ABSTRACT

According to a recent study (AwwaRF Report 2760, 2004), more than 90 percent of water treatment plants utilizing chloramination for distribution system residuals indicate a certain level of dissatisfaction towards the process performance. One factor that may lead to such dissatisfaction is the inadequacy of mixing when ammonia is added to chlorinated water. If mixing is not uniform, the actual chlorine to ammonia nitrogen molar ratio will become variable at a micro-level, even though the overall ratio at the macro-level is close to the desired 1:1 ratio. Because of the non-uniform mixing, certain portions of the mixture might have a molar ratio exceeding the stoichiometric ratio of 1:1. In such instances, certain unintended reactions (e.g., breakpoint type of chlorine chemistry) can occur. This will lead to the resultant monochloramine concentration being significantly less than the stoichiometric concentration, based upon the calculation using the overall molar ratio. Other factors, such as pH variation in the micro environment, could also affect the final chemical composition of the chloramination process.

In this study, the effect of mixing was studied by conducting breakpoint chlorination experiments under different levels of mixing, represented by the average velocity gradient, G in s⁻¹. A rather unique way of plotting breakpoint chlorination curve was utilized to analyze the data, which allowed a clear delineation whether the monochloramine formation was according to the stoichiometry. A quantitative comparison between experimental data and stoichiometry can clearly indicate the impact of non-uniform mixing. The experimental data clearly showed that as the G value increased from 35 to 500 s⁻¹ and the monochloramine formation increased from 75 percent to 87 percent of the stoichiometric value. The location of the breakpoint, correspondingly, increased from a molar ratio of 1.25 to 1.75.

Comparison of 50rpm and 200rpm experimental data was conducted and a breakpoint curve was plotted imposing one over the other. It has been observed from previous literature that in ideal conditions, breakpoint occurs at chlorine to ammonia nitrogen molar ratio of 1.5:1, and the peak of monochloramine is expected at a molar ratio of 1:1. Hence, breakpoint curve was plotted at mixing speed of 50 and 200 rpm, indicating free chlorine, monochloramine, dichloramine, trichloramine, and total chlorine concentration at contact time of 45 minutes.

Few studies were found in literature on mixing effects in chloramination. Data from a previous study (Yamamoto et al., Wat. Res., 1990) was re-analyzed and compared with the current study, and a similar trend was observed. In another case study, the design G value for a modern water treatment plant in metropolitan Boston was found to be 800 s⁻¹, which was higher than the maximum G value used in this study (500 s⁻¹), and is likely to be sufficient.
In conclusion, when chlorine and ammonia are combined to produce monochloramine, the degree of mixing indeed has significant impact on the performance of the chloramination process, and therefore must be a critical consideration in its design and operation.

**KEYWORDS**

Monochloramine, chloramination, mixing, velocity gradient, DBPs

**INTRODUCTION**

When disinfection by-products (DBPs) are a concern or the free chlorine residual is difficult to maintain, water treatment plants use chloramines to provide stable disinfection residual in distribution system. Chloramine (NH$_2$Cl, NHCl$_2$, and NCl$_3$) is formed by mixing residual free chlorine with ammonia in treated water prior to discharge into the distribution system. Recently, there has been growing concern about the biological instability in the drinking water distribution system for treatment plant utilizing chloramines. Researches have shown that excess ammonia released in the distribution system from incomplete mixing or chloramine decay can not only promote the growth of ammonia-oxidizing bacteria (AOB) but also contributes to an increase in organic material. The presence of AOB can lead to the production of nitrite and nitrates and increased organic material exerts an additional chloramine demand. Failure to achieve good mixing in chloramination could lead to treatment utilities compliance with Surface Water Treatment Rule and the Total Coliform Rule. (Liu and Ducoste, 2006)

Another study was performed using controlled bench scale mixing experiments to investigate the impact of mixing at the point of ammonia and chlorine addition on DBP formation (Symons et al., 1998). Three different mixing intensities i.e. $G$ value of 60 sec$^{-1}$, 500 sec$^{-1}$ and 1000 sec$^{-1}$ were studied to span the spectrum of practical approach. From their experiments they indicated that mixing conditions did not significantly affect the disinfectant speciation at the contact time characteristic of distribution systems and for contact time characteristic of rapid mix basins, mixing might have a substantial effect on speciation.

Yamamoto et al. (Yamamoto et al., 1990) studied the effects of different mixing speeds ranging from 12 to 240 rpm on residual chlorine during chlorination of seawater containing ammonia nitrogen. It was reported that mixing affects the concentration and proportion of residual chlorine during chlorination of seawater containing ammonia nitrogen. They found that at lower speed the peak of the breakpoint curve occurred at lower chlorine dosage as compared to the higher speed. Also, at high mixing speed, the increase in the residual chlorine level was directly proportional to the dose of chlorine. At low mixing speed, the residual chlorine level began to decline before the peak of the breakpoint curve, which was flatter than the one obtained with high mixing speed. Similar trend was seen in the experiments conducted in this study.

The design report of a recent major water treatment plant put into operation since 2005 was studied to compare the results obtained from this study (CDM, 2002). Chloramination treatment
unit design was the main area of focus. Post ammoniation is used as a part of their treatment process and sodium hypochlorite is the source of chlorine. Sodium hypochlorite with a concentration of 2-3 mg/L and aqua ammonia with a concentration of 0.5-0.75 mg/L are injected just before the dry feed mixing chamber to get adequate mixing. This chamber has the rapid mixing. There are four rapid mix chambers each having a velocity gradient of 800s⁻¹ which corresponds to 56 rpm. Plant flow in this chamber is 270 mgd on average and 405 mgd maximum with the retention time of 9.5 sec at 270 mgd flow. Following this chamber there is a dry feed reaction chamber with baffles installed.

It is clear from these studies that adequate degree of mixing is important to maintain the chlorine residual in the process of chloramination. In this study, an optimum value of $G$ for appropriate mixing in the process of chloramination under pre-set conditions is evaluated. Also, the best approach to utilize the results of this study in the real world, full-scale plant application is studied.

**CHLORAMINATION OPERATING PARAMETERS**

From a survey done by the American Water Work Association (AWWA) and AWWA Research Foundation (AwwaRF), the most important parameters to consider in designing, operating and in optimizing a chloramination process were studied and the key parameters are listed below (Kirmeyer et al., 2004).

- **Chemical application points.** This includes considering where chemicals are added in the treatment process, the order in which they are injected, and how chemical feed rates are controlled. For flexibility, multiple ammonia and chlorine injection points may be provided. Only one ammonia injection point is normally used at any one time.

- **pH and temperature.** The optimum pH range generally is 8.0 to 9.0, and the ideal temperature is 10 to 15 °C.

- **Chloramine residual.** The desirable chloramines residual depends on the water source and conditions within the distribution system. A range of chloramine residuals from 0.5 to 6.8 mg/L has been noted in this survey. Typical finished water chloramines levels are 2 to 3 mg/L in finished water. U.S. Environmental Protection Agency (USEPA) regulations require a detectable disinfectant residual or HPC (Heterotrophic Plate Count) less than 500 cfu/mL at monitoring points in the distribution system and limit the chloramines residual to a maximum of 4.0 mg/L.

- **Chlorine: Ammonia- Nitrogen ratio.** The Cl₂:NH₃-N weight ratio should generally be maintained between 4:1 and 5:1 at the point of application to enhance formation of monochloramine and minimize the excess of free ammonia. Further, to reduce the potential for nitrification, a free ammonia target of 0.10 mg/L as N or less (e.g. 0.05 mg/L as N) should be maintained in the distribution system.
• **Mixing and reaction time.** It is best to provide for immediate and thorough mixing of treatment chemicals within the process stream, a range of velocity gradient of 300 to 1000s⁻¹ is suggested. Mixing in the pipe is most common, but mechanical or static mixing may be employed.

• **Periodic switch to free chlorine.** It may be advantageous to switch to free chlorine periodically for short periods of time to rid the system of chloramine-resistant bacteria and to reduce the potential of nitrification. This is a significant undertaking and may not be feasible in large distribution systems.

**MIXING**

Intensity of mixing is an important design parameter in most of the treatment units. Ideal mixing is considered as one of the factors for the formation of chloramines species and proper breakpoint chlorination in chloramination process. Intensity of mixing is usually measured in terms of velocity gradient (G value). From previous studies and surveys it has been observed and reported that intensity of mixing affects the process of chloramination and is an important parameter (Yamamoto et al., 1990). Literature which gives an optimum value of velocity gradient for appropriate formation of chloramine species in the chloramination process is not available. However a Japanese group studied the mixing effect using seawater (Yamamoto et al., 1990).

**VELOCITY GRADIENT**

Steady state turbulence generation requires continuous power input to the system. The relationship between power dissipation and velocity gradient as elucidated by Camp and Stein (1943) has been widely adopted in practice. T.R. Camp (1955) developed a rational approach to design and evaluate mixing chambers. According to Camp, the intensity of mixing required in the rapid mix and flocculation is generally measured by the time of mixing (t) and velocity gradient (G). The equation for velocity gradient with no vertical baffles is

\[
G = \sqrt{\frac{W}{\mu}} = \sqrt{\frac{P}{\mu V}}
\]

(3.1)

Where,
- \( G \) = velocity gradient, fps/ft or sec⁻¹
- \( W \) = power imparted to the water per unit volume of the chamber, ft-lb/sec-ft³
- \( P \) = power imparted to the water, ft-lb/sec
- \( V \) = chamber volume, ft³
- \( \mu \) = Absolute viscosity of the water, lb-sec/ft²
The value of total power imparted to the liquid by various impellers in a baffled tank is determined by using relationships developed by Rushton, given by the following equation:

$$ P = \phi \rho n^3 D_i^5 $$

(3.2)

Where,
- \( P \) = power imparted to the water, ft-lb/sec
- \( \phi \) = impeller constant for turbulent flow also known as power number
- \( n \) = rotational speed, rps
- \( D_i \) = impeller diameter, ft
- \( \rho \) = density of liquid, \( \rho = \gamma / g_c \)
- \( \gamma \) = specific weight of the liquid, lb/ft\(^3\)
- \( g_c \) = acceleration due to gravity, 32.17 ft/sec\(^2\)

The power number (\( \phi \)) is a function of mixing chamber geometry, impeller geometry and the Reynolds number (\( R \)) where

$$ R = D_i^2 n \rho / \mu $$

Calculating the power number for impellers is a complex process. The manufacturers of the impellers usually provide these numbers.

"The rate of particulate collisions is proportional to the velocity gradient, G; therefore, the gradient must be sufficient to furnish the desired rate of particulate collisions. The velocity gradient is also related to the shear forces in the water; thus, large velocity gradients produce appreciable shear forces. If the velocity gradient is too great, excessive shear will result and prevent the desired floc formation. The total number of particle collisions is proportional to the product of the velocity gradient, G, and the detention time, t. Thus the value of Gt is of importance to design". (Reynolds T D and Richards P A, 1996)

**EXPERIMENTAL DESIGN**

The controlled bench scale experiments primarily investigated the impact of different degrees of mixing on the chloramination process where chlorine solution is dosed with a specified delay in dosing ammonia, which is also termed as post-ammoniation. Also there are some other important variables which need to be considered for optimization of the chloramination process. These variables include ammonia and chlorine application points, pH, and temperature, chlorine to ammonia-nitrogen ratio, mixing, and reaction time for chloramines formation. All these variables were taken into consideration while designing the experiment.

Experiments were conducted in a jar test apparatus at various known values of G (mean velocity gradient). The main experimental variables were the mixing speed (in rpm) and chlorine to ammonia nitrogen molar ratio.

Temperature was set to 10°C considering the applications at the utilities. pH was adjusted to a range of 7-9 in accordance with the chloramines chemistry. And the molar ratios of chlorine to ammonia nitrogen were selected based on the breakpoint pattern. Mixing intensities were
selected as per the jar test device and further adjusted looking at the experimental data available. Reaction time of 15 minutes and 45 minutes were also selected based on the chloramines chemistry.

The experiments were conducted in 2 liter reactors (B-KER² from PHIPPS & BIRD). Impeller speed was fixed. The calibration curve of Laboratory G curve for flat paddle in the gator jar (Manual of Water Supply Practices, 2000) was used to evaluate G as a function of impeller speed. Chlorine stock solutions were delivered to the reactors. Sodium bicarbonate was added to adjust the pH. The solution was then mixed for 1 minute at the fixed impeller speed. Ammonia stock solution was then added in the reactors and then samples were mixed continuously for 15 minutes after the completion of dosing at 10°C.

A standard jar test apparatus allows six reactors to be run simultaneously, with the same mixing intensity in each sample (see Figure 1). One sample was used as a control and was dosed only with chlorine stock solution. Chlorine to ammonia nitrogen molar ratio of 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0 and 4.0 was used for the experiments. Each of the molar ratios was studied for a reaction time of 15 minutes and 45 minutes. Three different mixing intensities with impeller speeds of 50rpm, 150rpm and 200rpm were studied to span the spectrum of practical applications.

Figure 1: Jar Test Set Up

![Figure 1: Jar Test Set Up](image)

**BREAKPOINT**

When chlorine is added to waters containing ammonia, the breakpoint phenomenon becomes significant in the pH range of 6-9. The breakpoint is that dosage of chlorine that produces the first detectable amount of free chlorine residual. Chloramine formation and oxidation of ammonia by chlorine combine to create a unique curve for the addition of chlorine to ammonia containing solutions (Figure 2). At a fixed ammonia concentration, as the chlorine dose
increases, the chlorine residual at first increases to a maximum at a Cl₂:NH₃-N molar ratio of 1:1. As the chlorine dose is increased further, the chlorine residual falls to a value close to zero. The chlorine dose corresponding to this minimum is called the “breakpoint” dose, and it occurs at Cl₂:NH₃-N molar ratio of 1.5 to 2:1, depending upon solution conditions. The primary reaction that causes the residual chlorine concentration to decrease and thus to form a breakpoint is the breakpoint reaction, which can be represented as

\[ 2\text{NH}_2\text{Cl} + \text{HOCl} \leftrightarrow \text{N}_2 + 3\text{H}^+ + 3\text{Cl}^- + \text{H}_2\text{O} \]

or as

\[ 3\text{HOCl} + 2\text{NH}_3 \leftrightarrow \text{N}_2 + 3\text{H}^+ + 3\text{Cl}^- + \text{H}_2\text{O} \]

During breakpoint chlorination, the amount and type of chlorine residual changes according to Figure 2. The nature of the chlorine residual present prior to the breakpoint reveals that it is composed almost entirely of chloramines. These are referred to as “combined chlorine residual” as opposed to Cl₂, OCI and HOCl which are known as “free chlorine residuals.” As the chlorine to ammonia nitrogen ratio increases, the ammonia molecule becomes progressively more chlorinated i.e., NH₃ (ammonia) to NH₂Cl to NHC₁ to NCl₃. Prior to the breakpoint, monochloramine and dichloramine are produced. Following the breakpoint, free chlorine (HOCl and OCI) predominate but some dichloramine and trichloramine may be in evidence.

As the dose of chlorine is increased, the residual decreases at a molar ratio of 1:1 to approximately 2:1 (breakpoint). At a Cl₂/NH₃-N molar ratio of 1.5:1, all of the available chlorine residuals are greatly reduced or eliminated. The residual would drop almost to zero as the molar ratio approached 1.5 to 2.0, depending on the conditions of pH and temperature, and then start to increase. As such, any utility considering chloramination should identify the specific breakpoint and chloraminate below the Cl₂:NH₃-N molar ratio at which significant dichloramine formation occurs (theoretically 1:1) to reduce the formation of noxious tastes and odors and DBPs.

In the reaction mechanism, each step has its own rate of reaction that depends on the pH, temperature and on the initial concentrations of reactants. These conditions will subsequently affect the rate of the overall breakpoint reaction, as well as the products formed. Lower pH and temperature favors the formation of NCl₃ as does higher initial ammonia molar ratios. This aspect is important in the determination and control of undesirable end products. The rates of the formation and subsequent decay of dichloramine determine the speed of the overall breakpoint reaction. Water pH can significantly alter the kinetics of breakpoint chlorination; the optimal pH range is 7-8. In the previous studies it was found that ratio of chlorine to ammonia needed for the reaction decreases with decreasing temperature and also decreases with increasing initial ammonia concentration (Kirmeyer et al., 2004).

Figure 2: Theoretical Breakpoint Curve
RESULTS AND DISCUSSIONS

Another effective way of plotting the breakpoint curve was demonstrated, marking Y axis ordinate as the molar ratio of residual chlorine to initial ammonia nitrogen concentration (Cl$_2$/NH$_3$-N$_0$) and the X axis ordinate as the molar ratio of initial chlorine to initial ammonia nitrogen (Cl$_0$/NH$_3$-N$_0$). Breakpoint curve presented in this fashion were clearer and allowed a quantitative elucidation of the effect of mixing on chloramination process, which was difficult to achieve by using the traditional plotting. This representation of breakpoint curve did not need any specification of the ammonia nitrogen concentration for each plot as both the axes represent the concentration of ammonia nitrogen. As we do not expect the monochloramine peak to go beyond 1.0, the amount of monochloramine formed was clearly represented in this type of plotting. Hence the maximum value represented on the Y axis is 1.0. This type of plotting was used to for all breakpoint curves.

Effect of Reaction Time

From the breakpoint curve plotted at different G value and different reaction time, it was observed that at 15 minutes the curve did not give as good pictures of the chloramines species
formation as with the 45 minutes (Figure 3) curve. Free chlorine, monochloramine, dichloramine, trichloramine and total chlorine were not as well defined as an ideal breakpoint curve for the reaction time of 15 minutes as compared to 45 minutes of reaction time because breakpoint reactions probably had not reached the equilibrium at 15 minutes.

Monochloramine plays a major role in the disinfection process and hence its pattern was observed closely. Dichloramine and trichloramine were found in negligible concentrations at reaction time of 15 minutes as well as at 45 minutes. After breakpoint total chlorine concentration consisted of only free chlorine.

**Effect of Mixing**

The scope of this study focuses on the effect of mixing in the chloramination process. Figure 4 show the breakpoint curve at various degree of mixing i.e. 50, 150, 200 rpm at 10°C. Regardless of the stirring speed, monochloramine was the predominant species in the residual chlorine that remained after 45 minutes and there were no detectable formation of di- and trichloramine.

From Table 1 it can be observed that at lower rpm monochloramine peak is lower than at higher rpm. This shows that amount of monochloramine formed is lower at 50 rpm than at 150 or 200 rpm, especially at 45 minutes when equilibrium is reached.

**Table 1:**

<table>
<thead>
<tr>
<th>Reaction Time (minutes)</th>
<th>Rpm</th>
<th>G Value sec⁻¹</th>
<th>Monochloramine Peak Cl/N₀</th>
<th>Cl₀/N₀ of Mono peak</th>
<th>Breakpoint Cl/N₀</th>
<th>Cl₀/N₀ of Breakpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>50</td>
<td>~40</td>
<td>~0.75</td>
<td>0.75</td>
<td>~0.11</td>
<td>1.25</td>
</tr>
<tr>
<td>45</td>
<td>150</td>
<td>200</td>
<td>~0.83</td>
<td>1.0</td>
<td>~0.1</td>
<td>~1.6</td>
</tr>
<tr>
<td>45</td>
<td>200</td>
<td>300</td>
<td>0.92</td>
<td>1.0</td>
<td>0.12</td>
<td>~1.75</td>
</tr>
</tbody>
</table>

**Comparison of 50 rpm and 200 rpm**

Comparison of 50 rpm and 200 rpm experimental data was done and a breakpoint curve was plotted imposing one over the other. It has been observed from previous literature that in ideal conditions breakpoint occurs at chlorine to ammonia nitrogen molar ratio of 1.5:1, and the peak of monochloramine is expected at a molar ratio of 1:1. Hence breakpoint curve was plotted at mixing speed of, 50 and 200 rpm, indicating free chlorine, monochloramine, dichloramine, trichloramine and total chlorine concentration at contact time 45 minutes Figure 3 to illustrate the effect of mixing on the breakpoint curve. Ammonia Nitrogen concentration is 1 mg/L.
At 50 rpm, peak of Monochloramine is located to the left of chlorine to ammonia molar ratio of 1.0 vs. 200 rpm. Also the breakpoint is located near a molar ratio of 1.25 which is to the left of molar ratio 1.5.

At 200 rpm, monochloramine peak is observed at a molar ratio of 1:1 and breakpoint occurs at a molar ratio of 1.5:1 for a reaction time of 45 minutes as expected theoretically at equilibrium. While at 50 rpm the breakpoint curve is shifted to the left (see Figure 3). Monochloramine peak is seen at a molar ratio of 0.75:1 and breakpoint occurs at a molar ratio of 1.25:1. When the breakpoint graphs at 120 rpm and 240 rpm (Figure 5 & 6) were compared in the study of the effects of different stirring speeds on residual chlorine during chlorination of seawater containing ammonia nitrogen (Yamamoto et al., 1990), similar trends were observed.

Figure 3: \( \text{Cl}/N_0 \) vs. \( \text{Cl}_2/\text{N}_0 \) @ 50 & 200 rpm at \( 10^\circ \text{C} \) after 45 minutes

![Figure 3](image)

Figure 4: Residual Chlorine @ 50, 150 and 250 rpm at \( 10^\circ \text{C} \) after 45 minutes

![Figure 4](image)
Comparison with the other study (Yamamoto et al., 1990)

A comprehensive study was done of the graphs obtained from the Japanese study (Yamamoto et al., 1990), and a comparison was done with the results obtained from this study. Data from the Japanese study were extracted by using the UnGraph software. A comparison was done between 120 rpm and 150 rpm (Figure 5). It is to be noted that these rpms refer to different mixing devices used for respective studies and might not imply quantitative comparison of mixing intensity.

All the graphs for both monochloramine and residual chlorine followed the same trend at different mixing speed except that at 120 and 240 rpm residual chlorine loss was higher via the disproportionation of monobromamine to form dibromamine and ammonia nitrogen (Yamamoto et al., 1990) as their area of study was seawater.

The velocity gradient (G value) range of 300s\(^{-1}\) to 1000s\(^{-1}\) was suggested for proper mixing in chloramination process (Kirmeyer et al., 2004). In this study, 200rpm corresponds to a G value of 300s\(^{-1}\) and 50rpm corresponds to a G value of 35s\(^{-1}\) at 10\(^{0}\)C from the calibration curve of
Laboratory G curve for flat paddle in the gator jar (Manual of Water Supply Practices, 2000). G value for 12, 60, 120, and 240 rpm from the Yamamoto et al., 1990 is not mentioned in the article and it cannot be determined.

Figure 5: Monochloramine @ 120 rpm at 20-25°C (Yamamoto et al., 1990) & 150 rpm at 10°C
CONCLUSIONS

• From Table 1 it can be concluded that mixing affected the concentration and proportions of residual chlorine during chloramination.

• At lower mixing speed, the residual chlorine level began to decline before the peak of the breakpoint curve which was flatter than the one obtained from the higher mixing speed.

• At higher mixing speed, the residual chlorine level rose in direct proportion to the dose of chlorine, and appears to approach Cl/N₀ of 1.0, as expected theoretically.

• At lower mixing speed the breakpoint shifts to the left of the higher mixing speed, e.g. Cl₀/N₀ of 1.25 vs. 1.75 in Figure 3.

• The degree of mixing of chlorine and ammonia in chloramination process is of importance in evaluating the residual chlorine concentrations.

• For bench scale mixing experiments, a G value of 300s⁻¹ (corresponds to 200 rpm) from the calibration curve of Laboratory G curve for flat paddle in the gator jar (Manual of
Water Supply Practices, 2000) is considered as a desirable mixing velocity gradient for complete mixing of ammonia and chlorine to form desirable level of monochloramine concentration. When used in real practices, scale-up is a factor which needs to be considered.

PRACTICAL APPLICATIONS

Given that mixing experiments were conducted on small scale in laboratory-sized reactors, it is appropriate to consider how these results relate to larger scale mixing occurring in practice. It has been observed from the literature review that unfortunately rapid mixing is not well understood in the field of chloramination treatment. G on large scale should be greater than, equal to, or less than the small scale G to achieve the same degree of mixing depending on the selected scale-up relationship. For this particular application, relationships that show G on larger scale equal to or greater than the small scale G are probably most appropriate because chloramines formation kinetics are relatively fast. Scale up is a factor which needs to be considered when being used in the real world applications.

The design report of an online water treatment plant was studied to compare the results obtained from this study. Chloramination treatment unit design was the main area of focus in the water treatment plant design report. Post ammoniation is used as a part of their treatment process and sodium hypochlorite is the source of chlorine. Sodium hypochlorite with a concentration of 2-3 mg/L and aqua ammonia with a concentration of 0.5-0.75 mg/L are injected just before the mixing chamber to get adequate mixing. This chamber has the rapid mixing. There are four rapid mix chambers each having a velocity gradient of 800s⁻¹ which corresponds to 56 rpm. Plant flow in this chamber is 270 mgd on average and 405 mgd maximum with the retention time of 9.5 sec at 270 mgd. Following this chamber there is a reaction chamber with baffles installed.

FUTURE RESEARCH

This study illustrates the impact of inadequate mixing in the chloramination process. Breakpoint curve is used to illustrate the effects of mixing showing different chloramine species at reaction time of 15 minutes and 45 minutes. Kinetics study of the formation of chloramines species at different stirring speed can be studied for further research to describe the effect of chloramine chemistry.

REFERENCES


