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Suspended Solids Removal Mechanism Comparison in Tube Settler

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Abstract
Suspended solids removal efficiency of tube settler was analyzed by measuring turbidity at several flow rates. 4*2.8*2 m dimension tube settler with 85 cm long, 40 mm dia. meter tubes was operated to meet the research objective. Analysis of tube settler was conducted for four discharges viz., 4.5, 7, 8.5 and 10 litre per seconds (lps). The maximum turbidity removal efficiency was found to be 50.786 % at flow rate of 4.5 lps (maximum removal in comparison to other discharge rates). This indicates the effectiveness of the tube settler. The observed actual data was compared with the YAO model, Khatri model and Rajbanshi model to check the validation of the model at the tube settler of Siddhipur Water Treatment Plant. YAO model developed based on coagulated water, and Rajbanshi model developed assuming linear relationship between influent and effluent turbidity cannot be justifiable for this study. Khatri model is showing same trend of data with the observed analytical method as both are for plain sedimentation concept. Khatri model can be used for the tube settler and the factor for the representation of observed value to Khatri model is 0.786.

Keywords
Efficiency, Models, Suspended solids, Surface Overflow, Tube Settler, Turbidity

1. Introduction

The most widespread chemical compound on the globe is water. Water is found in all three states liquid, solid and gaseous and is a key factor of life on earth [1]. Due to growing demand of water, it is main challenge and problem to provide safe, potable water to all. In surface source of water supply i.e. streams and rivers the main challenge is to remove the turbidity caused by suspended solids. Increasing deforestation, overgrazing of cattle's, unplanned excavation in construction activities results mass movement and landslides, which causes the water in the rivers and streams rich in suspended solids causing turbid water [2].

The major process for the water treatment is to separate the particles from suspension, as it has a direct impact on the overall working efficiency of treatment plant. Sedimentation under the action of gravitational force is considered as one of the most economical separation methods. Sedimentation is the most widely used method for the solid removal from the raw water. Several modifications in sedimentation tank were made to reduce the cost, detention time, footprints of land.

"Essentially horizontal ($\theta < 7.5°$)" and the "steeply inclined (θ up to 60°)" are the two commercially available compositions of tube settlers, where θ is the angle to the horizontal [3]. The study indicates that the tube settler concept needs further exploration to provide operating information and to verify design criteria, especially in the "essentially horizontal" tubes [4]. Tube settlers are generally treatment units with low footprints with detention time less than 15 min. HDPE pipes or tubes are used for the removal of suspended solids from the raw water in tube settler.

2. Research Objectives

The general objective of this study was to study the turbidity removal efficiency of tube settler. Furthermore, the turbidity removal efficiency was also compared for several models as Khatri model, YAO model, Rajbanshi model and Observed data for varying flow rates.

3. Materials and Methods

Raw water from the source at the inlet of tube settler is taken and the treated water at outlet of tube settler is used for the turbidity measurement. Initially, natural water samples from the inlet pipe of the tube settler were taken to analyze the mechanism of suspended solids removal. The influent water is then prepared by mixing influent raw water with fine solids particles at various flow rate and run the tube Settler constructed at SWTP. The fine solid articles were obtained from the sludge zone of the same tube settler. The study was then continued with turbid water at various flow rate in the tube settler located at Siddhipur Water Treatment Plant. Table 1 lists the parameters that were studied and the frequency with which they were tested.

Table 1: Experimental parameters and frequency of measurements

S. N.	Experimental Parameters	Unit	Frequency of Test	Methods
1	Turbidity	NTU	Thrice a week	Nephelometric method
2	Flow Rate	l/min	Every time before measurement	Weir Formula and Volumetric method (Beaker and Timer)
3	Temperature	° C	Thrice a week	Thermometer
4	pH		Thrice a week	Digital pH meter
5	Solid Calculation	mg/lit	Four times throughout study	Oven, muffle furnace

4. Experimental Setup

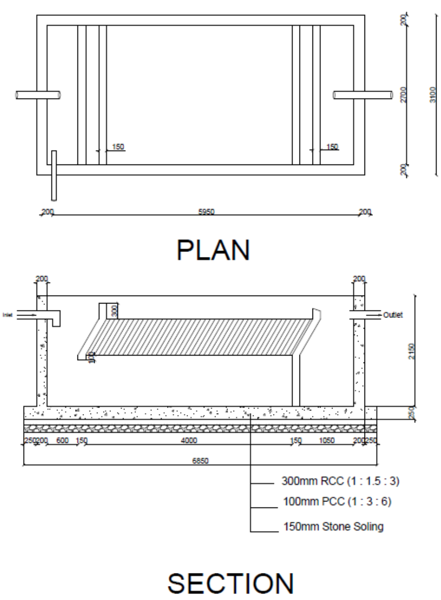


Figure 1: Schematic Diagram of Tube Settler

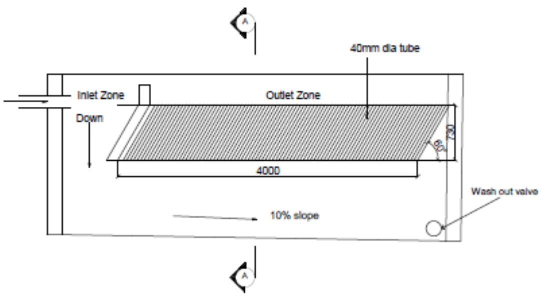
Siddhipur Water Treatment Plant, Siddhipur, Lalitpur was used as working station. The general arrangement of tube settler located at SWTP is shown in the figure 1 and figure 2.

Raw turbid water flows from the inlet chamber to the 4*2.8*2 m tube settler. The settling of suspended particles take place through 85 cm long HDPE pipes or tubes placed at 60° inclination to horizontal with 40 mm diameter in the designed detention time of 8.5 minutes [5, 6].The removal efficiency depends upon the nature and size of suspended particles present in water.

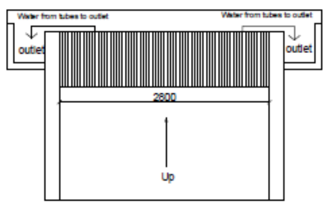
Experimental setup for the completion of the study was conducted as:

Sampling holding tank:
Sample was prepared in 50 liter capacity drum and continued mixing with the wooden stick. Constant turbidity was maintained throughout the experiment period.

Settler Pipes:
HDPE pipes having diameters of 40 mm were used. Inlet pipe was connected about at 15 cm from the lower end of pipe for allowing accumulation of sludge.



Tube settler in SWTP (Longitudinal sction at A-A)



Tube settler in SWTP (cross sction at A-A)

Figure 2: Longitudinal and Cross-section of Tube Settler

Experimental sample:
Sludge were taken from the sludge zone of the tube

settler located at Siddhipur Water Treatment Plant (SWTP). This sludge was used for the preparation of artificial turbid water at different time with different turbidity to conduct the experiment in a real field situation. Laboratory measurement works were conducted on the lab of SWTP but the essential measurement instrument were installed in the laboratory.

Turbidity meter:
A digital turbidity meter Model 331 (manufactured by Electronics India) was used for the turbidity measurement during the whole study period. The range for the turbidity measurement by the device was 0 to 1000 NTU.

Discharge Measurement:
For the calculation of discharge into the channel, Triangular V notch weir with central angle 60° was used. The triangular V notch weir was placed at the outlet of tube settler for discharge measurement.

5. Comparison of Several Models

For the completion of the study the observed data by analytical method is compared with the YAO model, Khatri Model and Rajbanshi Model. For the comparison of observed data with Khatri model or theoretical model Beaker Test was conducted for various SOR ranging from 0.6 m/hr to 3m/hr.

a. YAO model: for coagulated water

$$T_e = a(t)V_s \quad (1)$$

where,
T_e = effluent turbidity in % of influent Turbidity T_o
$a(t)$ and $b(t)$ = empirical constants depends on influent turbidity and dose of coagulant
V_s = settling velocity in m/h

b. Khatri model: Khatri [3], developed a model of tube settler based on beaker test in the laboratory for prediction of effluent turbidity.

$$T_e = a\, V_s{}^b \left(\left(\frac{3}{(3b+4)} \right) + 0.25 \right) \quad (2)$$

c. Rajbanshi Formula: Rajbanshi [5] carried out the study in the tube settler located at Siddhipur water treatment plant in 2009. The flow range operated by Rajbanshi was between 2.4 lps to 10.1 lps.

$$T_r = 0.6927 \times T_o – 8.7216 \quad (3)$$

Where,
T_r = Turbidity removed in NTU
T_o = Influent Turbidity in NTU

d. Observed data or Analytical Method:

$$\text{Removal efficiency }(\%) = \frac{(C_o - C_e)}{C_o} \times 100\% \quad (4)$$

Where,
C_o = initial turbidity concentration and
C_e= Final turbidity concentration after tube settler.

6. Results and Discussion

Different parameters were measured in the site for the fulfillment of the objectives of the study.

Table 2: Experimental parameters measurement

S.N.	Parameter	Unit	Range
1	pH	-	8.1 – 8.4
2	Temperature	° C	15.2 – 21.0
3	Inlet water Turbidity	NTU	4 - 160
4	Outlet water Turbidity	NTU	2 - 98
5	Volatile solids in inlet water	mg/l	80 – 200
6	Fixed solids in inlet water	mg/l	200 - 520

The turbidity removal capacity of the tube settler is observed by measuring influent and effluent turbidity at discharges 4.5, 7, 8.5 and 10 lps and SOR: 0.283, 0.45, 0.597 and 0.643 m/hr., at different turbidity ranges from 20 to 160 NTU. With the increase in SOR, Flow rates also increases as a result of which the turbidity removal efficiency goes on decreasing.

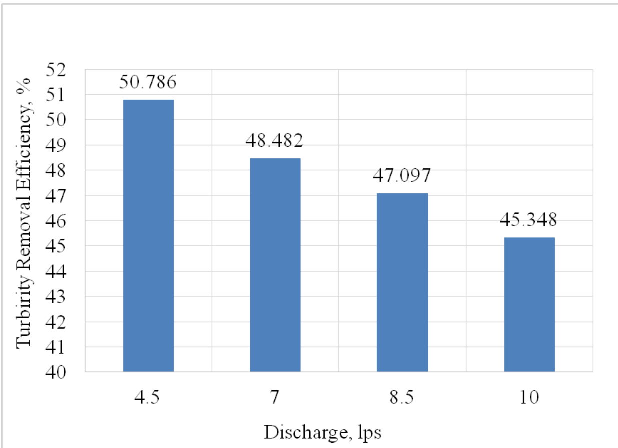


Figure 3: Average Turbidity Removal efficiency at various flow rates

With the increment in discharge, average removal efficiency of the tube settler reduces. SOR increases, flow velocity increases resulting lower settlement of particles leads decrease in turbidity removal. The increase in the turbidity increases the concentration of the suspended solids and at the same time with the change in the flow rates alters the detention time, as a result of which removal efficiency changes.

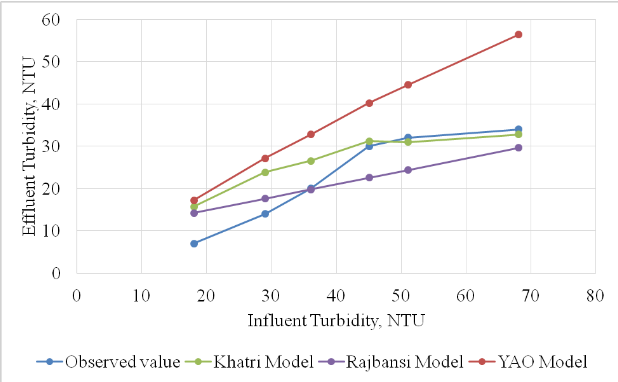


Figure 4: Comparison of various model at 4.5 lps or 0.283 m/h

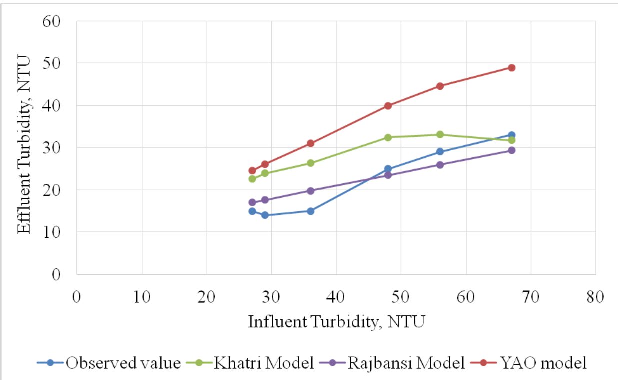


Figure 5: Comparison of various model at 7 lps or 0.45 m/h

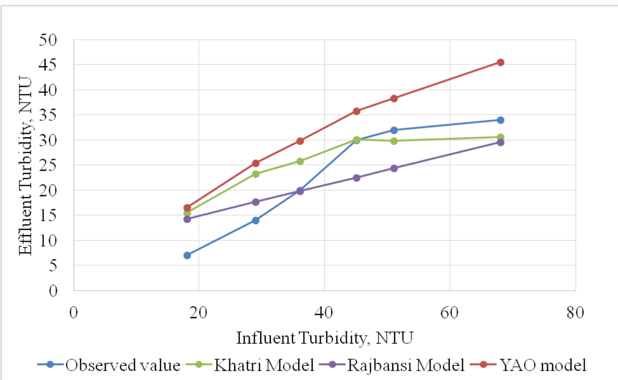


Figure 6: Comparison of various model at 8.5 lps or 0.597 m/h

Figure 4, 5 and 6 shows the sensitivity curve for the comparison of various model at various flow rates and SOR. Beaker tests was conducted and the obtained data were fitted in the power curve to find removal efficiency for both YAO and Khatri model. Equation no. 1, 2, 3, and 4 were used to find the turbidity removal. For discharge 8.5 lps, 7 lps and 4.5 lps or SOR 0.597 m/hr, 0.45 m/hr, and 0.2832 m/hr correlation between Khatri model and Observed actual model is 0.96161, 0.90246, 0.97046 respectively and between Rajbanshi formula and Observed actual model is 0.94432, 0.97981, 0.94432 respectively. Rajbanshi model always present linear data as it is fitted in linear trend, so it doesn't involve the role of flow rate for turbidity removal. Comparing the turbidity removal at various flow rates it is found from the study that turbidity removal changes with the flow rates for same range of influent turbidity. Comparison of Beaker test with Observed actual data shows the advantages of tube settler over sedimentation tank as the removal in actual observed data is more in same detention time.

7. Conclusions

The tube settler in the Siddhipur Water Treatment Plant was studied in this paper. This study shows that turbidity removal efficiency of tube settler decreases thereby increase in the flow rates. This study was aimed to determine the suspended solids removal efficiency of tube settler in SWTP at various flow rates. The maximum turbidity removal efficiency in tube settler is obtained as 50.786%, 48.482 %, 47.096 % and 45.348 % at SOR of: 0.2832 m/hr, 0.45 m/hr, 0.597 m/hr and 0.643 m/hr respectively. From the parameters measured, pH and temperature are within the WHO limits [7]. Turbidity has a high range then the drinking water limit. For the reduction of turbidity, tube settler has been installed and this study is also carried to check the kinetics of turbidity removal in tube settler. Turbidity up to 160 NTU has been introduced to find the removal mechanism. The effluent water from the slow sand filter installed after tube settler reduces the turbidity of water within the WHO limit. From the above results in the comparison of models, Khatri Model i.e. theoretical model and observed analytical model are alike as both are based for plain sedimentation concept. We can draw a conclusion that Khari model can be used at any working place of tube settler but data must be obtained from Beaker test. YAO model and observed data are not similar in nature so we can draw conclusion that YAO cannot be used in this type of plain sedimentation case of tube settler as YAO is for coagulated water only. Rajbanshi model always shows the linear data as it is fitted as a linear relationship between influent turbidity and effluent turbidity, it is found that there is no role of discharge in the Rajbanshi model. So, YAO due to coagulated water not appropriate for plain sedimentation concept tube settler and Rajbanshi model due to linear model are not appropriate for the tube settler. Correction Factor value is smaller for the smaller influent turbidity. Mean value of Factor for Khatri model and observed value is 0.786.

Acknowledgments

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