX XL-60	1.04		4	1	2	3	4	5	5	6.82	0.327	<0.05		<5	2
5	PAX XL-60	1.04		7	1	2	3	3	4	4	6.44	0.355			5	
6	PAX XL-60	1.04		10	1	2	3	3	4	4	5.75	0.33			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
7.94	7.85	10 to 15	2.4	19.6	146.4

Sheet for flocculation-test

Date: Oct 4 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-60	1.73		0	2	3	4	4	4^+	5	7.78	0.118	0.15		<5	1.77
2	PAX XL-60	1.73		1	2	3	4	4	5	5	7.5	0.228			<5	
3	PAX XL-60	1.73		3	2	4	4	4^+	5	5	7.02	0.146			<5	1.53
4	PAX XL-60	1.73		6	2	3	4	4	4^+	5	6.53	0.117	<0.05		<5	1.43
5	PAX XL-60	1.73		8	2	3	4	4	4^+	5	6.12	0.11			<5	
6	PAX XL-60	1.73		10	2	3	4	4	5	5	5.66	0.13			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
7.95	8.85	15	2.3	19.6	134.2

Sheet for flocculation-test

Date: Oct 8 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses					
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-60	2.76		0	2	3	3^+	3^+	5	5	7.72	0.175	0.1-0.05		<5	1.7
2	PAX XL-60	2.76		1	2	3	3^+	3^+	4	4	7.42	0.18			<5	
3	PAX XL-60	2.76		2	2	3	3^+	3^+	4	4	7.12	0.18	<0.05		<5	1.35
4	PAX XL-60	2.76		5	2	3	3	3	3^+	3^+	6.72	0.39			<5	
5	PAX XL-60	2.76		8	2	3	3	3	3^+	3^+	6.33	0.175			<5	
6	PAX XL-60	2.76		10	2	3	3	3	3^+	3^+	5.72	0.432			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.07	9.12	10	2.5	17.8	136.4

Sheet for flocculation-test

Date: Oct 8 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PIX 111		1.73	0	1	2	3	4	5	6	7.9	0.814		0.07	<5	2
2	PIX 111		1.73	2	1	2	3	4	6	6	7.35	0.96			<5	
3	PIX 111		1.73	5	1	2	3	4	5	6	6.77	1.149			5 to 10	
4	PIX 111		1.73	8	1	2	3	4	5	6	6.32	0.824			<5	
5	PIX 111		1.73	10	1	2	3^+	4^+	6	6	5.74	0.532		0.125	5	
6	PIX 111		1.73	10.5	1	2	3^+	4^+	6	6	5.6	0.464			<5	1.35
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
7.94	7.6	10	2.5	17.8	136.6

Sheet for flocculation-test

Date: Oct 9 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PIX 111		1.04	0	1	2	3^+	4	4	4	7.85	1.73			<5	
2	PIX 111		1.04	2	1	2	3	4^-	4^-	4	7.3	2.33			5	
3	PIX 111		1.04	5	1	2	2	3^-	3^-	3	6.75	3.1			5 to 10	
4	PIX 111		1.04	8	1	2	2	2	2	2	6.32	4.1			5 to 10	
5	PIX 111		1.04	10	1	2	3	3	4	5	5.52	1.88			10	
6	PIX 111		1.04	10.5	1	2	3	3	4	5^-	4.98	1.57			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.04	7.5	>10	2.3	17.8	136.6

Sheet for flocculation-test

Date: Oct 9 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
					0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm								Filtrated water			
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)								Turbidity (NTU)	Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PIX 111		2.76	0	1	3^+	4	4	5	5	7.68	0.364		0.1	<5	1.15
2	PIX 111		2.76	2	1	4	4	4	5	5	7.28	0.453			<5	
3	PIX 111		2.76	6	1	4	4	4	5	5	6.64	0.321			5	
4	PIX 111		2.76	9	1	4	4^+	5	5	5	6.1	0.225			<5	
5	PIX 111		2.76	10.5	2	4^+	4^+	5	6^-	6^-	5.52	0.34		0.06	<5	1.85
6	PIX 111		2.76	11.5	1	4	4^+	4^+	5^+	5^+	4.42	0.23			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.02	6.8	>10	2.55	17.4	142.7

Sheet for flocculation-test

Date: Oct 10 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-1	1.73		0	1	3	3	4	4^+	5	8.08	0.34	0.1		<5	1.7
2	PAX XL-1	1.73		1	1	2^+	3	3^+	4	4^+	7.68	0.46	0.06		<5	1.7
3	PAX XL-1	1.73		2	1	2	2^+	3	3^+	4	7.34	0.41			<5	
4	PAX XL-1	1.73		5	1	2^-	2	3	3	3	6.88	0.5			<5	
5	PAX XL-1	1.73		8	1	1	2	2^+	2^+	2^+	6.48	1.26			5	
6	PAX XL-1	1.73		10	1	1	1	2	2	2	5.86	1.47			5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.46	6.93	>15	3.25		

Sheet for flocculation-test

Date: Oct 10 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
					0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm								Filtrated water			
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)								Turbidity (NTU)	Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-1	2.76		0	2	3	3^+	3^+	4	4^+	8	0.22	<0.05		<5	1.8
2	PAX XL-1	2.76		1	2	2^+	3	3	3^+	4	7.62	0.35	0.15		<5	
3	PAX XL-1	2.76		3	1	2	3^-	3	3	3^+	7.12	0.345			<5	
4	PAX XL-1	2.76		6	1	2	2	3	3	3^+	6.71	0.75			<5	1.5
5	PAX XL-1	2.76		9	1	2	2	3	3	3^+	6.04	0.845			5	
6	PAX XL-1	2.76		10.5	1	1	1	2	2	2	5.58	1.56			5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.57	5.7	>15	3.3		

Sheet for flocculation-test

Date: Oct 14 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-1	1.04		0	1	2	3	3	4	4	8.08	0.39	0.1 to 0.05		<5	
2	PAX XL-1	1.04		4	1	2	2	2	3	4	7.48	0.65			<5	
3	PAX XL-1	1.04		8	1	1	2	2	2^+	3	6.86	0.74			<5	
4	PAX XL-1	1.04		11.5	0	0	1	1	1	2^-	6.18	2.25			<5	
5	$FeCl_3$		2.76	11.5	1	3	4^+	5	6	6	5.76	0.16		1.33	<5	0.65
6	$FeCl_3$		2.76	12.1	1	4	4	4	5	5^+	4.92	0.21		1.33	<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.1	5	5 to 10	2.9	18	157.4

Sheet for flocculation-test

Date: Oct 14 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
					0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm								Filtrated water			
													Residual		Color	COD
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	5 min	10 min	15 min	20 min	25 min	30 min		Turbidity (NTU)	Al (mg/l)	Fe (mg/l)		
1	PAX XL-1	1.04		0	1	2	3	4^-	4	4	8.03	0.29	0.1 to 0.05		<5	2.1
2	$FeCl_3$		1.73	0	1	2^+	3	4	4	5^+	7.85	0.89		0.175	<5	2
3	$FeCl_3$		1.73	12.2	1	3	3	4	4^+	5	5.94	0.385			<5	
4	$FeCl_3$		1.73	12.5	1	3^-	3	4	4	5	5.83	0.35		0.87	<5	1.4
5	PIX 111		1.73	0	1	2^+	3	4	4	5	7.98	0.49		0.065	<5	2.95
6	PIX 111		1.73	12.4	1	3	3^+	4	4^+	5	5.86	0.37		0.18	<5	1.4
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.04	4.6	5 to 10	2.65	18	161

Sheet for flocculation-test

Date: Oct 15 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses					
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water				
													Residual		Color	COD	
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)			
1	PAX 10	1.73		0	1	3	4	4	5	5^+	7.75	0.18	0.15		<5	1.3	
2	PAX 10	1.73		4	1	3	4	4	5	5	7.1	0.2			<5		
3	PAX 10	1.73		8	1	3	3^+	3^+	4	5	6.45	0.26	<0.05		<5		
4	PAX 10	1.73		10	1	2^+	3	3^+	4	4^+	6.22	0.19	0.05		<5	1.8	
5	PAX 10	1.73		11.5	1	2	3	3	4^-	4	5.85	0.36			<5		
6	PAX 10	1.73		13	1	2	3	3	3^+	4	5.31	0.34			<5		
	Rotationvelocity (rpm)				350	20	20	10	10	10							

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.02	4.8	10 to 15	2.8	18	163.48

Sheet for flocculation-test

Date: Oct 15 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX 10	1.04		0	1	2	3	4	4^+	5^+	7.7	0.37	0.15		<5	1.7
2	PAX 10	1.04		4	1	2	3	4^-	4	5^-	6.97	0.35			<5	
3	PAX 10	1.04		7	1	2	3	3^+	4	4^+	6.52	0.29	<0.05		<5	1.5
4	PAX 10	1.04		9	1	2	3^-	3	4^-	4	6.36	0.46	<0.05		<5	1.4
5	PAX 10	1.04		11	1	2	3^-	3	3	4	5.95	0.51			<5	
6	PAX 10	1.04		12.5	1	1^+	2	3^-	3^-	3	5.52	0.69			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
7.8	5.2	10 to 15	2.6	18	161.04

Sheet for flocculation-test

Date: Oct 16 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX 16	1.73		0	1	2^+	3	3^+	4^+	5	8.03	0.75	0.2 to 0.15		5	2.3
2	PAX 16	1.73		6	1	2^+	3	3^+	4^+	5	7.23	0.46			<5	
3	PAX 16	1.73		11	1	2^+	3	3^+	4	4^+	6.51	0.42	<0.05		<5	1.45
4	PAX 16	1.73		13	1	2	3^-	3	4	4^+	6.38	0.5			<5	
5	PAX 16	1.73		15.5	1	2	2^+	3^-	4^-	4	5.96	1.27			5	
6	PAX 16	1.73		16.8	1	1	2^-	2^+	3	3^+	5.54	2.06			5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8,08	5.7	10 to 15	3.3	17.7	215.9

Sheet for flocculation-test

Date: Oct 16 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual Al (mg/l)	Residual Fe (mg/l)	Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min						
1	ALG	1.73		0	1	2	2^+	3	4^+	4^+	7.97	1.35	0.15		5	
2	ALG	1.73		7	1	2^+	3	4^-	5^+	6	7	0.88			<5	
3	ALG	1.73		10	1	3	4^-	4	5	6	6.67	0.64			<5	
4	ALG	1.73		12	1	3	3^+	4	5^-	5^+	6.6	0.62	0.05		<5	1.8
5	ALG	1.73		13.5	1	3	3^+	4^-	5	5^+	6.27	0.73			<5	
6	ALG	1.73		16.2	1	3^-	3	3^+	4	5^-	6.04	0.98			<5	
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.28	6.2	10 to 15	4.2	17.7	223.3

Sheet for flocculation-test

Date: Oct 28 1996 (a.m.)

The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	ALG	1.73		8.3	1	3^-	3	4^-	4^+	5	6.73	0.16	<0.05		<5	1.3
2	PAX 16	1.73		7	1	3	3	4^-	4^+	5	6.97	0.17			<5	1.2
3	PAX 10	1.73		7.5	1	3	3^+	4	5	5^+	6.76	0.2	<0.05		<5	
4	PAX 10	1.73		0	1	3	4^-	4	5	6	7.77	0.12	0.1		<5	2
5	PAX XL-60	1.73		6	1	3	4^-	4	5^-	5^+	7	0.06	<0.05		<5	1.5
6	PIX 111		1.73	11.5	1	2^+	3	3^+	5	6	5.42	0.35		0.11	<5	1.25
	Rotationvelocity (rpm)				350	20	20	10	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.13	6.1	10 to 15	2.2	14.8	146.4

Sheet for flocculation-test

Date: Oct 28 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
					0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm								Filtrated water			
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)								Turbidity (NTU)	Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	$FeCl_3$		1.73	0	1	3	4	4^+	4^+	4^+	6.73	0.96		0.3	<5	1.1
2	PIX 111		1.73	0	1	2^+	4^-	4	4	4	6.97	0.6		0.125	<5	1.7
3	PAX XL-60	1.73		0	1	4	4^+	4^+	4^+	4^+	6.76	0.09	0.05 to 0.1		<5	1.5
4	PAX XL-1	1.73		0	1	3^+	4	4	4	4	7.77	0.32	0.05		<5	1.3
5	ALG	1.73		9	1	3^-	3^-	3	3	3	7	0.65	<0.05		<5	1.1
6	PAX 16	1.73		8	1	3^-	3^-	3^-	3	3	5.42	0.53	<0.05		<5	1.2
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.1	9.6	10 to 15	2.2	14.8	144

Sheet for flocculation-test

Date: Oct 30 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PIX 115		1.73	0	2	3	4^-	4	4^+		7.84	1.11		0.1	<5	2
2	PIX 115		1.73	3	2	3	4^-	4	4^+		7.24	1.21			<5	
3	PIX 115		1.73	6	2	3	4	4	4^+		6.78	1.3			<5	
4	PIX 115		1.73	9	2	3	4	4	4^+		6.25	0.84			<5	
5	PIX 115		1.73	11	2	3^+	4^+	4^+	6	6	5.7	0.46			<5	
6	PIX 115		1.73	11.7	2	3^+	4^+	4^+	6	6	5.16	0.36		0.1	<5	1.1
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.12	7.3	5 to 10	2.25	14.2	148.84

Sheet for flocculation-test

Date: Oct 30 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-61	1.73		0	1	2^+	3	3^+	4^+	4^+	7.98	0.14	<0.05		<5	1.8
2	PAX XL-61	1.73		3	1	2	2	3	4^-	4	7.24	0.26			<5	
3	PAX XL-61	1.73		6	1	2	2	2^+	3	4	6.74	0.39			<5	
4	PAX XL-61	1.73		7.2	1	2	2	2^+	3	4	6.61	0.6			<5	
5	PAX XL-61	1.73		10	1	2	2	2^+	3	4	6.12	0.39			<5	
6	PAX XL-61	1.73		11.5	1	2	2	2^+	3^+	4^+	5.5	0.52			<5	
	Rotationvelocity (rpm)				350	20	20	20	10	10						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.11	7	5 to 10	2.4	14.2	146.4

Sheet for flocculation-test

Date: Oct 31 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	ALG	1.73		9	1	3	3	3	3	3^+	6.34	0.37	$<0.05^+$		<5	1.15
2	PAX 10	1.73		7.5	1	3	3^+	4	4	4	6.56	0.17	<0.05		<5	1.3
3	PIX 115		1.73	11.7	1	3	4^-	4	4	4	5.5	0.205		0.11	<5	1.15
4	PAX XL-60	1.73		7	1	3^+	4	4	4	4	6.62	0.11	$<0.05^-$		<5	1.2
5	PAX 16	1.73		7.5	1	3	3	3	3^+	3^+	6.63	0.365	$<0.05^-$		<5	1.1
6	PIX 111		1.73	11.5	1	3	4^-	4^+	4^+	4^+	5.54	0.23		0.11	<5	1.1
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.05	6.8	10 to 15	2.2	13.8	148.8

Sheet for flocculation-test

Date: Oct 31 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-1	1.73		0	1	3	4^-	4	4	4	7.94	0.14	0.05^+		<5	1.4
2	PAX XL-60	1.73		0	1	3	4	4^+	4^+	4^+	7.87	0.17	0.1		<5	1.8
3	$FeCl_3$		1.73	0	1	3^-	3^+	4	4	4	7.76	1.12		0.27	<5	1.6
4	PAX XL-61	1.73		0	1	3	3^+	4^-	4^-	4^-	7.98	0.2	0.05		<5	1.65
5	PIX 115		1.73	0	1	2	3	4^-	4	4	7.91	0.7		0.075	<5	1.7
6	PAX 10	1.73		0	1	3^+	4	4^+	5^-	5^-	7.78	0.14	0.05^+		<5	1.5
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.07	6.7	10 to 15	2.2	13.8	148.8

Sheet for flocculation-test

Date: Nov 1 1996

The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm							Turbidity (NTU)	Filtrated water			
													Residual		Color	COD
					5 min	10 min	15 min	20 min	25 min	30 min			Al (mg/l)	Fe (mg/l)		
1	PAX XL-1	1.73		0	1	3	3^+	4^-	4	4	7.86	0.13	0.05^+		<5	1.65
2	PAX XL-60	1.73		0	1	3^+	4	4	5	5	7.79	0.16	0.1 to 0.05^+		<5	1.6
3	PAX XL-61	1.73		0	1	3^+	4	4	4	4	7.91	0.1	0.05		<5	1.45
4	$FeCl_3$		1.73	0	1	2^+	3	4^-	4^+	4^+	7.62	1.24		0.375	<5	1.85
5	PIX 115		1.73	0	1	2	3	4^-	4^+	4^+	7.76	0.68		0.165	<5	1.95
6	PAX 10	1.73		0	1	3	4	4^+	5	5	7.68	0.14	0.1 to 0.05		<5	1.7
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.08	6.8	10 to 15	2.4		

Sheet for flocculation-test

Date: Nov 5 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose: Al^{3+} (mg/l)	Dose: Fe^{tot} (mg/l)	pH-adj. H_2SO_4 0.1M (ml)	Coagulation: 5 min	10 min	15 min	20 min	25 min	30 min	pH-value	Analyses: Turbidity (NTU)	Filtrated water: Residual Al (mg/l)	Residual Fe (mg/l)	Color	COD
1	PAX 16	1.04		7.5	1^-	2^-	2^+	2^+	2^+	2^+	6.6	0.5	<0.05		<5	1.4
2	PAX XL-61	1.04		0	1^-	2^+	3	3^+	3^+	3^+	8.04	0.2	$<0.05^+$		<5	1.2
3	PAX XL-1	1.04		0	1	3^-	3^+	4^-	4^-	4^-	8.02	0.16	0.05		<5	1.5
4	PAX XL-60	1.04		7.2	1	3	4	4	4	4	6.68	0.18	$<0.05^-$		<5	1.35
5	PAX 10	1.04		7.2	1	3^-	3^+	4^-	4^-	4^-	6.58	0.26	<0.05		<5	1.4
6	ALG	1.04		9.2	1	2	2^+	3	3	3	6.28	0.64	0.05^+		<5	1.5
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Coagulation: 0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.14	7.8	5 to 10	2		150.1

Sheet for flocculation-test

Date: Nov 5 1996 (p.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose		pH-adj.	Coagulation						pH-value	Analyses				
					0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm								Filtrated water			
													Residual		Color	COD
		Al^{3+} (mg/l)	Fe^{tot} (mg/l)	H_2SO_4 0.1M (ml)	5 min	10 min	15 min	20 min	25 min	30 min		Turbidity (NTU)	Al (mg/l)	Fe (mg/l)		
1	PAX XL-61	1.04		0	1^-	2^+	3	3	3	3	8.08	0.26				
2	PAX XL-60	1.04		0	1	3	4	4^+	4^+	5	7.96	0.23				
3	ALG	1.04		9.2	1	2^-	2^+	3^-	3^-	3^-	6.31	0.61				
4	$FeCl_3$		1.73	0	1	3^-	4^-	4	4	4	7.77	1.03				
5	PIX 111		1.73	0	1	2^+	3^+	4^-	4	4	7.83	0.51				
6	PAX 10	1.04		0	1	3	4	4^+	4^+	4^+	7.91	0.29				
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.13	7.8	5 to 10	2		150.1

Sheet for flocculation-test

Date: Nov 6 1996 (a.m.)
The sample was taken from: Luanhe River

Jar number	Coagulant	Dose: Al^{3+} (mg/l)	Dose: Fe^{tot} (mg/l)	pH-adj. H_2SO_4 0.1M (ml)	Coagulation: 5 min	10 min	15 min	20 min	25 min	30 min	pH-value	Analyses: Turbidity (NTU)	Filtrated water: Residual Al (mg/l)	Residual Fe (mg/l)	Color	COD
					0) No floc 1) Unclear 2) Cloudy 3) Small flocs 0.5 mm 4) Flocs 1mm 5) Big flocs 2mm 6) Very big flocs 3-4 mm											
1	PAX XL-1	0.69		0	1	2	2^+	3^-	3^-	3	8.1	0.62				
2	PAX XL-60	0.69		0	1	2^+	3^+	4	4	4	8.1	0.47				
3	PAX 10	0.69		0	1	2^+	3^+	4	4^+	4^+	8.04	0.6				
4	ALG	0.69		9.2	1^-	1	1	1	1^+	1^+	6.03	6.1				
5	$FeCl_3$		1.38	0	1	2^+	3^+	4	4	4^+	7.84	1.2				
6	PIX 111		1.38	0	1	2^+	3	3^+	4	4^+	7.94	0.83				
	Rotationvelocity (rpm)				350	20	20	20	20	20						

Raw water-analyse

pH-value	Turbidity (NTU)	Color	COD	Temp. (C)	$[HCO_3^-]$ (mg/l)
8.14	6.7	10 to 15	2.1	12.1	149.5

APPENDIX C

COAGULANTS IN DIFFERENT DOSES AT DIFFERENT pH C1-C9

Figure C:1-9 present data on the effect of adding the coagulants in different doses at different pH. The data shows that the performances of the coagulants are depending on the pH. The iron based coagulants need a lower pH than the aluminum based coagulants, in order to get optimum performance.

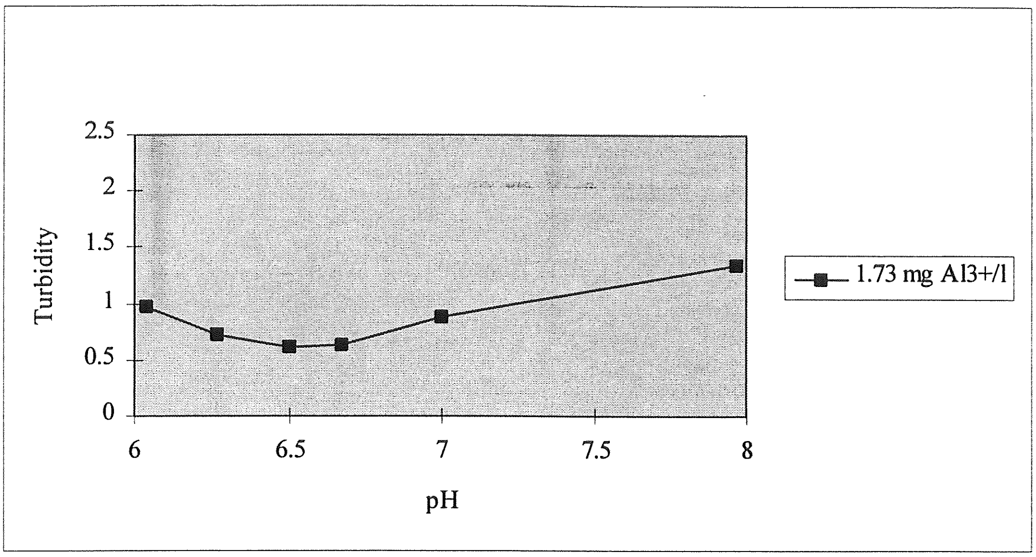

Figure C:1 Effect of pH using ALG

As shown in Figure C:1, ALG get the lowest turbidity at a pH around 6.5.

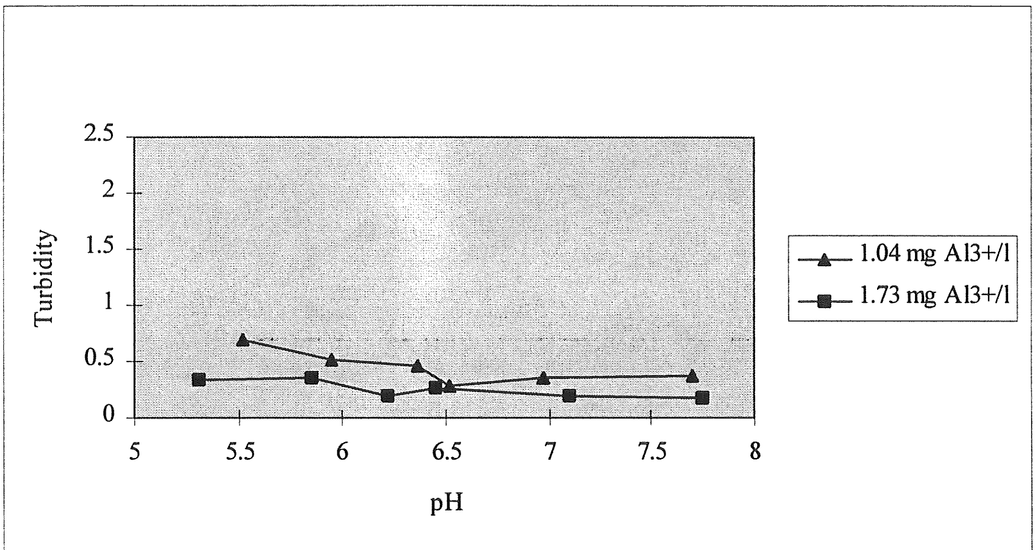

Figure C:2 Effect of dose and pH using PAX 10

The results in Figure C:2 indicates that PAX 10 works well within a wide range of pH-values.

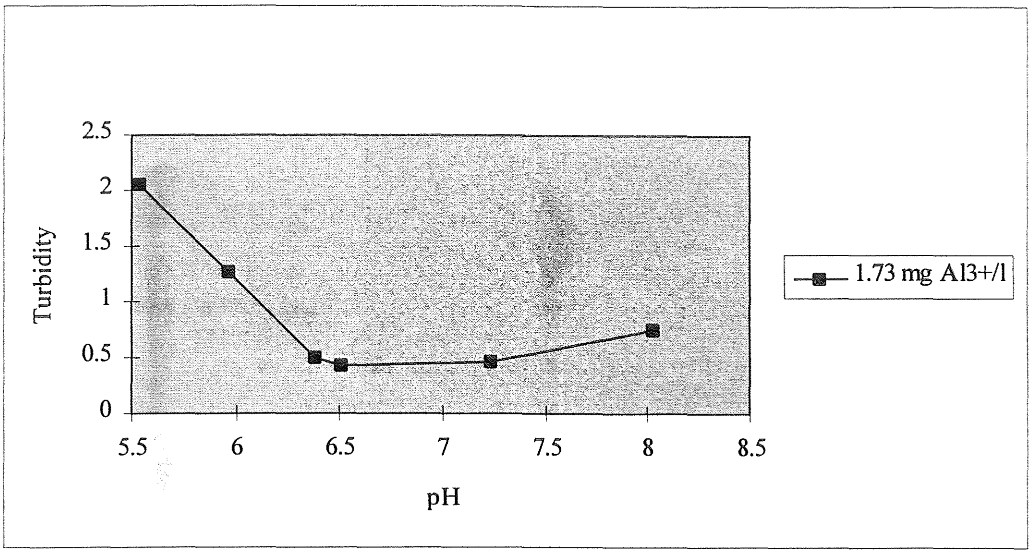

Figure C:3 Effect of pH using PAX 16

The results in Figure C:3 suggest that the best performance of PAX 16 is seen with pH around 6.5 to 7.3.

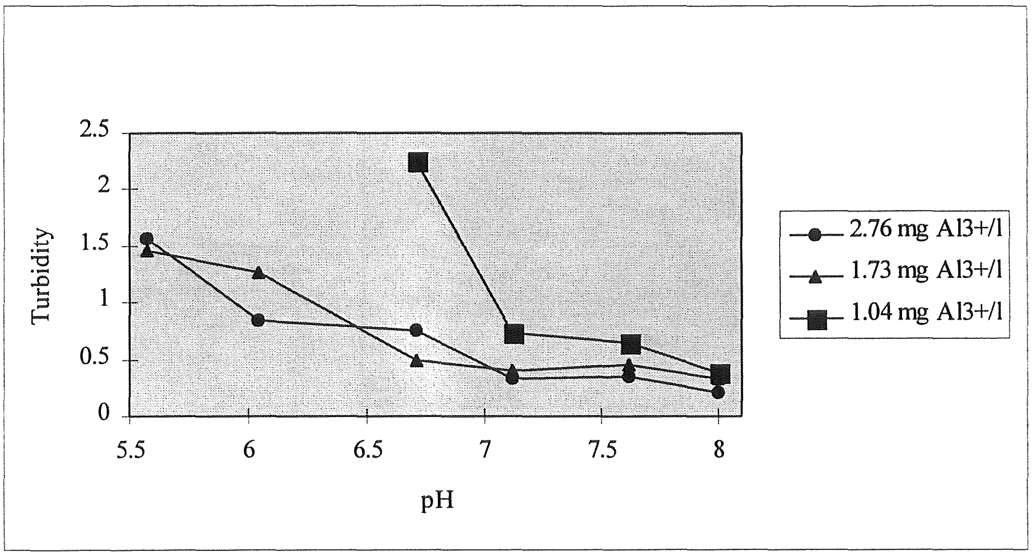

Figure C:4 Effect of dose and pH using PAX XL-1

As shown in Figure C:4 PAX XL-1 performs best at a high pH. Therefore the addition of acid to the raw water was not needed in order to get optimum pH.

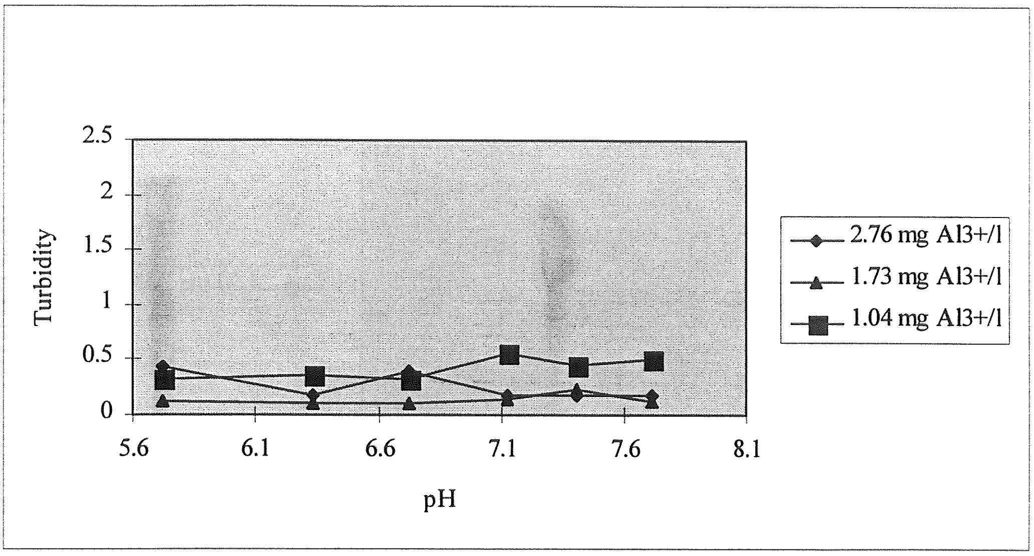

Figure C:5 Effect of dose and pH using PAX XL-60

The results in Figure C:5 indicates that PAX XL-60 performs well at low doses and at a wide range of pH-values.

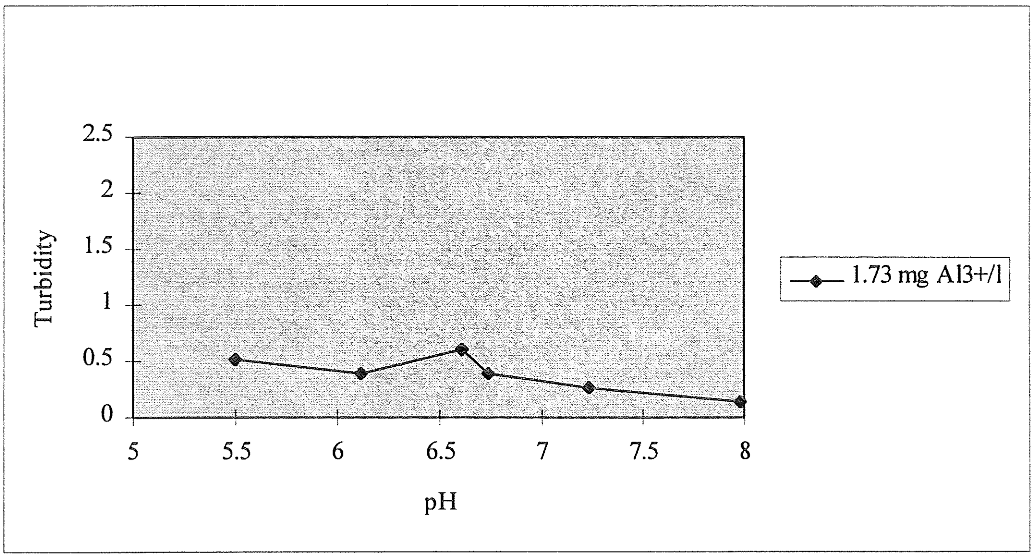

Figure C:6 Effect of pH using PAX XL-61

Figure C:6 shows that PAX XL-61 performs well at a wide range of pH-values and best at a high pH. Addition of acid, in order to get optimum pH of the raw water, was not needed using PAX XL-61.

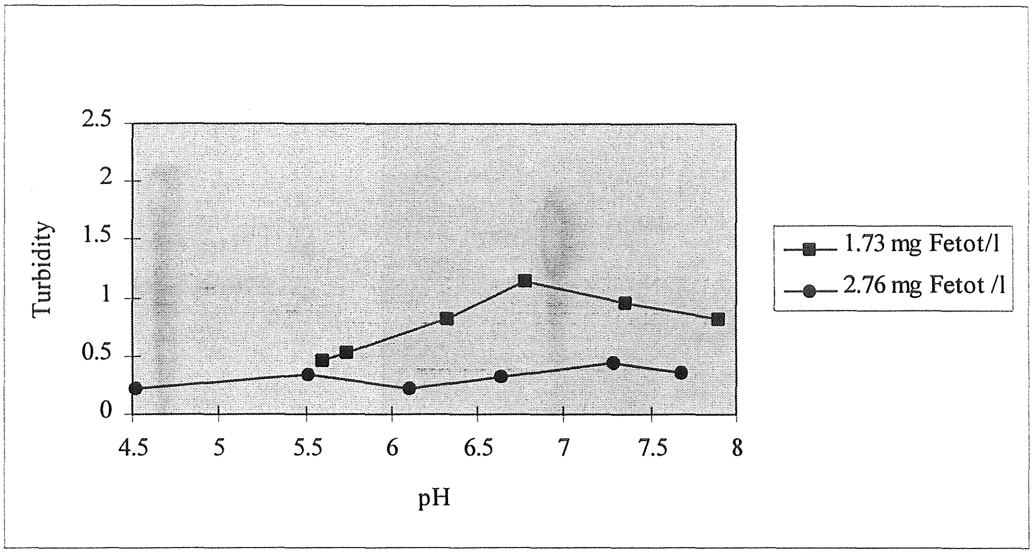

Figure C:7 Effect of dose and pH using PIX 111

As shown in Figure C:7 the best performance with PIX 111 is seen using a high dose. The optimum pH seem to be around 5.5.

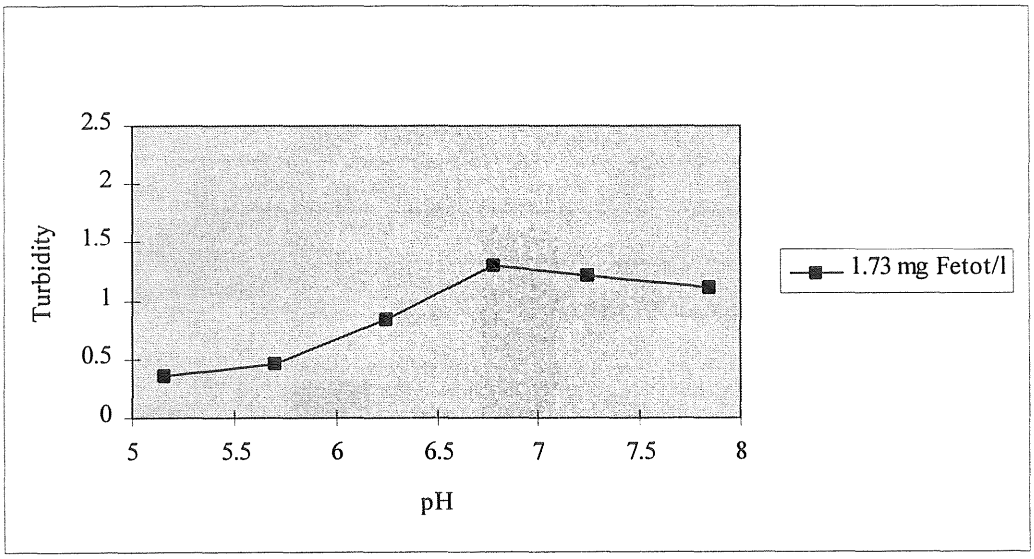

Figure C:8 Effect of dose and pH using PIX 115

As shown in Figure C:8, PIX 115 need a low pH for optimum performance.

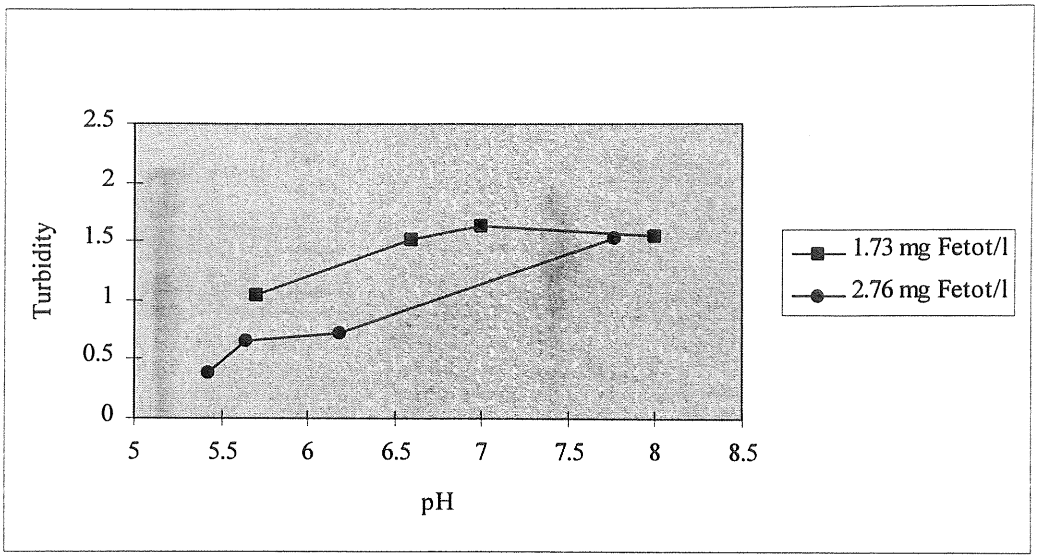

Figure C:9 Effect of dose and pH using $FeCl_3$

The results in Figure C:9 shows that a low pH is needed in order to get optimum performance using $FeCl_3$.

Figure C:10-18 presents data on turbidity with the dose 1.73 mg Al^{3+}/l or 1.73 mg Fe^{tot}/l at either optimum pH or at unadjusted raw water. The data shows that low turbidity is achieved, with the same coagulant and the same dose, using different samples of raw water.

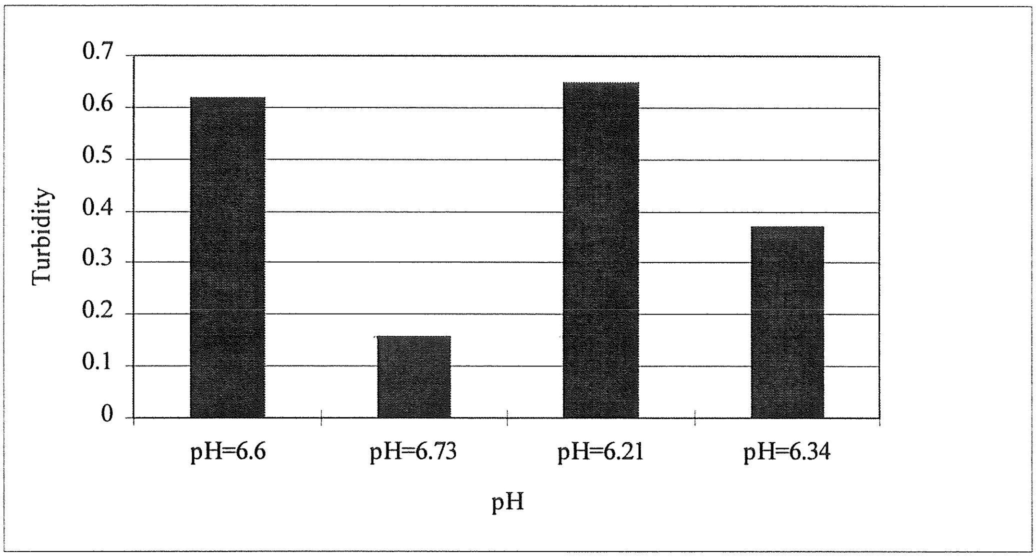

Figure C:10 ALG; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water

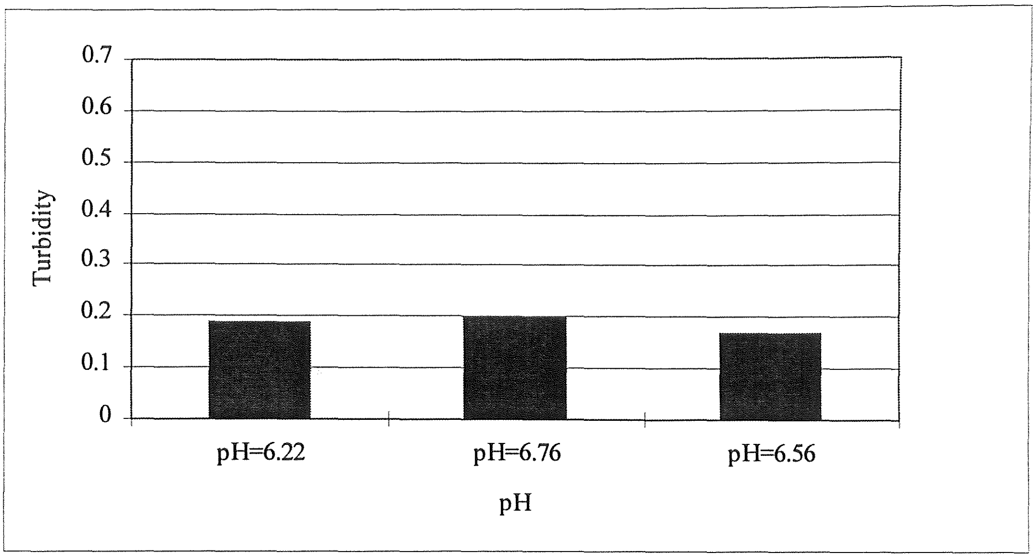

Figure C:11 *PAX 10; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water*

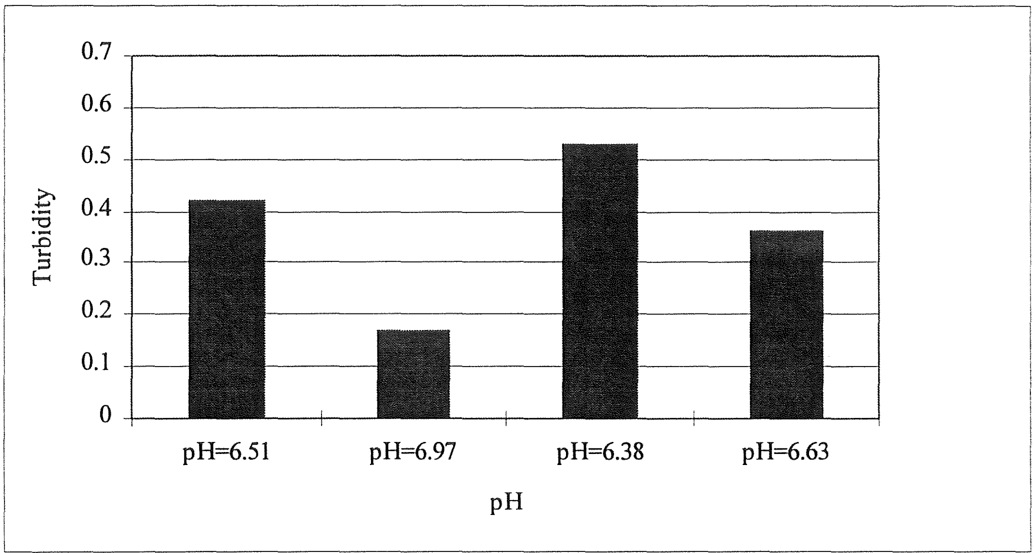

Figure C:12 *PAX 16; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water*

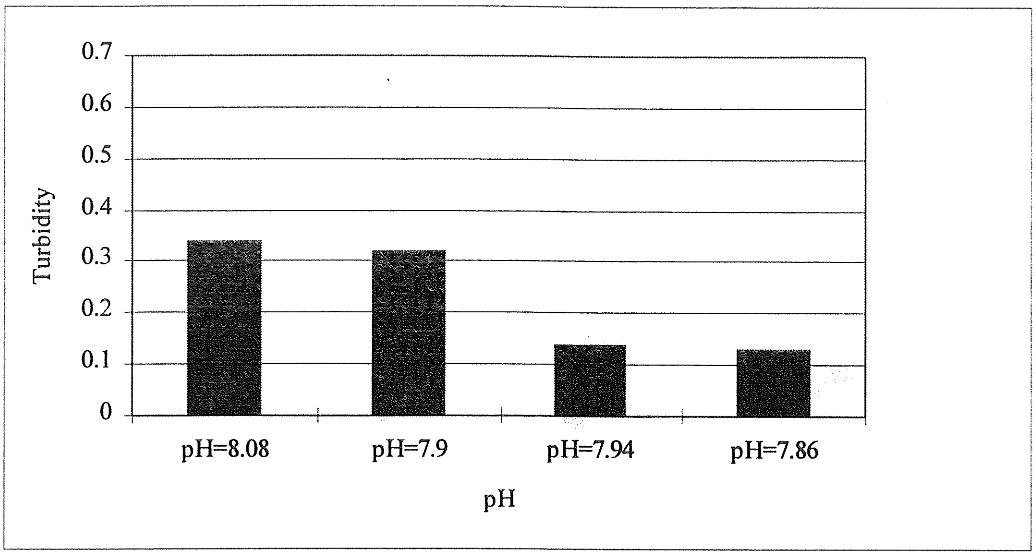

Figure C:13 PAX XL-1; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water

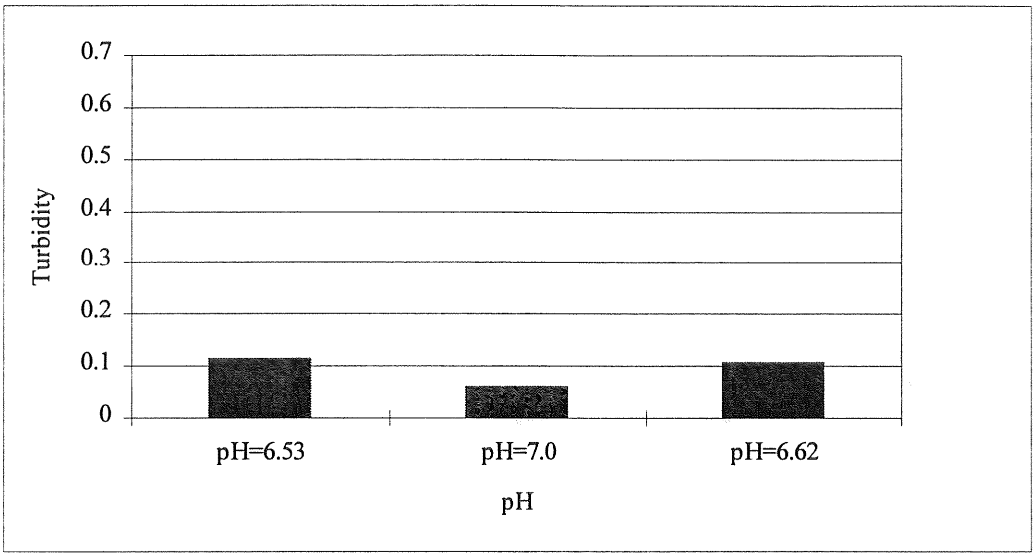

Figure C:14 PAX XL-60; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water

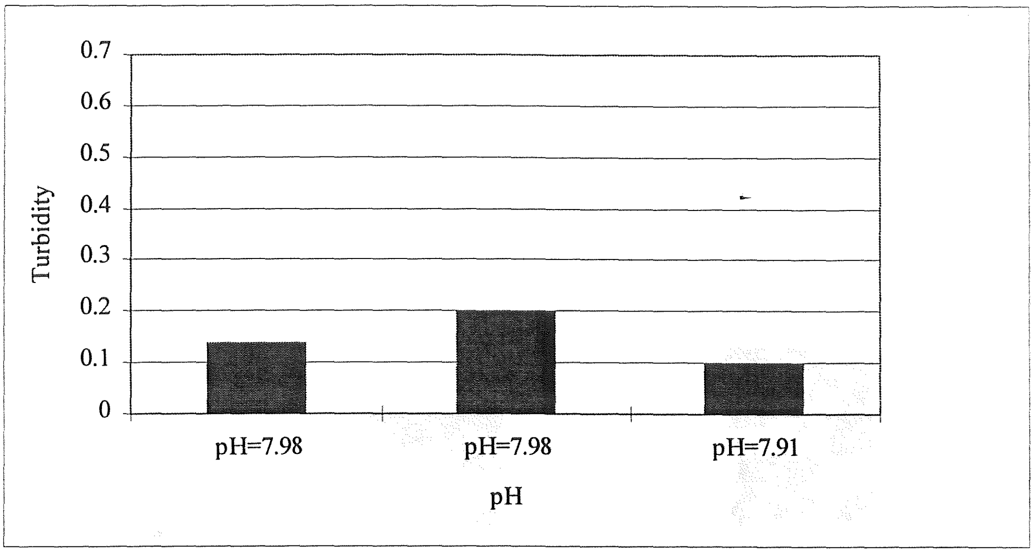

Figure C:15 *PAX XL-61; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water*

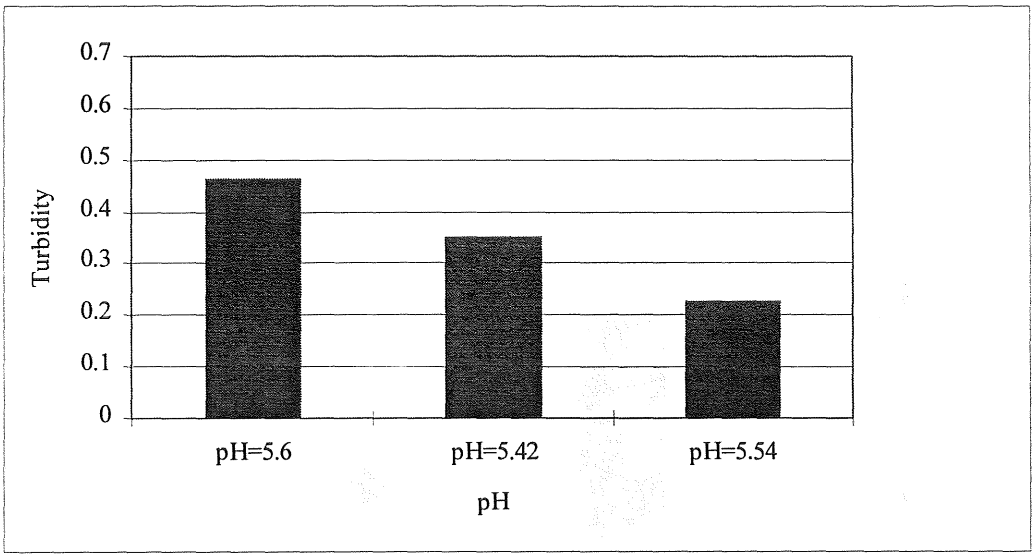

Figure C:16 *PIX 111; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}/l, using different samples of raw water*

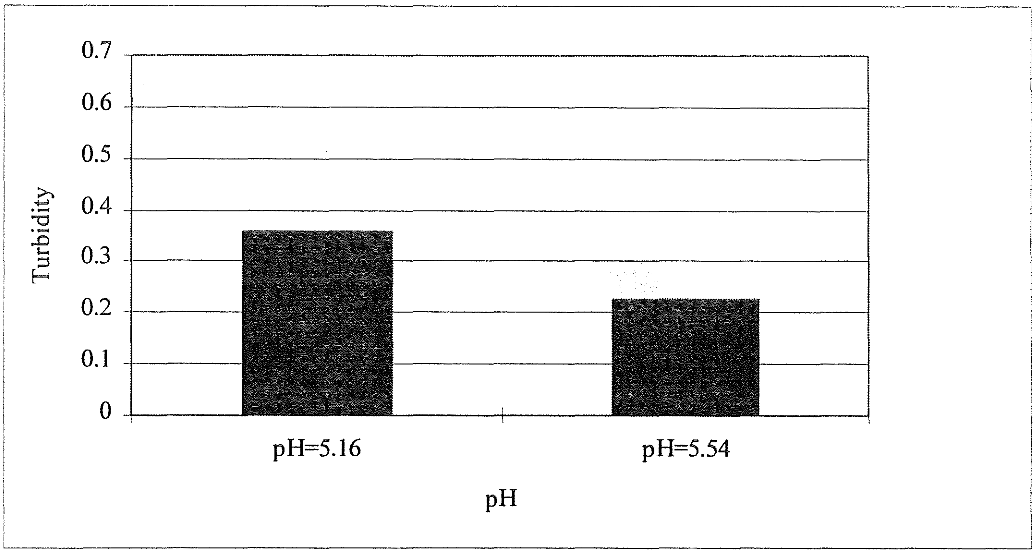

Figure C:17 PIX 115; Turbidity at around optimum pH, dose 1.73 mg Al^{3+}*/l, using different samples of raw water*

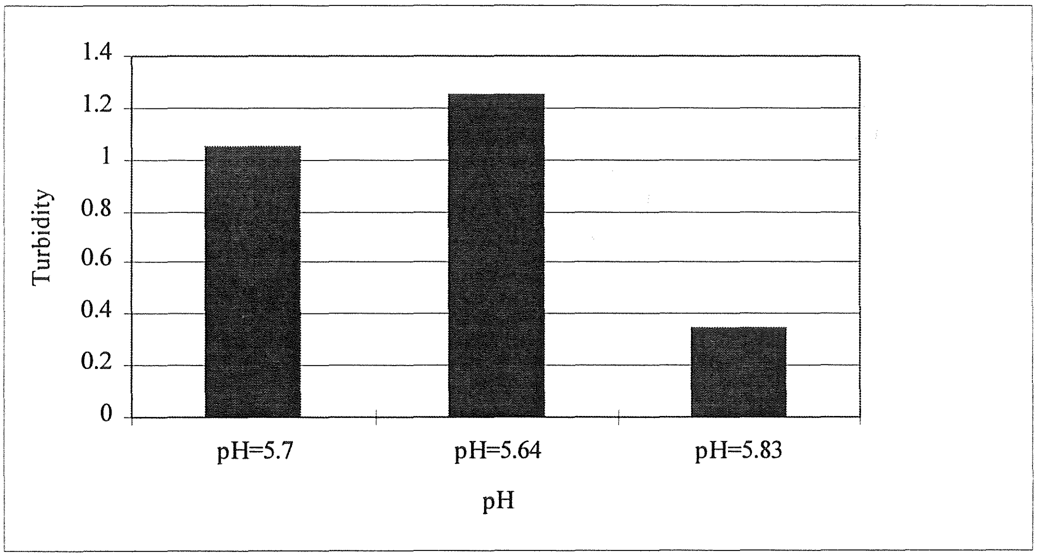

Figure C:18 $FeCl_3$*; Turbidity at around optimum pH, dose 1.73 mg* Fe^{tot}*/l, using different samples of raw water*

The scale is different in Figure C:18, compared to Figure C:10-17, because of the great difference in residual turbidity in the treated water.