Effect of Grit Chamber Configuration on Particle Removal: Using Response Surface Method

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Abstract: In recent years ever-increasing industrial growth has resulted in a significant increase in the production of wastewater, this wastewater sometimes contains high levels of suspended solids. Therefore, the need to formulate an appropriate course of action for managing this wastewater has reached a critical level. In this study, the removal of suspended particles in wastewater that were a byproduct of an idustrial cut stone production process were investigated. For these purposes, a laboratory grit chamber was employed, and response surface methodology (RSM) was used to simulate the contributing parameters in the settling process. In order to study the performance of the grit chamber, factors such as flow rate, inlet location and mesh size, parameters of pH, COD, BOD, TSS and turbidity in influent and effluent were monitored. Results indicated that values of pH, COD and BOD in raw wastewater were within the standard range of discharging wastewater. The results indicated that the model with a high correlation of 0.95 was able to simulate the process. In addition, turbidity removal was found to be affected by three parameters among which mesh size and its interaction with the flow rate were the most influential ones.

Keywords: Grit chamber, Configuration, Response surface method, suspended solids.

Rapid urbanization and industrial development during last the decade, have caused considerable concerne for the environment. One major concern is the quality of water being discharged from industries that may contain chemical pollutants. Over the years, continuous contaminating has resulted in damage to the ecosystems; which human life, relies on [1]. Thus, regulations have been imposed to ensure appropriate disposal of chemicals, to protect the environment, and to encourage the remediation of polluted environment. Due to the rising stringent legislation, there is a need for applicable treatment process in terms of operation efficiency and operation costs [2].

One issue for concern in the wastewater treatment process is grit removal systems and its performance in plant headwork's. The presence of grit in effluent can interfere with the treatment process and sometimes cause mechanical damage and premature ware to wastewater treatment equipment. In addition, this kind of wastewater can cause problems in receiving water if it's not properly treated (such as increase turbidity in the receiving water and making the floor muddier when the slurry finally settles down). Grit comprises a range of particles including sand, gravel, cinder and other heavy, discrete inorganic materials. The Environmental Protection Agency's Wastewater Technology Fact Sheet (Screening & Grit Removal), defines grit as particles larger than 0.21 mm and with a specific gravity of greater than 2.65 [3,4].

In order to remove the grit, three types of chambers are used i.e. horizontal flow grit chamber, aeration grit chamber and vortex flow grit chamber. The hydraulics of the grit chamber does not differ in the systems. The horizontal flow grit removal system is used in small plants. In this case, the wastewater flow moves slowly and the grit is deposited with a free fall to the bottom of the channel. Many factors clearly affect the capacity and performance of a grit chamber: surface and solids loading rates, tank type, solids removal mechanism, inlet design, weir placement and loading rate, etc. To account for them, present-day designs are typically oversizing the settling tanks. In that way, designers hope to cope with the poor design that is responsible for undesired and unpredictable system disturbances, which may be from hydraulic, biological or physico-chemical origin [5,6].

In the present work the effects of mesh size, flow rate and inlet location on turbidity removal was investigated.

2. EXPERIMENTAL SET-UP

The marble slurry was supplied directly from cut-stone mill and sample was taken in its original slurry state from the discharging canal, dried and brought to the laboratory. The sample was sieved and divided into the 5 accumulated mesh size of 60, 140, 200, 270 and above. Solid ratio of the suspension was selected as 4% (w/w), simulated of cut-stone wastewater. Pilot design of the grit chamber was carried out according to Metcalf and Eddy [7]. The glass grit chamber was

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made in the dimensions of 20 (h) × 20 (w) × 120 (L) cm. The sample was prepared in a well mixed 100-litter storage tank and connected to the grit chamber at the flow rate of 10.5, 24 and 40 L/min. The prepared sample entered the grit chamber through 3 different inlets from the bottom up to 6.6, 10 and 16.6 cm from the floor (bottom, middle and top), respectively. The performance of grit chamber was analyzed by turbidity and mesh size measurement of the effluent.

The most popular class of second-order designs, the central composite design (CCD), was used for response surface method (RSM) in the experimental design and is presented in Table **1**. The central composite design with three numerical factors was applied using Design-Expert 6.0.

Second order designs are used in many applications, and one of the most popular ones named CCD or Central Composite Design, was applied for the RSM or Response Surface Method, and Table **1** depicts the related details. By taking advantage of Design-Expert 6, CCD was implemented accompanied by three numerical factors.

Table 1: Model Variables and their Ranges

Variables	Range
Mesh size	60-270
Inlet location (cm)	6.6-16.6
Flow rate (L/min)	10.5-40

3. RESULT AND DISCUSSION

Evaluation of RSM Model

The experimental results were studied by Design-Expert 6.0 software using approximating functions of independent variables: mesh size (A), flow rate (B) and inlet location(C). Equation 1 presents the approximate functions of percentage of turbidity removal obtained using Design-Expert software.

$$\begin{aligned}&\textit{Percentage of turbidity removal} = +36.13 - 70.88 * A\\&-2.42 * B - 2.73 * C + 48.07 * A^2 - 11.06 * B^2 \qquad (1)\\&-6.65 * C^2 - 0.033 * A * B - 1.13 * A * C + 6.44 * B * C\end{aligned}$$

The value of Model F indicates that the model is not appropriate. The occurrence chance of Model F due to noise is only 0.01%. It is notable that “ProbeF” values lower than 0.05 imply the insignificance of model terms. In this case, A and A^2 are significant model terms. The “Pred R-squared” of 0.9177 is in reasonable accordance to “Adj R-Squared” of 0.9422. The plots of actual and predicted percentage of dye removal, accompanied with test data, are presented in Figure **1**. Actual values are the measured response data for a specific run, and the predicted values are evaluated from the models. It can be clearly seen that the values of R^2 for model is 0.95, which indicates good fitness of the response models. Thus, model is able to predict the experimental results with acceptable accuracy.

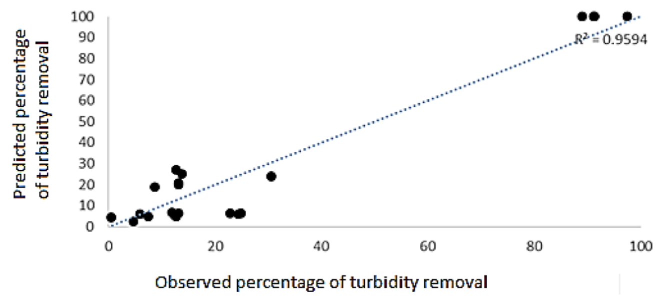

Figure 1: The actual and predicted plots of RSM model.

Characteristics of the Wastewater

The sample was analyzed for the following parameters: COD, BOD, TDS, TSS which is listed in Table **2**.

Table 2: Characteristic of Cut-Stone Wastewater

Parameters	Value
COD (mg/l)	60
BOD (mg/l)	20
TSS (mg/l)	40000
TDS (mg/l)	300
Grit density (gr/cm^3)	2.5
pH	8.1

The results from Table **2** shows that wastewater sample had the effluent discharge standards to land for COD, BOD, pH and TDS. Only TSS didn’t cope with required standards and needed to be investigated.

Mesh Size Analysis

To predict the behavior of particles in the grit chamber, it is necessary to calculate particle sedimentation velocity as well as scouring velocity by using Equation 2 and 3, respectively [8].

$$Vs = \sqrt{\frac{1.33(\rho s - \rho w)gd}{\rho wCD}} \qquad 2$$

$$Vsc = \frac{\sqrt{\left(\frac{8\beta}{f}\right) g(\rho g - \rho w) d}}{\rho w} \qquad 3$$

Which Vs is settling velocity (m/s), g gravity acceleration (m/s^2), CD drag coefficient, d particle diameter (m), ρ density (kg/m^3), Vsc scouring velocity (m/s) and β and *f* are constants.

The critical values of Vs and Vsc are listed in Table **3**. To compare the theoretical anticipation and real outcome of the grit chamber, the mesh sizes results of wastewater and effluent are also listed in Table **4** and **5**, respectively.

As it can be observed from Table **5**, all particles with mesh smaller than 140 were deposited before leaving the grit chamber and meshes 140, 200, 270 and larger than 270 were found in the effluent. Whereas, according to the Table **3**, only in flow rate of 40 L/min and mesh sizes of 200 and 270 the presence of particle in the effluent was expected. It can be attributed to the lack of uniformly distributed particles over the cross-section of the flow, turbulent flow, momentary vortex and short circuiting [9].

Effect of Mesh Size

As shown in Figure **2**, with the increase in particle mesh size, the efficiency of the turbidity removal decreased. It is due to the fact that by decreasing the particle size, the sedimentation rate decreases and this increases the probability of leaving the particle. On the other hand, reducing the size of the particle comes with weight reduction and consequently less gravitational force, and thus the particle is more prone to be affected by turbulence and laminar flows. Finally, the results of the research shows that the particles that failed to settle down to the outlet are guided [10,11].

Effects of Flow Rate

As it can be observed from Figures **3** and **4**, the efficiency of removing turbidity decreased with increasing flow rate from 10.5 to 40 L/min. This is

Table 3: Critical Values of Settling and Scouring Velocity

Linear velocity[1] (m/s)	Settling time[2] (s)	HRT (s)	Vsc (m/s)	Vs (m/s)	Q (L/min)	Mesh size
0.1	100	72	1/0	002/0	40	200
0.1	200	72	08/0	001/0	40	270

[1]Values of linear velocity more than Vsc indicate that there is possibility for settled out particles to re-entrain to the stream.
[2]Values of settling time more than HRT indicate that the particles may not have enough time to settle and leave the grit chamber.

Table 4: Wastewater Mesh Size Based on the Weigh Distribution

Mesh values	<60	<140	<200	<270	>270
TSS analysis w/w	20.2 %	13.3 %	26.2 %	18.9 %	21.4 %

Table 5: Grit Chamber Effluent Mesh Size Based on the Weigh Distribution

Mesh values	<60	<140	<200	<270	>270
Top inlet 40 L/min	0	1.5 %	3.5%	5 %	90 %
Middle inlet 40 L/min	0	1.5%	3.5%	5 %	90 %
Bottom inlet 40 L/min	0	1.5%	3.5%	5 %	90 %
Top inlet 24 L/min	0	0	2 %	5 %	93 %
Middle inlet 24 L/min	0	0	1 %	5 %	94 %
Bottom inlet 24 L/min	0	0	2 %	5 %	93 %
Top inlet 10.5 L/min	0	0	1 %	4 %	95 %
Middle inlet 10.5 L/min	0	0	0	3 %	97 %
Bottom inlet 10.5 L/min	0	0	1 %	3 %	96 %

because as the flow rate increased, the residence time of the particles in the tank decreased and as such, the particles did not have enough time to settle [12]. On the other hand, rising flow rate is associated with increasing flow velocity and thus, it caused further turbulence [13]. The particle settlement may occur in laminar or turbulent flow. In the latter condition, the settling process depends on the relative density, the particle size and the turbulent eddies. The turbulence can increase, decrease or prevent the settling. Reduction in the settling velocity can be observed when particles are moving upward and not downward as in the case of re-entrainment of particles [14].

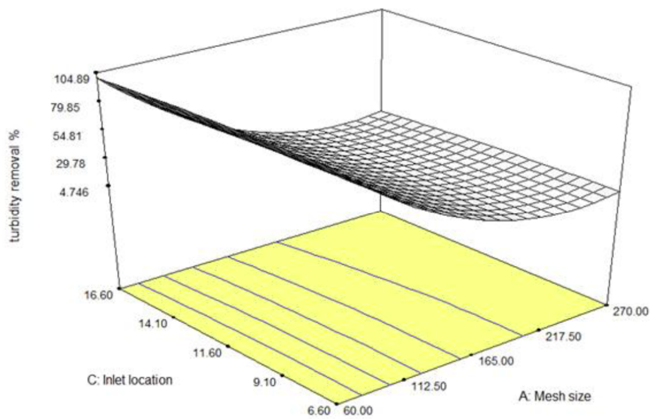

Figure 2: Effects of mesh size and inlet location on turbidity removal.

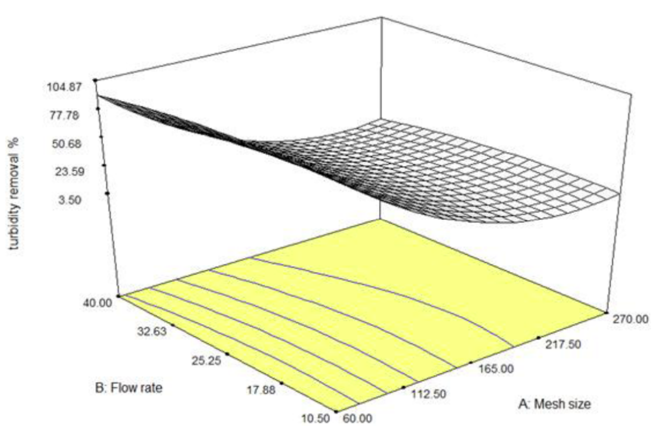

Figure 3: Effects of mesh size and flow rate on turbidity removal.

Effects of Inlet Location

Figures **4** and **5** show that the value of turbidity removal for middle inlet was higher than the bottom inlet and for bottom inlet was higher than the top inlet. It can be attributed to the fact that in the top inlet flow caused a weaker mixing effect compared to the middle inlet. On the other hand, the flow in the bottom inlet caused a re-entrainment effect and thus, in the top and bottom inlets the settling particles partially were able to leave the grit chamber. The performance of the grit chamber depends directly on the flow pattern and the amount of mixing in the tank, so the inlet position of the tank plays an effective role in creating a uniform flow and the smallest vortex flows. It is concluded that when the flow passed through the middle inlet the least amount of short circuits and re-entrainment in the grit chamber were created [15].

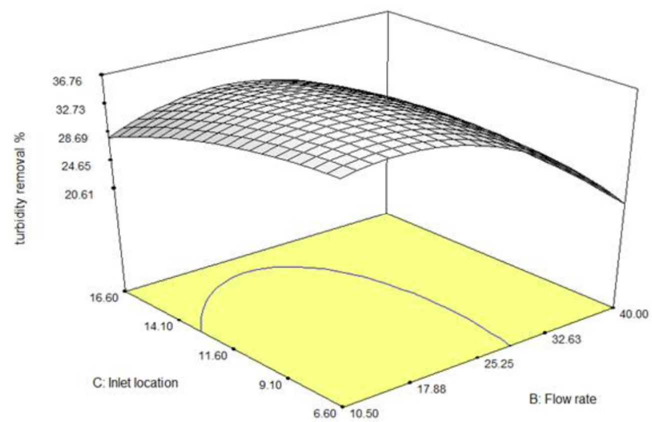

Figure 4: Effects of flow rate and inlet location on turbidity removal.

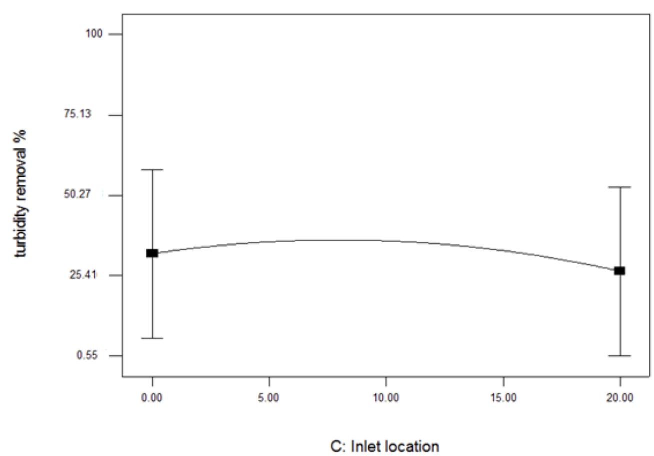

Figure 5: Effect of inlet location on turbidity removal.

CONCLUSION

The evaluation results of RSM model indicated that the model with a high correlation of 0.95 was able to simulate the grit chamber sedimentation. In addition, a decrease in turbidity was affected by three parameters and their interactions i.e. flow rate, inlet location and mesh size, of which mesh size was the most influential. Results revealed that increasing the flow rate from 10.5 to 40 L/min led to a decrease in turbidity removal from 34.7 to 22.73%. Also, the maximum reduction of

86.72% in turbidity removal occurred by increasing mesh size from 60 to 270. Results indicated that changing the inlet location from 3 to 10 cm increased the turbidity removal from 34.73 to 36.1% but changing the inlet location to 17 cm, decreased the turbidity removal to 31%.

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