Comparison of Two Modules in Sedimentation Process using Mathematical Techniques

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ABSTRACT

Raw water must be purified before being distributed to any village, town, or city. To purify raw water, various significant processes must be performed in a water treatment plant, with sedimentation being one of the most important. Solid particles in the form of dirt and other contaminants can be found in raw water, especially during the rainy season, which can be removed through sedimentation. Plate settlers or tube settlers are commonly utilized in sedimentation units to treat water quickly, reducing the detention time to 15-20 minutes. This study modified conventional tubes in terms of manufacturing and repositioning to increase turbidity removal in raw water. The experimental work was carried out for one year to calculate the balanced turbidity of the raw water using conventional and modified square-shaped tube settlers. Mathematical analysis was deployed to compare the output from one year's data from both experimental studies. Regression, R^2, relative standard deviation, and ANOVA were employed to analyze the experimental models, and the observed and calculated findings were compared. The results show that the modified tube settlers removed more turbidity from the raw water than the conventional ones.

Keywords-tube settler; coagulant dose; detention time; regression equation; coefficient of variation; ANOVA

I. INTRODUCTION

Several countries have used high-rate settling as a standard procedure in the water treatment process. However, the effective implementation and efficiency of high-rate settling cannot be followed absolutely [1]. Shallow-depth gravity settlers with shorter detention times (up to 20 minutes) are more efficient than traditional methods (up to 2.5 to 3 hours). This new trend has resulted in cost savings in terms of area, size, building materials, and treatment chemicals [2]. The two basic tube settling systems developed by authors in [3] were essentially horizontal and steeply inclined plates/tubes [3-5]. Many studies have presented early attempts at shallow-depth settlement, including the creation of clarifiers, plate settlers, tube settlers, and practical applications. The application of two different square-shaped tube settlers in a sedimentation tank was demonstrated in [6]. This study analyzes the results of both methods using regression equations, coefficient of determination, coefficient of variance, and ANOVA. To remove maximum turbidity in the raw water, the parameters were studied based on the requirements of the experiment.

A. *Historical Developments in High Rate Settling and Tube Settler*

According to [7], the proportions of solid particles to be removed in a sedimentation tank are primarily a function of the surface area of the tank and are not affected by the duration. In [7], a horizontal tray was installed and the surface area expanded twofold, doubling the capacity of the sedimentation basin. In [8], a constant velocity profile was designed for a tank to help solid particles follow a specific path. Subsequently, an ideal settling tank was created with horizontal trays separated at 12 cm, built specifically for sludge settling. With a flow rate of 168 m/h and a surface overflow rate of 27 m^3/m^2-d, this tank had a detention time of 11 minutes [8]. In [9], horizontal trays were installed in series with a 4.75 m spacing and cleaned by draining and hand washing. In the water treatment tank, this design was known as a two-story settling tank.

B. Development, Modifications, Application, and Performance of Tube Settlers

In [10], an improved tube settler concept was proposed. In the rectangular tank, a hopper bottom layout was divided into three functional zones, namely the inlet, outflow, and central zones. The inclined tubes were joined to the partition wall in such a way that the lower end was in the intake zone and the upper end was in the outflow zone. The inclined tubes were affixed to the partition wall in such manner that the lower end of the tubes was in the intake zone and the upper end was in the outflow zone. In [11], the wetted perimeter of triangular-shaped tube settlers was expanded, and their performance was studied. A model was created that consisted of six tubes measuring 50 mm^2, while each of them had a 60 cm length and a 60° angle to the horizontal. In [12], a review on sedimentation studies was conducted, indicating a gap in analysis methods. This study attempts to fill this gap.

C. Inclination of Tubes

In [5], the inclination of the tubes was examined, demonstrating that if a tube is inclined at more than 45°, then the accumulated particles try to move in a downward direction after reaching a certain depth. In [4], the sedimentation efficiency was explored based on tube inclination. This study exhibited that the competence of the tube settler system depends on the tube inclination, efficiency increases with an inclination of up to 35°- 45° and degrades when the inclination increases beyond. A tube inclination between 45° and 60° causes significant sludge sliding activity under gravity and turbidity removal efficiency. In [13], it was mentioned that to achieve self-cleaning activity under gravity by tubes, the inclination must be only at 60°. However, there may be little sacrifice for efficiency. This study also introduced the concept of a tilted plate separator, which consists of closely spaced parallel inclined plates. The space between plates was 0.3", the inclination was kept at 60° to the plane, and the solid removal efficiency was found to be 90%. In [14], the angle of inclination was kept at 45°, achieving better efficiency in turbidity removal.

D. Factors Affecting Tube Settlers

In [3, 5, 13, 15-17], factors that affect the performance of tube settlers were studied and discussed. These factors included flow velocity and regime, diameter and length of tube settler, tube shape, inlet and outlet arrangement, angle of inclination, and entrance length.

E. Mathematical Analysis

This study formulated a regression equation between the influent turbidity passing through the inlet and the turbidity remaining after the outlet of conventional and modified square-shaped tubes using data from one year. The coefficient of variance was used to compare turbidity. ANOVA was deployed to calculate the highest rate of turbidity for season-wise data. A regression equation defines the relationship between two variables. If the dependent variable is a function of more than one variable, then the regression equation can estimate the effect of changing one independent variable on the dependent variable while keeping the other independent variables constant. This method helps determine the role of each independent variable without having to worry about the model's other variables. The regression equation can also be utilized to predict the output from the input and provides a more comprehensive picture of the relationship between variables.

The coefficient of determination (R^2) is employed to measure how closely the data fit the regression line. A linear model's coefficient of determination is the percentage of the dependent variable variance explained by the independent variable. The higher the R^2 score is, the better the model fits the data in general. Higher R^2 values represent smaller discrepancies between the observed and fitted data. The coefficient of variation (CV) or relative standard deviation was also put into service to compare turbidity using the two different methods. CV is a dimensionless quantity defined as the ratio of the standard deviation to the mean. For sample data, the standard deviation is given by

$$s = \sqrt{\frac{\Sigma(x_i-\mu)^2}{N-1}}$$

and:

$$CV = \frac{s}{\mu} * 100,$$

where μ is the mean. In season-wise analysis, the data of one year were divided into three parts by considering seasons in India. The turbidities in the three seasons were compared implementing ANOVA. This study aims to verify the experimental results of conventional and modified tube settlers.

A linear regression model has many applications in various engineering, industrial, medical, economic, and real-life applications [18-22]. In [23], the focus was on linear regression analysis in the field of coastal engineering, particularly since it can be used in conjunction with dimensional analysis. In [24], a pseudo-linear regression framework was developed to predict the volume of work in construction companies in Qatar. In [25], CV was utilized for in situ tests on sand. In [26], different machine learning algorithms, R^2, linear regression, mean absolute error, and median absolute error were deployed to create a prediction model of groundwater recharge in climate change scenarios. In [27], artificial neural networks were used to predict and decide the optimal doses of chlorine and coagulants in a water treatment plant. In [28], an adaptive neural fuzzy system was applied to investigate pollutants. According to [29], high-rate settlers can be an option to treat raw water. In [30], the modified tube settlers were much more efficient than the conventional settling method.

II. METHODOLOGY

A. Experimental Setup and Tube Configuration

A 240 MLD capacity water treatment plant in Nagpur was identified for the experimental work. The plant is on the bank of a river whose average raw water turbidity exceeds 500 NTU. A tube settler unit with two basic configurations was manufactured and installed in the plant for a live case study. Figure 1 depicts the cross-sections of the tube settlers. The arrangement is done in such a way that flocculated water is readily transferred from the flocculation tank. The inclination angle of the tubes with respect to the horizontal plane was kept at 60° to facilitate particle settling in the desludging of the tube base, and then flocculated water was supplied to the tube settler unit and the cleared water sample. After that, a Nephlo-turbid meter was used to test the material in the lab. The turbidity was found to be greater than 1000 NTU during the rainy season, and in most cases the turbidity of the treated sample was less than 10 NTU.

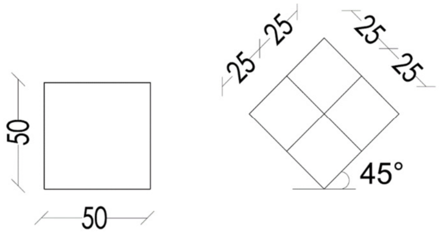

Fig. 1. Conventional and modified square-shaped tubes.

B. Analysis

Regression analysis was performed to delineate the relation between the influent turbidity passing through the inlet and turbidity remaining after the outlet of the conventional and modified square-shaped tubes. The coefficient of determination (R^2) was utilized to determine how close the data are to the fitted regression line, given by:

$$R^2 = \frac{Variance\ explained\ by\ the\ model}{Total\ variance}$$

For this experimental work, a linear regression equation was found between the influent turbidity passing through the inlet and the turbidity remaining after the outlet of conventional square-shaped tubes. The relation is:

$$T_R = 0.1503\, T_I + 0.1041$$

with R^2 of 0.9807. T_I refers to the turbidity of the inflow and T_R denotes the turbidity remaining after passing through the conventional square-shaped tube. Figure 2 depicts the linear graph between the two variables.

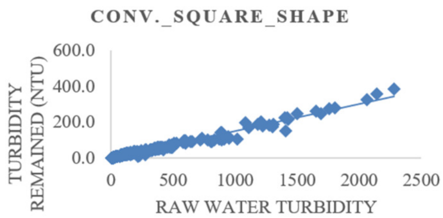

Fig. 2. Linear graph between the two variables for the conventional tube settlers.

The regression equation for the influent turbidity passing through the inlet and the turbidity remaining after the outlet of the modified square-shaped tubes is:

$$T_R = 0.071\, T_I + 0.8337$$

with an R^2 of 0.99368. Figure 3 portrays the linear graph between the two variables.

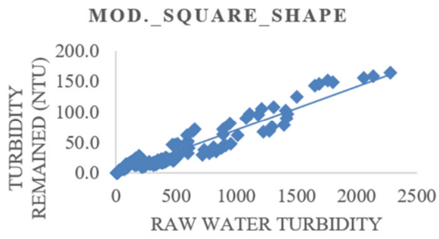

Fig. 3. Linear graph between the two variables for modified tube settlers.

C. Turbidity Comparison

The regression analysis manifests the effect of how the changes in each independent variable make the changes in the dependent variable. Three turbidity results were compared using CV:

- Turbidity in raw water.
- The remaining turbidity obtained using the conventional square-shaped tube.
- The remaining turbidity obtained employing the modified square-shaped tube.

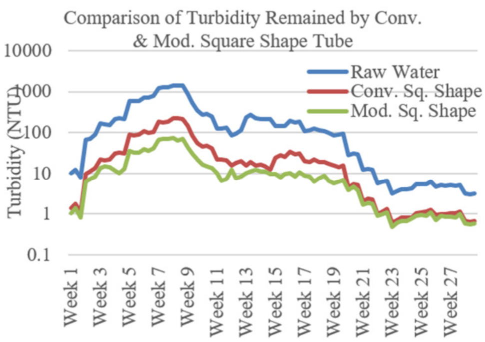

Fig. 4. Comparison of remaining turbidity using the conventional and modified square-shaped tubes.

To find the maximum turbidity based on the seasons in India, the data for one year were divided into three parts: June to September, October to January, and February to May. ANOVA was deployed to check the highest turbidity among all seasons with the null hypothesis being that there is no significant seasonal effect on turbidity.

III. RESULTS AND DISCUSSION

The results reveal that the influent turbidity and the remaining turbidity after passing through the square-shaped tubes have a linear relationship. R^2 for the original square-shaped tube was 0.9807, while for the modified one it was 0.99368, indicating good connectivity. Raw water has a CV of 3.29%, 2.13% for the conventional tube and 1.74% for the modified square-shaped tube. When analyzing the CV of these data, it was found that the conventional approach reduced turbidity in raw water by 1.26%, whereas the modified experiment reduced turbidity by 1.55%.

Using the ANOVA test with a 99% level of confidence, the null hypothesis that turbidity and season had no connection is rejected. The result shows the highest impurity in the rainy season from June to September.

Future work could utilize these results to obtain better efficiency by employing modified tubes to remove turbidity in areas where raw water turbidity is approximately 20 NTU, without using any additive coagulant, which will result in saving operational costs. This study considered all possibilities during the execution of this investigation, but one limitation is that the model may be less efficient when raw water turbidity is more than 1000 NTU and there is an absence of additive coagulants such as Poly-Aluminum Chloride (PAC).

IV. CONCLUSION

When comparing the balanced turbidity of the conventional and modified methods, it was observed that the modified tube settlers were more effective than the conventional ones. For the modified model, R^2 was 99.68%, displaying a good score for the relation between the balanced and raw water turbidities. The comparison of CV demonstrates that the modified method outperforms the conventional method. By implementing ANOVA, it was found that turbidity depends on seasons, with the highest turbinated water found in the monsoon. Future studies could take advantage of the results of this study to enhance efficiency in turbidity removal.

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