
THE EFFECT OF HYDRAULIC JUMP COAGULATION MIXER ON THE PERFORMANCE OF DRINKING WATER TREATMENT PLANT

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ABSTRACT

Drinking water are the natural source for daily consumption which supplied from drinking water treatment plant, therefore the drinking water should be healthy and clear, and safe for drinking, and without odor. This research focuses on hydraulic jump mixing in the coagulation process for improved turbidity removal in water treatment. Hydraulic jump characteristics have been studied through physical model. Hydraulic jump mixing aims to instantly and efficiently disperse coagulant species into raw water, before flocculation processes. Mechanical mixing with a longer retention time cannot guarantee an instantaneous and uniform coagulant dispersion. To overcome this problem, the hydraulic jump can be used for chemicals mixing to replace the mechanical mixing by impeller. It is cheaper and easier. The results of experiment in University of Al-Qadisiyah Collage of Engineering Department of Civil Engineering Hydraulics Laboratory and the application on mathematical model showed that the velocity gradient of 800 s^{-1} is enough for hydraulic jump mixing. In this study pilot plant test was used to assess the effectiveness of hydraulic jump mixer module for treatment of synthetic turbid water using alum. Using various hydraulic jump experiments to test the turbidity removal performance, it is showed that hydraulic jump mixers are able to achieve performance equivalent to that of the mechanical mixing type at a lower coagulant dosage. Turbidity removal efficiency was sufficient to meet national drinking water limits (5 NTU) at optimum alum dose. Using 10 mg L^{-1} alum as a coagulant aid could improve turbidity removal and drinking water treatment plant.

Keywords: Hydraulic jump mixing, Coagulation, Turbidity, Water Treatment, Velocity Gradient

1. INTRODUCTION

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking water can result in tangible benefits to health (**Kumar and Kansagara, 2014**). The purpose of hydraulic mixing is to disperse coagulant chemicals uniformly throughout the raw water as rapidly as possible in order to destabilize the colloidal particles present in water. The chemicals dosing system is one of the important processes on water treatment plant, that cause the coagulation. In general, the coagulation process needs the mechanical mixing and dosing pump which are generated by electrical energy. These systems make the increasing of the energy cost. In many of the conventional treatment plants, however, the coagulant mixing is typically performed in a concrete basin with a mechanical mixer, and requires about 1–2 min of retention time. The mechanical mixing with a longer retention time cannot guarantee an instantaneous and uniform coagulant dispersion (**Kim and Lee (2006), Baghvand et al., 2010, Sánchez-Martín et al., 2010, and Jr-Lin et al., 2013**). For this reason, the hydraulic jump mixer (rapid mixer) has been proposed. Rapid mixing (**Cheremisinoff (2002), Asano et al. (2007), Mavros (2001)**), in water treatment is to rapidly disperse the coagulant into raw water, followed by flocculation (**Ghernaout and Naceur (2011)**), sedimentation (**Goula et al. (2008)**), and filtration (**Kurita (1999)**,

De Zuane (1997), Xiao et al. (2008)). This process has a strong influence on the overall treatment efficiency (**O’connor et al. (2009)**).

In the coagulation process, coagulant chemicals are added to the water as it passes through the hydraulic jump mixer. A hydraulic jump mixer is used to mix chemicals into the water quickly; it does this by the turbulence created by the mixer, so agitation of water by hydraulic controls mixing cause velocity gradients. The equipment used to disperse the chemical in coagulation process consist of a channel with fully turbulent flow of sufficient length to yield the desired detention time, followed by a hydraulic jump, has been used successfully. Mixing has always been acknowledged to be one of the key issues in producing good quality treated water in the chemical water treatment process .The hydraulic mixer is the most basic type of rapid mixer that utilizes the potential head of water for generation of turbulence and eddies for mixing. Commonly, a hydraulic jump is used for this purpose. A hydraulic jump is created when flow in an open channel is abruptly transferred from supercritical conditions to sub-critical conditions. Hydraulic jump mixers are suitable for raw waters that require short mixing time (of the order of one to two seconds) (**Vigneswaran et al. 1995**).

This study is focusing on hydraulic jump coagulant mixer to find the active constituents which are responsible about the coagulation mechanism and improving the coagulation property. In this article the experimental and mathematical model have been used to study the effect of hydraulic jump mixer on improve the efficiency of water treatment plant. The Armfield's teaching flume available at the University of Al-Qadisiyah Collage of Engineering Department of Civil Engineering Hydraulics Laboratory which was used in this research. This study on the effect of hydraulic jump on the performance of coagulant mixing is therefore undertaken to determine whether the introduction of hydraulic jump would increase the efficiency of the treatment process. Some attempts have been made to model the relationships between raw water quality characteristics and the optima coagulant dosage rate.

2. MATERIALS AND METHODS

2.1 Mathematical model

The coagulation process requires rapid mixing of the coagulant to facilitate uniform dispersion of the coagulant (Heber 1986). The coagulation process is made possible through mechanical or hydraulic

means. Mechanical devices may not be appropriate for many developing nations due to the costs and operation and maintenance requirements associated with mechanical equipment. However, hydraulic devices can be just as effective if properly designed. To facilitate the rapid mixing necessary for coagulation, hydraulic jumps can be adopted (Smet and Wijk 2002). Of these options, hydraulic jumps are the most commonly adopted hydraulic device and are generally effective if the influent water has a Froude number equal or greater than 2.5 (Bratby 2006).

Hydraulic mixers are mixers that use the energy of a flowing fluid to create the power dissipation required for mixing. This fluid must have already been given the energy before reaching the point in which the mixing is occurring. What needs to be done at the point of mixing is simply to dissipate this energy in such a way that the correct value of G (velocity gradient) for effective mixing is attained. Figure 1 shows a hydraulic jump and its schematic. Hydraulic-jump mixers are designed as rectangular in cross section. In this study the mathematical model which developed by Sincero and Sincero 2003 has been used and developed to study hydraulic jump mixer.

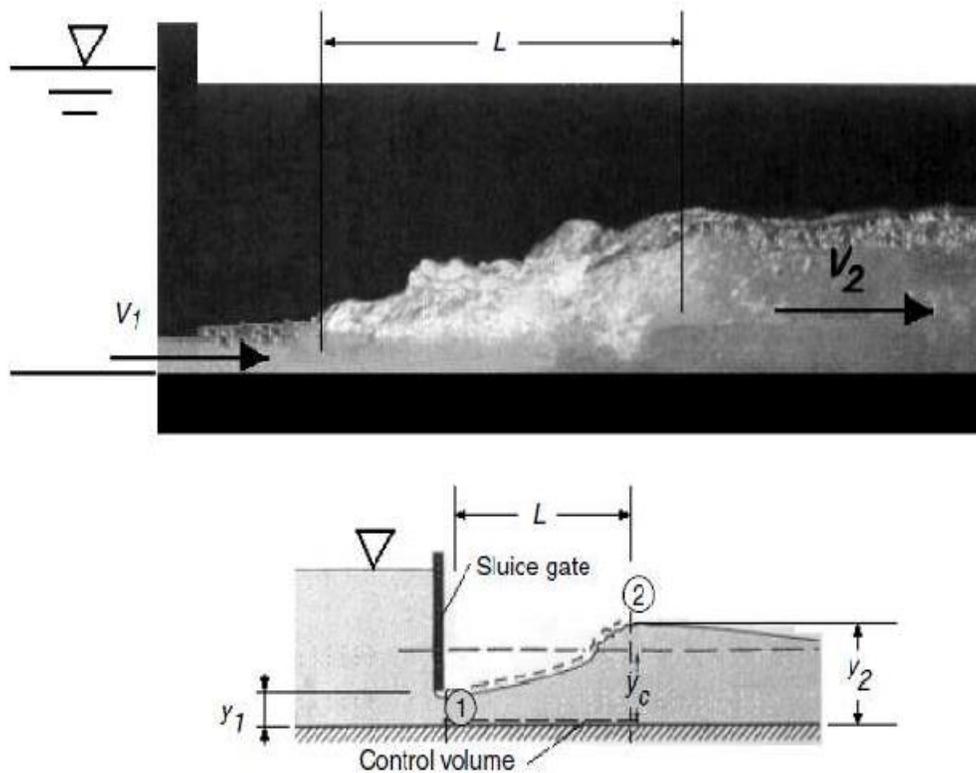


Figure 1: Hydraulic Jump Mixer

2.2 Preparation of synthetic water samples

The synthetic turbid water prepared by adding laboratory grade kaolin into distilled water. This kaolin suspension was used as the stock solution for the preparation of water samples in the coagulation tests. Three level of turbidity were chosen for this study (high turbidity 500- 1000 NTU, medium turbidity 50-250 NTU and low turbidity 20-50 NTU).

2.3 Coagulant

Aluminum sulfate stock solution 1000 mg/L was prepared to develop different alum dose for coagulation process.

2.4 Turbidity Meter

To measure the turbidity the turbidity meter type Lovibond TurbiDirect was used.

2.5 Analytical Method

A Jar test apparatus type Lovibond was used to obtain the optimum alum coagulant dose. Jar tests were performed using six paddle standard jar test.

3. LABORATORY MODEL

3.1 Experimental Methodology and Set up for Hydraulic Jump

The experimental work was executed at Sanitary Engineering Laboratory Public Works Civil Engineering Department at Faculty of Engineering- University of Al-Qadisiyah Iraq. To investigate the characteristics of hydraulic jump produced. The pilot plant consists of water tank, coagulation tank (hydraulic jump flash mixer), flocculation and rectangular

settling tank, rapid gravity filter, coagulant dosing tank and treated water tank.

3.2 Physical Model

The hydraulic jumps are obtained in a channel of the Hydraulic Laboratory (The Armfield's C4-MkII flume) at the University of Al-Qadisiyah Collage of Engineering Department of Civil Engineering. The channel is 5-meter long and 0.076-meter wide. The hydraulic jumps were obtained downstream of a sluice gate (Figure 2, and 3) (Gilberto, 2010), (Armfield, 2010).

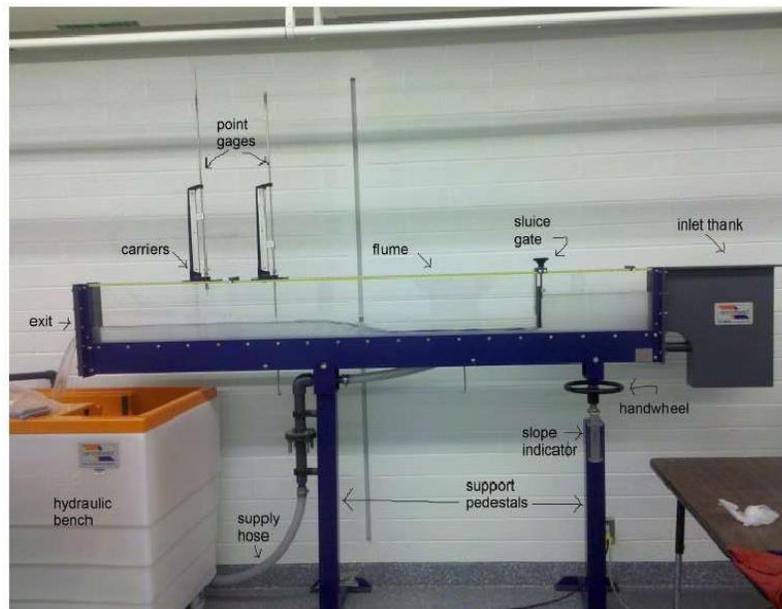


Figure 2: Picture of the C4-MKII Armfield's Multipurpose Teaching Flume with a Sluice Gate (Gilberto, 2010)

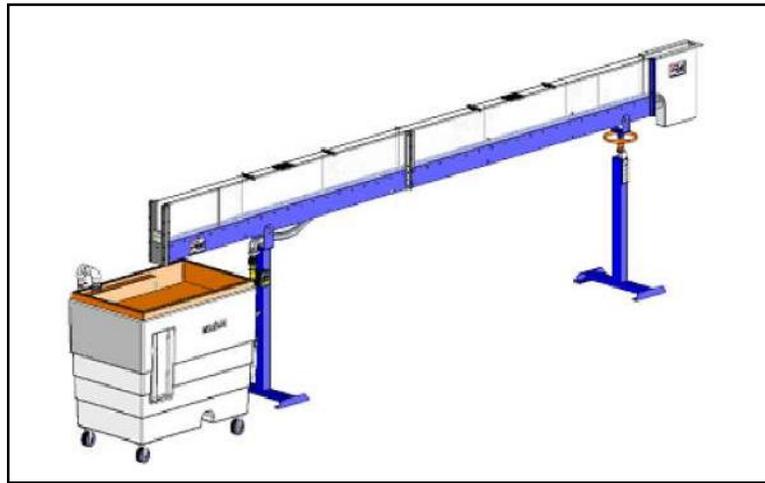


Figure 3: C4-MkII Multi-Purpose Teaching Flume (Armfield, 2010)

Details of the flow upstream and downstream of the sluice gate are presented in Figure 4. The knob on top of the weir was adjusted to position the sharp edge of the weir 0.015m above the bed of the flume. One stop log was placed at the discharge end of the flume. Then gradually the flow control valves were opened and adjust the flow until an undular jump is created with

small ripples decaying towards the discharge end of the flume. Then the flow pattern was observed. The heights of water upstream of the weir was increased by increasing the flowrate and increase the height of the stop logs to create a hydraulic jump in the centre of the working section. And the flow pattern was observed.

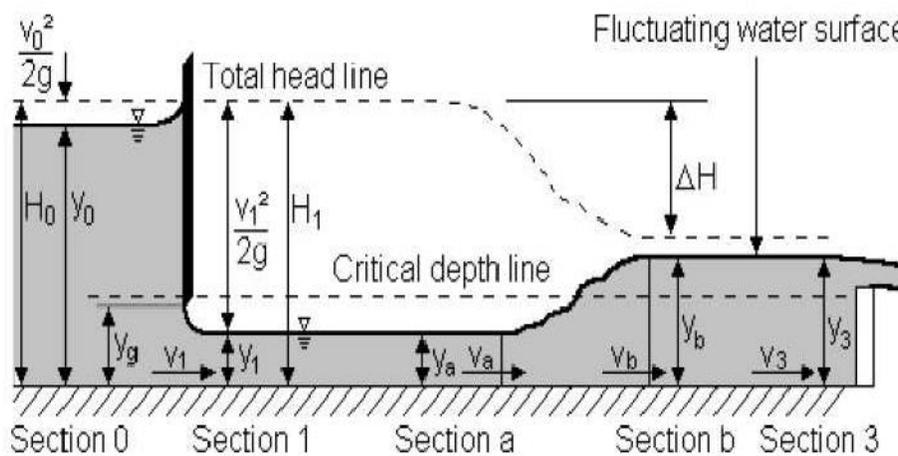


Figure 4: Energy Loss in Hydraulic Jump Mixer

One leveled gauge was moved to the region of rapid flow just upstream of the jump (section a). And the second level gauge was moved to the region of tranquil flow just after the jump (section b). The values of y_1 , y_3 , y_g and Q were measured and recorded. Also this was repeated for other flowrates Q (upstream head) and heights of the gate y_g . The procedure consists of five runs. Each run consists of a constant flow rate and two different opening gates. Measure the accurate flowrate, the upstream depth, and the downstream depth. Alum is injected at section a, and mixed into the water by hydraulic jump, and turbidity measured after filter. The slopes were selected based on the flume facility.

4. RESULTS AND DISCUSSION

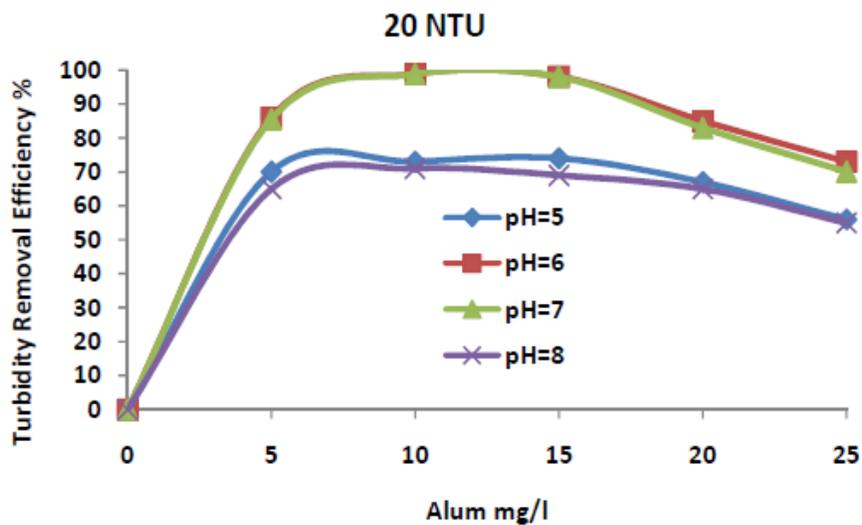
Chemical rapid mixing at is done by hydraulic jump. This phenomena happens when water at high velocity flows into the lower velocity zone. Normally, it depends on the different elevations of water before and after the jump because the energy loss is created at this jump. Alum is injected and mixed into the water by hydraulic jump. When a hydraulic jump was being used, the coagulant feed point was approximately 1.5 inches upstream of the jump toe. Alum is used for water treatment. Alum is fed to a hydraulic jump through a constant flow feeding arrangement. The parameters which were chosen to describe the mixing in the hydraulic jump were dosing, pH, and detention time and velocity gradient (G).

4.1 Effect of Alum Dose and pH on Turbidity Removal Efficiency

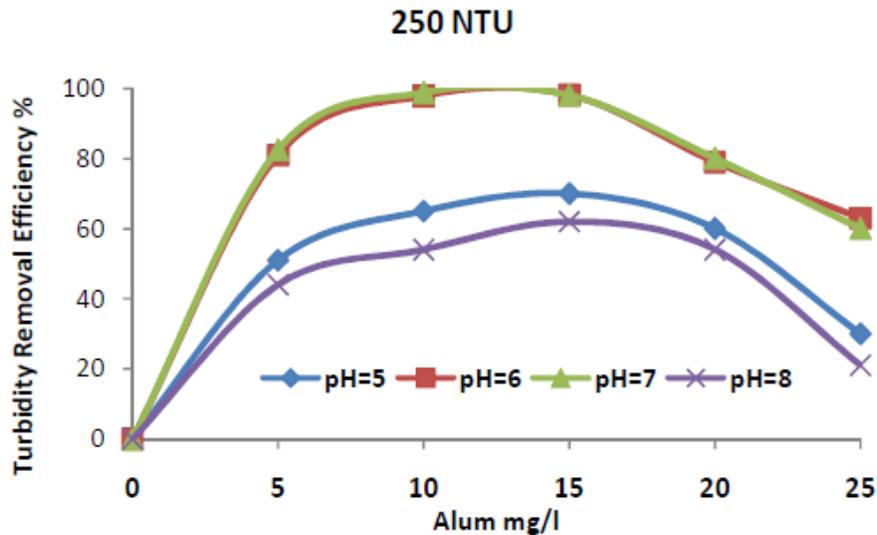
Hydraulic jump mixer Experiments were implementer with five runs (Table 1). Each run consists of a constant flow rate and two different opening gates. The downstream gate was used to form clear jumps in the test section. Three level of turbidity were chosen for this study (high turbidity 500-1000 NTU, medium turbidity 50-250 NTU and low turbidity 20-50 NTU). In this study pilot plant test was used to assess the effectiveness of hydraulic jump rapid flash mixer module for treatment of synthetic turbid water using alum. The approaching flow Froude numbers were in the range of 0.5 to 1. After the hydraulic jump occupies the steady position, the turbidity measurements were done before the jump and after the jump (after filtration) using turbidity meter. Also the pH was measured by Lovibond model SD300. Figure 5 presents turbidity removal efficiency as a function of alum dose at pH range of 5-8. Initial turbidities of water samples were adjusted to be 20, 250 and 500 NTU. The best performance of alum was observed at pH 7 over the selected range of turbidity but its performance decreased to some extent at pH values of 5 and 8. Coagulation efficiency of alum at pH 6 was almost close to that of at pH 7. The highest turbidity removal was attained at pH 7 when 10 mg L⁻¹ alum was used except for initial turbidity of 500 NTU. The optimum alum dosage was (15 mg L⁻¹) for initial turbidity of 500 NTU which was the lowest required

dosage obtained the highest turbidity removal. The coagulation efficiency of alum remained almost constant within the dosage range of 10-15 mg L⁻¹ at pH range of 5-8. Turbidity removal efficiency was slightly decreased by increasing alum concentration from 10-15 mgL⁻¹, e.g., turbidity

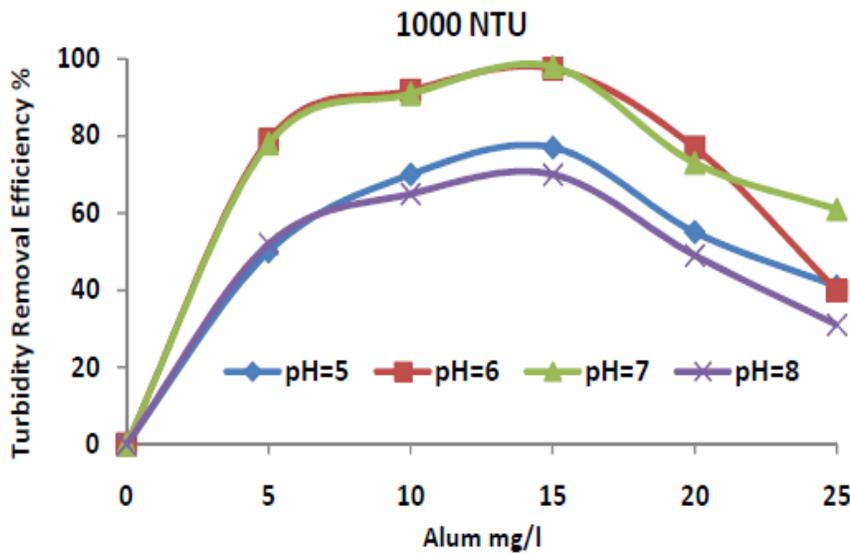
removal decreased from 97.6-94.9% at pH 6 (initial turbidity of 20 NTU). At the optimum condition (optimal dose and pH), turbidity removal efficiencies of alum were 98.9, 97.3, 96.9 percent for initial turbidities of 20, 250 and 500 NTU, respectively.



a) Initial Turbidity 20 NTU



b) Initial Turbidity 250 NTU



c) Initial Turbidity 1000 NTU

Figure 5: Effect of Alum Dose on Turbidity Removal Efficiency at pH rang 5-8 (High turbidity 1000 NTU, medium turbidity 250 NTU and low turbidity 20NTU)

Table 1: Hydraulic Jump Mixer Experiments Runs

Run	Flow Rate L/s	Initial Opening Gate mm	Final Opening Gate mm
1	0.55	7	15
2	1.03	15	21
3	1.6	21	26
4	2.1	26	33
5	2.5	33	38

In Figure 6 the results of hydraulic jump experiment is shown. It can be concluded from the figure that turbidity decreases with an increased coagulant dosing. The lowest turbidity is attained when about 10 mg L⁻¹ alum is dosed. With a higher dosage the

turbidity does not increase and thus restabilization does not occur. In Figure 7 a coagulant dose of 10 mg L⁻¹ and a varying pH is represented. The turbidity increases with a decreasing pH (6-7).

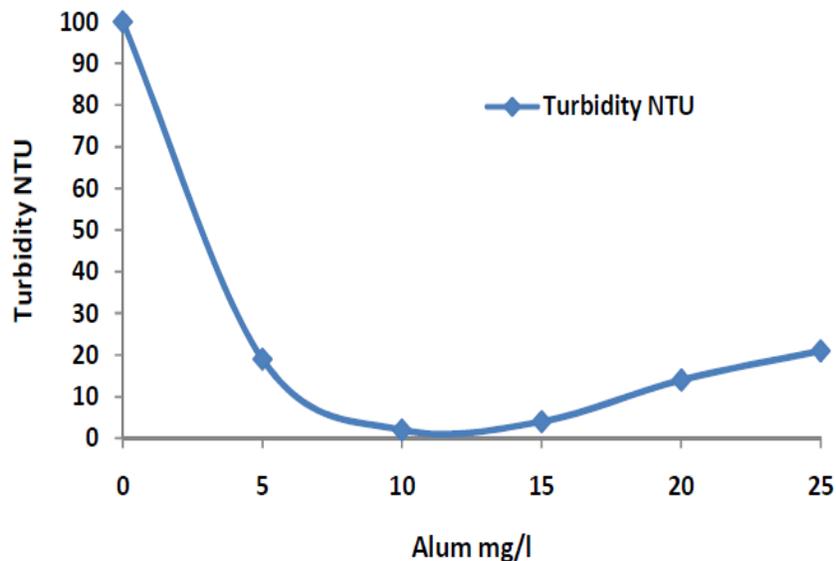


Figure 6: Effect of Alum Dose on Turbidity Removal Efficiency

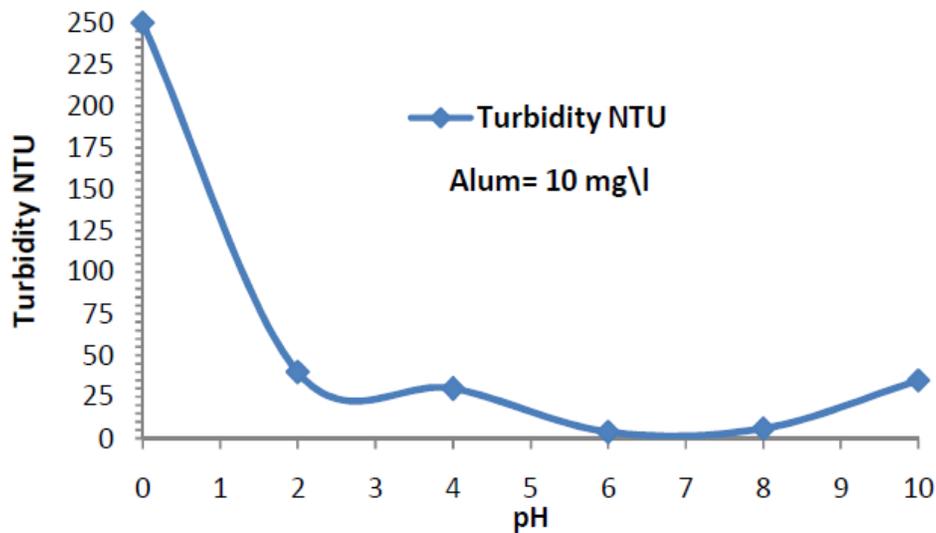


Figure 7: Effect of pH on Turbidity Removal Efficiency

Figure 8 show the variation of turbidity removal efficiency with approaching flow Froude number for hydraulic jump depth y_1 values as shown in Table 1. From Figure 8 it is observed that with increase in approaching flow Froude number the turbidity removal efficiency enhances. This is due to larger turbulence which results into the channel. In the present study, the

maximum turbidity removal efficiency 98.8% is obtained for Froude number = 1 with $y_1 = 38$ mm. From the results obtained from the laboratory analysis, $y_1 = 38$ mm was observed to record the highest efficiency of turbidity removal followed by $y_1 = 33$ mm and $y_1 = 26$ mm as shown in (Figure 8).

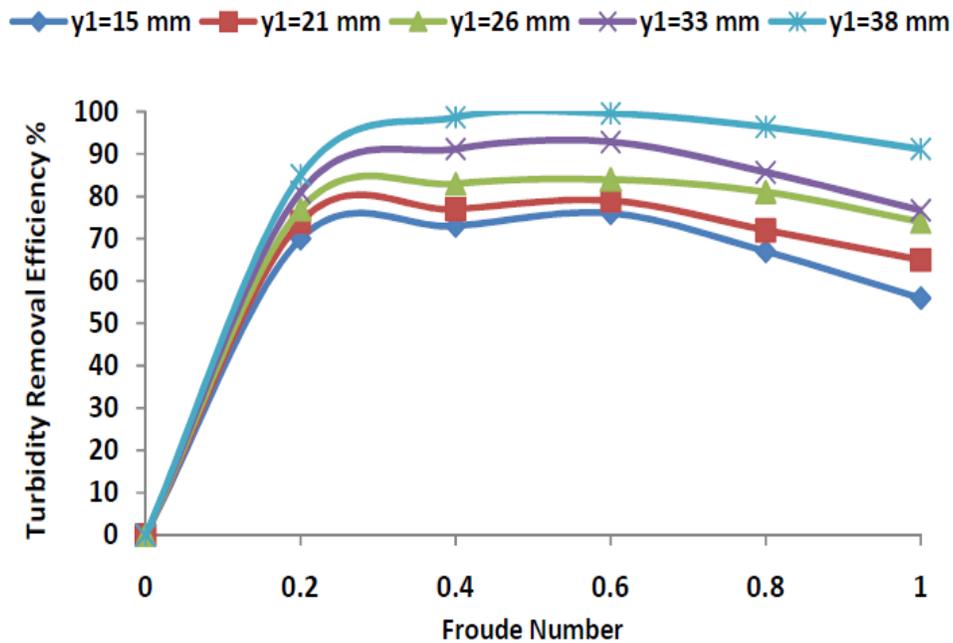


Figure 8: Effect of Froude number on Turbidity Removal Efficiency

4.2 Effect of Mixing Intensity

Many of experiments and calculation were conducted with alum to examine the effect of the initial mixing intensity (velocity gradient) on the removal efficiency of turbidity. The results of this hydraulic jump using alum are shown in Figure 9, over a

range of dosages from 0 to 20 mgL⁻¹ for velocity gradient of 500, 600, 800 and 1100 s⁻¹. For the removal of turbidity, the significant difference was seen between the velocity gradients. The 800 s⁻¹ velocity gradients improve the removal of turbidity, due to reduced shearing of the floc during initial formation.

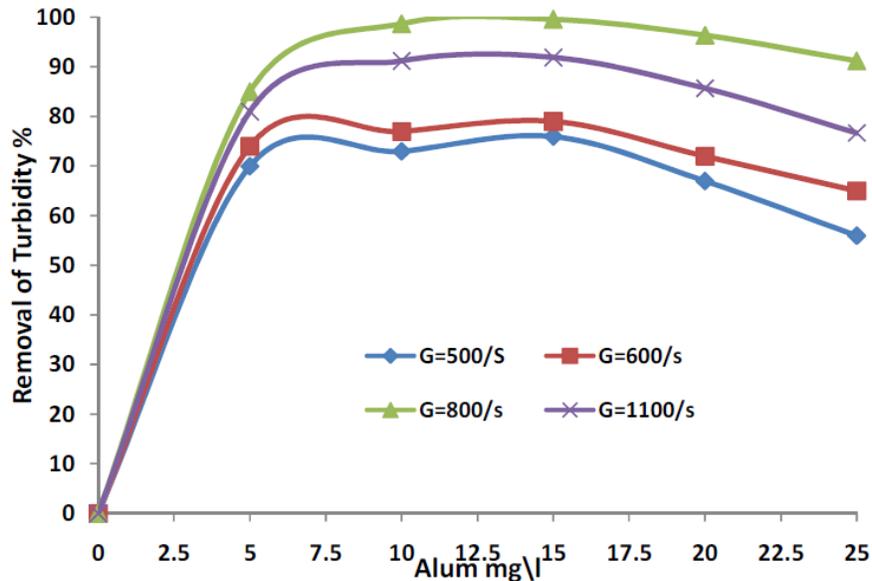


Figure 9: Effect of Mixing Intensity on Turbidity Removal Efficiency

4.3 Effect of Mixing Time

Figure 10 shows that the turbidity removal efficiencies changed with mixing time and hydraulic jump intensity such that less fast mixing time was needed for higher intensity values. The velocity gradient influence can be determined by hydraulic jump experiments and mathematical model. Three seconds of fast mixing were required when the velocity gradient was 600 s^{-1} ; while two seconds were sufficient for optimum turbidity removal efficiencies at 800 s^{-1} . When the turbid water was mixed at 720 s^{-1} , fast mixing time of two and half seconds yielded highest turbidity removal

efficiencies. Its shows that for two seconds of fast mixing, the highest turbidity removal efficiencies were obtained at 800 s^{-1} ; but when the fast mixing time was extended to two and half and three seconds, 800 s^{-1} was sufficient to yield optimum turbidity removals. Fast mixing Gt values were varied between 1500 and 4000. Turbidity removal efficiency maintained high values (always above 99%) for Gt values = 1600. When the velocity gradient is low, the turbidity will be higher than in situations where the velocity gradient is high. In practice, the recommended G-value for hydraulic jump mixing is 800 s^{-1} .

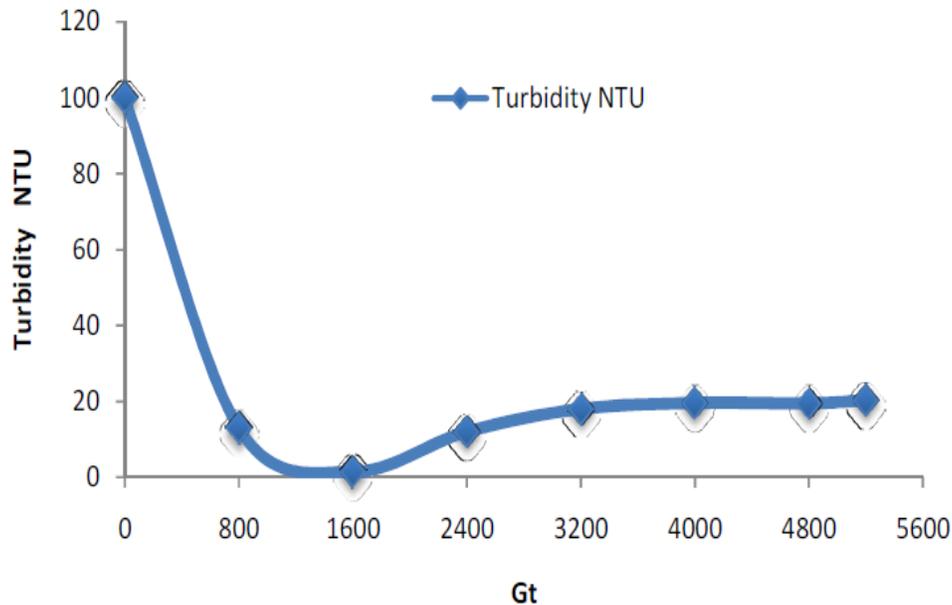


Figure 10: Variation in Water Treatment Plant Turbidity Removal Efficiency With Gt

5. CONCLUSION

The physical and mathematical models of hydraulic jump mixer were performed on three levels of turbidity waters. The coagulation experiments using alum indicated that coagulation process effectively removed turbidity from water using 10-15 mg L⁻¹ of the used coagulants.

The optimum dose of alum for coagulation was 10 mg L⁻¹, which is very low amount. High range of water turbidities could be effectively removed by using hydraulic jump coagulation mixer to under the standard of drinking water turbidity, 5 NTU. Maximum water turbidity removal was observed at water pH 6-7. Results demonstrated that the hydraulic jump mixer

removed more than 96.9% of all initial turbidity values (20, 250, and 500 NTU). The coagulation process by hydraulic jump and turbidity removal was considerably affected by pH, coagulant dosage, mixing time, intensity of mixing, velocity gradient parameters as well as initial turbidity of water for alum. At optimal dosage, the turbidity can be effectively reduced by increasing the G value of hydraulic jump mixing to 800 s⁻¹. The efficiency of removing turbidity can be improved more than with the hydraulic jump mixer, especially at G > 800 s⁻¹. The use of hydraulic jump coagulation in water treatment is technically feasible for water treatment plants, so as to effectively enhance the efficiency of removing turbidity.

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