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Research Article

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Modelling and development of laboratory based portable water treatment plant

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ABSTRACT

Water treatment is one of the sophisticated chemical processes, which controls the water quality. Turbidity is one among the water quality parameters. This research focuses on the modelling of water treatment process and the development of laboratory based water treatment plant. For developing the model for the water treatment process the three main stages namely, coagulation, flocculation, and sedimentation were considered. Based on the model obtained, a laboratory based water treatment plant was designed and developed. It serves as an experimental setup to carryout coagulation, flocculation and sedimentation processes.

Keywords: mathematical model, water treatment plant, detention time, Jar Test

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INTRODUCTION

Modelling is a study of developing models for the actual system. The developed model should represent the physical process. Modelling a process involves experimental analysis and theoretical studies of the given process [1, 2]. Experimental approach is based on the various input and output data obtained through measuring devices from the process. The second approach is based on the physical fundamentals and mass balance equations. Differential equations are used to represent the process model in the theoretical approach. This research work focuses on the development of dynamic model using mass balance equations. The dynamic model represents the dynamic nature of the system [3].

EXPERIMENTAL SECTION

In the water treatment process coagulation, flocculation and sedimentation are the three major processes [4, 5]. Mass balance equations are used for development of dynamic model for all three processes. The processes mentioned above are considered as mixing processes. In all the three processes raw water containing suspended solids flows at a constant volumetric flow rate into a tank of constant holdup volume**.** The concentration of the suspended solids in the entering stream varies with time. It is desired to determine the transferfunction relating the outlet concentration to the inlet concentration. The density of the stream is assumed to be constant. Since the holdup volume is fixed inlet flow rate equals to the outlet flowrate.Thissystem is analysed by writing a mass balance equation as shown in equation 1[6].

Flow rate of suspended solids in- flow rate suspended solids out
= rate of accumulation of suspended solids (1)

Design criteria for the portable Water Treatment Plant

Detention time is the important factor for designing tank dimensions. Specific detention time is required for all the three unit processes. Detention time is the duration of time for which the water is retained in a vessel [7].The flow rate of inlet water to the water treatment process is constant for all the three unit processes taken into consideration. The three unit processes are mixing processes; hence the mass balance equations are developed from equation 1[8, 9]. The alum flow into the coagulation process is negligible, hence it is not considered in mass balance equation. The mass balance equation for the coagulation process is given in equation 2.

$$QC_1 - QC_2 = V_1 \frac{dC_2}{dt} \tag{2}$$

Where,

Q Inlet flow rate to the coagulation process.

C_1 Suspended solids concentration of inlet water to coagulation process.

C_2 Suspended solids concentration of inlet water to flocculation process and outlet water suspended solids concentration from coagulation process.

V_1 Volume of the coagulation tank.

Detention time of coagulation process is given by the equation 3. Generally the detention time is measured in seconds [7].

$$T_1 = \frac{V_1}{Q} \tag{3}$$

Mass balance equations for flocculation and sedimentation processes were developed similar to coagulation process. The equations 4 and 5 are the mass balance equations for flocculation and sedimentation processes.

$$QC_2 - QC_3 = V_2 \frac{dC_3}{dt} \tag{4}$$

$$QC_3 - QC_4 = V_3 \frac{dC_4}{dt} \tag{5}$$

Where,

C_3 Suspended solids concentration of inlet water to sedimentation process and outlet water Suspended solids concentration from flocculation process.

V_2 Volume of the flocculation tank.

C_4 Outlet water suspended solids concentration from sedimentation Process.

V_3 Volume of the sedimentation tank.

Detention time of flocculation and sedimentation processes are given in equations 6 and 7. The detention time of flocculation process is 5 to 30 minutes and for sedimentation processes the detention time is 1 to 3 hours[7].

$$T_2 = \frac{V_2}{Q} \tag{6}$$

$$T_3 = \frac{V_3}{Q} \tag{7}$$

State space model development

State space equations were developed from mass balance equations [10]. The state space equations for coagulation, flocculation and sedimentation processes are given in equations 8, 9 and 10. The state and the output equation for the laboratory based water treatment plant are given in equation 11 and 12 respectively. In the three unit processes detention time is considered as an important parameter.

$$\frac{dC_2}{dt} = -0.0166C_2 + 0.0166C_1 \tag{8}$$

$$\frac{dC_3}{dt} = 0.000833C_2 - 0.000833C_3 \tag{9}$$

$$\frac{dC_4}{dt} = 0.000277C_3 - 0.000277C_4 \qquad (10)$$

$$\begin{pmatrix} \dot{C}_2 \\ \dot{C}_3 \\ \dot{C}_4 \end{pmatrix} = \begin{pmatrix} -0.0166 & 0 & 0 \\ 0.000833 & -0.000833 & 0 \\ 0 & 0.000277 & -0.000277 \end{pmatrix} \begin{pmatrix} C_2 \\ C_3 \\ C_4 \end{pmatrix} + \begin{pmatrix} 0.0166 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} C_1 \\ 0 \\ 0 \end{pmatrix} \qquad (11)$$

$$y = \begin{pmatrix} 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} C_2 \\ C_3 \\ C_4 \end{pmatrix} \qquad (12)$$

The concentration of suspended solid causes the turbidity [11]; hence the concentration of suspended solids can be used to indicate turbidity. The developed system will have inlet water turbidity as input and outlet water turbidity as output.

Design and development of portable Water Treatment Plant

The laboratory based water treatment plant consists of three processes namely coagulation, flocculation and sedimentation and analum dosing tank with a dosing pump. The dosage is supplied to the coagulation process. The raw water flow rate is fixed at 1.67×10^{-5} cubic meter per second. Both the raw water and the alum were subjected to a fast mixing process to produce flocs [12, 13]. These flocs will stick together in the flocculation process. In the sedimentation process flocs are removed by gravity. The detention time for the coagulation, flocculation and sedimentation processes are calculated and tabulated in table 1. The volume of coagulation, flocculation and sedimentation process tanks are also found and tabulated in the same table

Table 1: Process Parameters of coagulation, flocculation and sedimentation

	Coagulation	**Flocculation**	**Sedimentation**
Raw water flow rate (Cubic Meter per second)	1.667×10^{-5}	1.667×10^{-5}	1.667×10^{-5}
Detention time required	60 seconds	1200 seconds	3600 seconds
Volume of Coagulation Tank (cubic Meter)	1×10^{-3}	2×10^{-2}	6×10^{-2}

The laboratory based water treatment plant was designed and fabricated based on the dimensions given in Table 1. The plant is shown in Figure 1.

Implementing Water treatment process

Controlling the turbidity is considered as a difficult task in water treatment process. Turbidity control is achieved by adding coagulant in the coagulation process. Determining the coagulant dosage is another difficulty in water treatment. There are different approaches suggested by many authors. Traditionally Jar Test was used to determine the optimal coagulant dosage. Hence optimal coagulant dosage was determined using Jar Test for the water to be treated.

Alum Dosage prediction by Jar Test

The jar test is a common laboratory procedure used to determine the optimal coagulant dosage [14, 15]. Jar test apparatus has six Jars with a capacity of one litre each. Various amount of alum are used in the six jars to carry out the test. 500 milli litre of water is treated in each jar. Before the Jar test,raw water turbidity and various alum dosages in each jar was noted. After the Jar test the treated water turbidity of water in each jar was noted. The alum dosage which gives the minimum treated water turbidity is considered as an optimal alum dosage. Amount of alum dosage required to treat 500 ml of water is found from the Jar test. As per the optimal alum dosage predicted by Jar Test the dosage is adjusted by the dosing pump available in the experimental setup to achieve the turbidity control.

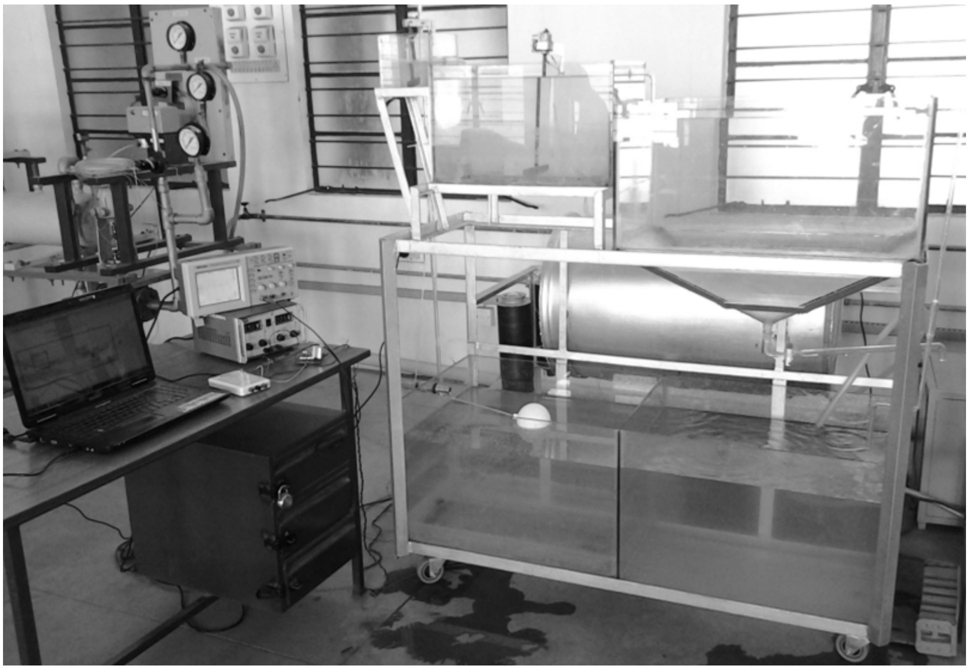

Fig 1: Portable Water Treatment Plant

RESULTS AND DISCUSSION

The Jar Test results are tabulated in Table 2, Table 3 and Table 4. Only few samples are shown in the above tables. The observations have been plotted in Figure 2, Figure 3 and Figure 4. The optimal alum dosage for the sample with initial turbidity 11.86 NTU is 4 grams, for the sample with initial turbidity 39.24 NTU the optimal alum dosage is 5.8 grams and for the sample with initial turbidity 10.11NTU the optimal alum dosage is 5.4 grams.

Table 2: Jar Test result for the sample with Initial turbidity- 11.86(NTU)

Alum(g)	Treated water Turbidity(NTU)
2.0	15.39
2.5	13.15
3.0	2.486
3.5	0.828
4.0	0.312
4.5	1.954
5.0	3.457
6.0	8.972

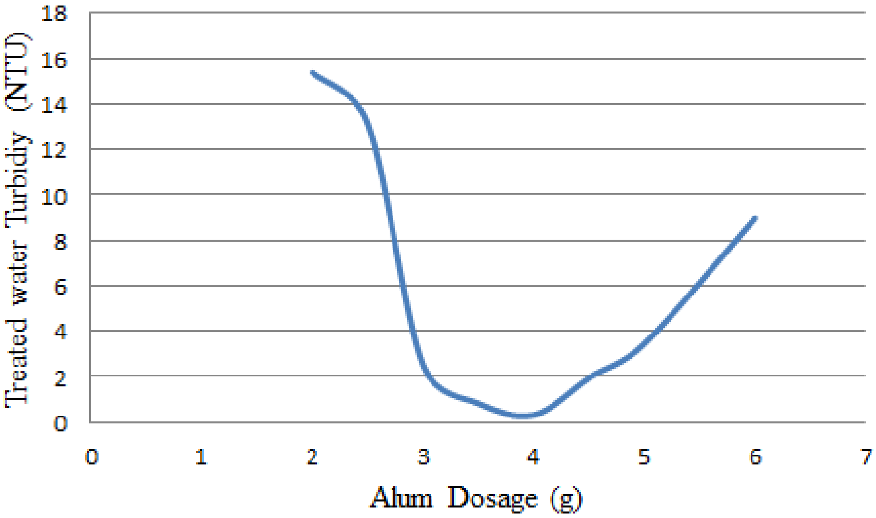

Fig 2: Optimal alum dosage for sample with Initial turbidity- 11.86(NTU)

Table 3: Jar Test result for the sample with Initial turbidity- 39.24(NTU)

Alum(g)	Turbidity(NTU)
4.5	13.73
5.0	2.716
5.4	0.841
5.8	0.298
6.0	2.165
6.5	9.686
7.0	14.33

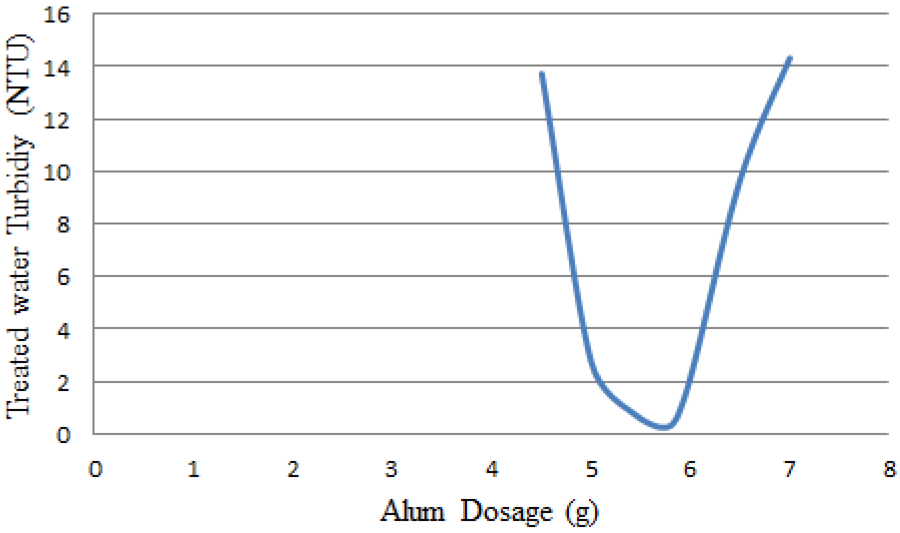

Fig 3: Optimal alum dosage for sample with Initial turbidity- 39.24(NTU)

Table 4: Jar Test result for the sample with Initial turbidity-10.11(NTU)

Alum(g)	Turbidity(NTU)
4	4.759
4.4	2.208
4.8	0.759
5	0.591
5.2	0.241
5.4	0.086
5.5	0.446
5.8	1.825

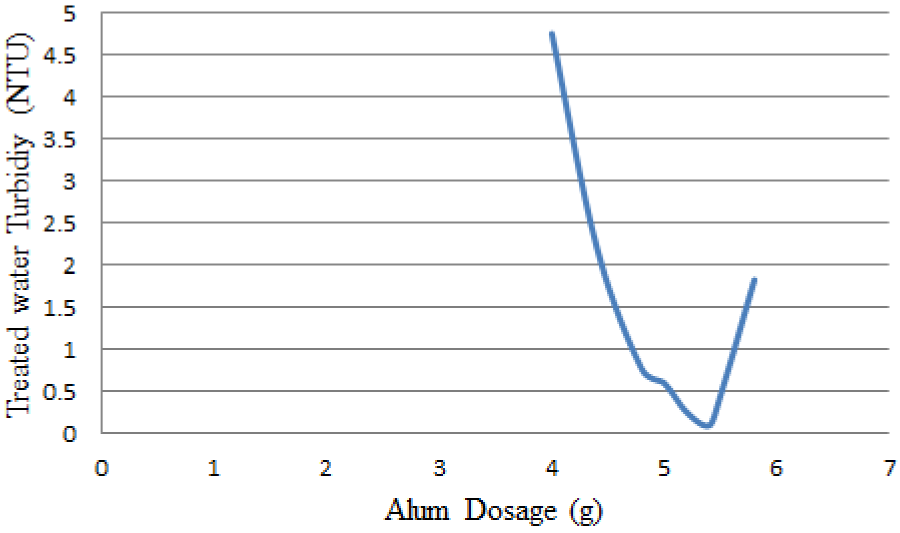

Fig 4: Optimal alum dosage for sample with Initial turbidity- 10.11(NTU)

CONCLUSION

In this research, modelling of a laboratory based water treatment plant was experimented to develop a real plant suitable for laboratory purpose. It was designed for the raw water flow rate of 1.67×10^{-5} cubic meter per second. The coagulation, flocculation and sedimentation processes were designed with required detention time. The optimal alum dosage was determined using Jar Test. This experimental setup will help in testing and implementing various control algorithms to control the alum dosage and thereby controlling water turbidity.

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