

Effect of Solid Concentration and Impeller Type on Mixing Operations in an Agitated Vessel

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Abstract: In the present work two mixing operations, adsorption and decomposition of carcinogenic methylene blue were performed in a flat bottomed mechanically agitated tank with a six-blade Rushton turbine (6DT) and a Pitched blade turbine (PBT). Both the operations were carried at Njs, which is the key process objective to make all the surface area of the solids available for mass transfer. The first operation involves the adsorption of eosin dye on Granular Activated Charcoal (GAC), which resulted in a 67% color removal. This work would help in designing systems for wastewater treatment. The second operation involves the photo catalytic effect of TiO_2 on methylene blue to decompose it into carbon dioxide and water, which resulted in a 62.3% degradation of methylene blue. The work can be adopted by the textile industry in order to reduce the carcinogenic content of effluents, thus making it less of a health hazard. In both the cases, it is inferred that power required for a Pitched Blade turbine is significantly lower than that of Rushton turbine, also there is a linear rise in power required with increase in solid volume percent.

Keywords: Agitated Vessel, Mixing Operations, Adsorption, Decomposition of methylene blue

1. Introduction:

Solid-liquid mixing is the common operation in the field of chemical and mineral industry. The examples include dissolution, adsorption, crystallization, leaching, precipitation, ion exchange and catalytic multiphase processes. Odor and taste are not the only problems with drinking water. Many organic and inorganic compounds are present in water, which needs to be strictly controlled. The entire process of purification includes filtration, distillation, flocculation, chlorination and adsorption by activated carbon amongst a host of other physical processes. Dyeing industry in India plays a major role in the growth of Indian economy and the effluent from these industries severely pollutes the surface water. Photo catalytic oxidation has been shown to be a good method for dye degradation and hence therefore considered as a possible solution due to the wide availability of solar energy source. As an excellent photocatalyst, TiO_2 has a good prospect in water purification. Organic contaminants present in an aqueous suspension of TiO_2 can be degraded with UV light. It was investigated that synthetic dye, methylene blue was degraded in the presence of activated TiO_2 [1].

Several works has been done on solid-liquid hydrodynamic studies in an agitated vessel. Some of those studies include finding of the critical impeller speed [2,3,4,5], Mixing time[6,7], effect of solid and liquid properties [8], could height [9], velocity profiles [11,12] and concentration profiles [13,14,15]

So far very few attempts have been reported with respect to solid-liquid application study in an agitated vessel. Agitated vessel can be used as good adsorption equipment for effective contacting of solid and liquid

since the entire surface of solid is in continuous contact with the liquid. In the past, researchers have developed a method to determine the inter particle diffusivities and surface diffusion coefficients in agitated vessel and shown that the result predicted by this method coincide very well with the experimental data [16, 17]

The present work focuses on adsorption of eosin dye by activated carbon and the photo catalytic decomposition of the methylene blue in the presence of activated TiO_2 in a standard agitated vessel.

2. Experimentation:

Fig.1 shows the agitated vessel with Rushton impeller. The cylindrical, flat bottom agitated tank diameter $T=294$ mm, equal to the liquid height H , equipped with four vertical baffles of width $w=T/10$. Agitation was provided with six bladed Rushton turbine and pitched blade turbine with a diameter $D=98$ mm located at $T/3$ from the bottom of the agitated vessel. The parameters of the impeller are listed in Table 1. Two parameters are mainly used to study the suspension performance are the critical impeller speed and the power required for suspension. Zweitering [18] method was used to find out the critical impeller speed. According to Zweitering critical suspension speed is achieved when all the solids are lifted off the vessel bottom for more than a short period of time, e.g. 1-2 s.

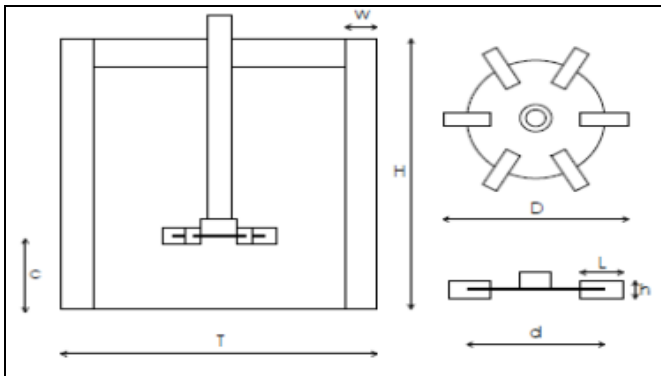


Fig.1. Vessel geometry

Table 1. Parameters of the impeller.

	D	d	D_{hub}	L	h	t_{disc}
Value(m)	0.098	0.0735	0.0196	0.0245	0.0196	0.003

Power consumption was determined by using a Piezoelectric Ceramic Transducer shown in Fig.2. Piezoelectric ceramic discs were pressed against the rotating shaft of the agitator on both the sides; it generated a voltage which was displayed by the multi meter. This further helped to calculate the torque and hence the power consumed by the shaft for solid suspension.

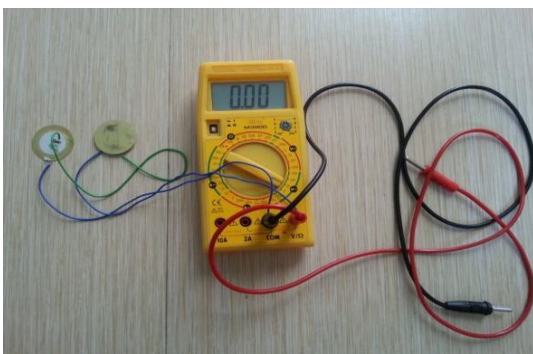


Fig.2. Piezoelectric Transducer

Formulae used for the calculation of Torque and Power Consumption are as follows:

$$(i) V = d \cdot t \cdot F / \epsilon \epsilon' A \quad (ii) P = 2 \cdot \pi \cdot N_{js} \cdot (T - T_r) / 60$$

Where,

Symbol	Name	Formula	Value	Unit
V	Voltage	(i)	-	V
d	Charge coefficient	-	450	-
t	Thickness of Ceramic Plate	-	0.2	mm
F	Force	-	-	N
ϵ	Permittivity in free space	-	8.854	-
ϵ'	Relative Permittivity	-	1700	-
A	Area of Ceramic Plate	πR^2	415.265	mm ²
P	Power	(ii)	-	W
π	Pi	-	3.14	-
N_{js}	Critical Impeller Speed	-	-	rpm
T	Torque	$F \times r$	-	Nm
T_r	Residual Torque	-	0.02	Nm
r	Shaft Radius	-	6	mm
R	Radius of Ceramic Plate	-	11.5	mm

Study 1: Adsorption of eosin dye present in red ink using granular activated carbon in an agitated vessel.

Experiments were carried out in an agitated vessel contains 20 liters of water and 10ml of red ink. Granular Activated Charcoal (GAC) used as the adsorbent and eosin dye (red dye) as the adsorbate. Camel Scarlet red ink is a dye-based ink which contains eosin dye. The concentration of dye was held constant for all batches in order to analyze the effect to which the dye was adsorbed with varying volume percentages of granular activated charcoal. The physical properties of solid and liquid used in study.1 are given in Table 2.

Table 2. Physical properties of the solid-liquid system

		Liquid	Solid
Study I	Density (kg/m ³)	1000	1080
	Viscosity(Pa s)	1x10 ⁻³	-
	Particle diameter (μ m)	-	3-4mm
	Volume fraction (vol%)	-	0.25%, 1% and 1.45%.

The volume percentages of the GAC were varied as 0.25%, 1% and 1.45%. Every batch was run for a uniform 25 minutes and samples were extracted every 3, 6, 15, 20 and 25 minutes. These samples were tested by UV-Vis spectroscopy for intensity of light transmitted through the solution to indicate the extent of adsorption of eosin dye. The lower the absorbance, the more the extents of adsorption of eosin dye on the GAC.

The shaft speed was maintained at critical impeller speed (N_{js}) to get most efficient mixing for least power consumption. Rushton turbine and Pitched Blade turbine were used to compare the efficiency of different flow patterns. Hence every batch of varying concentration of GAC was conducted with each of the two turbines.

Application 2: Photo catalytic activity of TiO₂ on methylene blue in an agitated vessel.

The detailed mechanisms of methylene blue dye catalyzed degradation states that conduction band electron (e⁻) and the valance band holes (h⁺) are generated when aqueous titanium dioxide suspension is irradiated with light energy greater than its band gap energy ($E_g = 3.2eV$). The photo generated electrons could reduce the dye or react with electron acceptors such as O₂ adsorbed on the Ti (IV) surface or dissolved in water reducing it to superoxide radical anion. The photo-generated holes can oxidize the organic molecule to form R⁺ or react with OH or H₂O oxidizing them to form OH[·] radicals. Together with other highly oxidant species

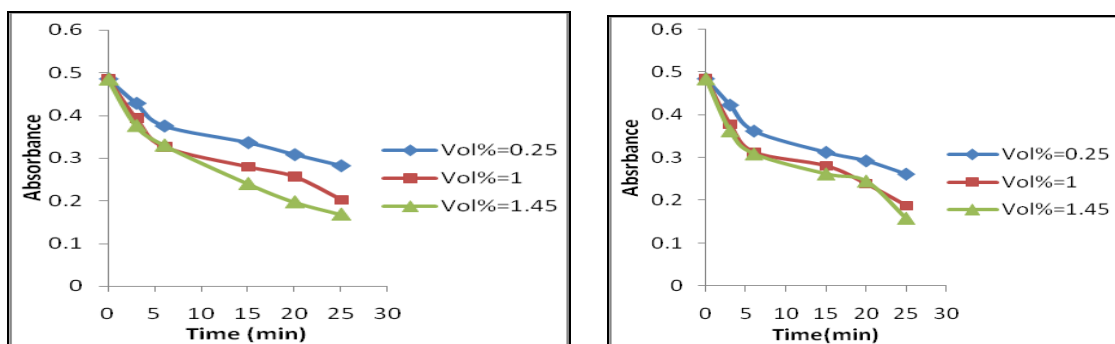
(peroxide radicals), they are reported to be responsible for the heterogeneous TiO₂ photodecomposition of organic substrates as dyes. The resulting OH⁻ radical, being a very strong oxidizing agent (standard redox potential + 2.8eV, can oxidize most of the methylene blue dye material.

According to the proposed mechanism, the resultant solution should be colorless which shows that the dye is decomposed into carbon dioxide and water. The contributing factors towards dye degradation include both the dye concentration as well as the quantity of TiO₂ used. Sunlight is used as the irradiation source and the rate of photo-oxidation of the dye depends on initial dye concentration, irradiation intensity and the dosage of titanium dioxide.

TiO₂ was first activated under UV light and then agitated with methylene blue solution in the experimental set-up while being exposed to sunlight. Rushton turbine and Pitched blade turbine were used and the agitation was carried out at Njs. The quantity of TiO₂ was varied as 2 g, 3 g and 4 g for each of the turbines. Samples were taken every hour for 3 hours and after 12 hours for UV-Vis spectroscopy analysis. The absorbance versus time plot was made for each of the 6 cases. The quantity of dye used in each of the cases was 30 mg. Power consumption was determined by using a Piezoelectric Ceramic Transducer.

3. Results and Discussion:

Study 1: Adsorption of eosin dye present in red ink using granular activated carbon in an agitated vessel.

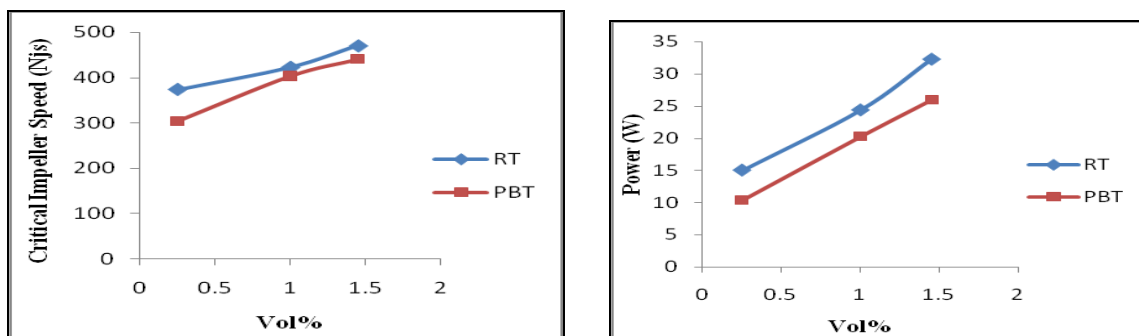


(a) Rushton turbine

(b) Pitched blade turbine

Fig.3. The variation of Absorbance with time for varying volume% of GAC

Fig.3 (a) shows the variation of absorbance with time for varying volume% of GAC for Rushton turbine and Fig.3 (b) shows the variation of absorbance with time for varying volume% of GAC for Pitched blade turbine. It is observed that higher the vol% of activated charcoal, higher is the adsorption. It is also inferred that Pitched blade shows better results in color removal. This proves that mixed flow pattern is more efficient than radial flow. It shows a maximum of 67% color removal (using 1.45 vol%). Pitched blade (mixed flow) decolorizes the water quicker.



(a)

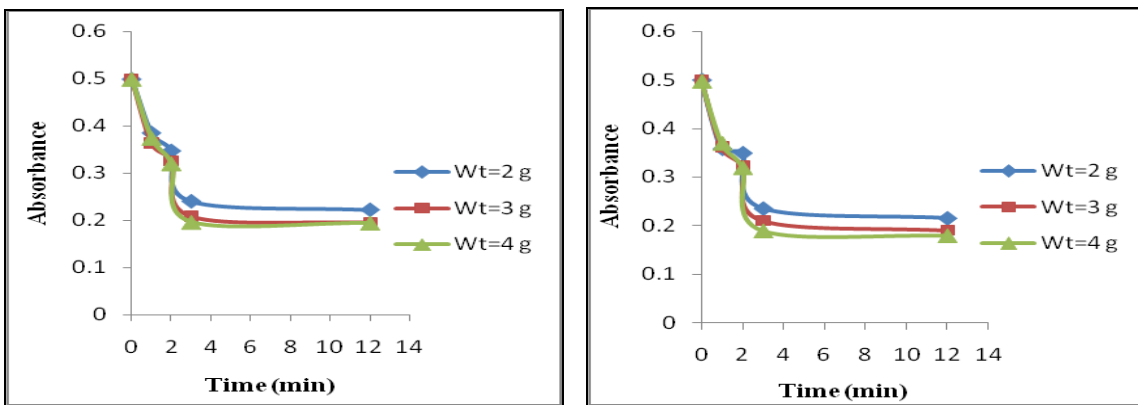
(b)

Fig.4. Variation of critical impeller speed and power with varying volume% of GAC for different impellers.

The variation of critical impeller speed with varying volume% of GAC for different impellers was shown in Fig.4 (a) and the variation of power with varying volume% of GAC for different impellers was shown in Fig.4 (b). It was inferred that the complete off bottom suspension is achieved at a lower impeller speed using a Pitched blade turbine as compared to Rushton turbine. It was noted that power required for a Pitched Blade Turbine is significantly lower than that of Rushton Turbine. Also there is a linear rise in power required with increase in solid volume percent.

Application 2: Photo catalytic activity of TiO₂ on methylene blue in an agitated vessel.

The variation of absorbance with time for varying quantity of GAC for Rushton turbine and pitched blade turbine was shown in Fig.5. It is observed that the best results of decomposition of methylene blue dye take place with 4 grams TiO₂. Using Rushton turbine, an absorbance of 0.195 was reached after 3 hours with 4 grams of TiO₂ whereas with 3 grams of TiO₂, the same absorbance was reached after about 12 hours. The same trend is followed when using a Pitched blade turbine. Hence an important inference from this result is that with a slight increase in TiO₂ quantity (from 3 grams to 4 grams), which results in increase in cost, the agitation would draw 3-4 times less power, which is very important from an industrial point of view.



(a) Rushton turbine

(b) Pitched blade turbine

Fig.5. The variation of absorbance with time for varying volume% of GAC

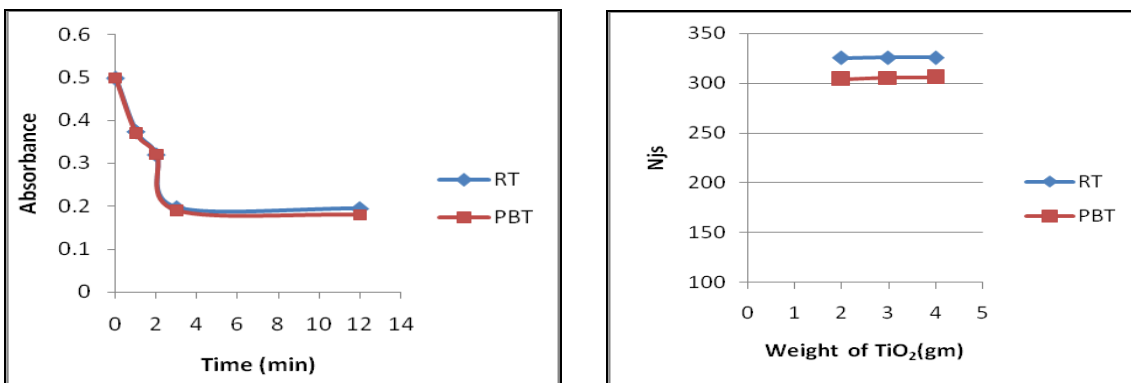


Fig.6. The variation of Absorbance with time for different impellers

Fig. 7. The variation of N_{js} with weight of TiO₂ for different impellers

It is noted from fig.7 the N_{js} value for each type of impeller remained fairly constant owing to the fact that the TiO₂ particles are of micro diameter and low density. However we see that the N_{js} value drops when using pitched blade turbine over Rushton turbine. The above point coupled with the result from the ‘Rushton turbine vs Pitched blade turbine with 4 g of TiO₂ the fig.6 clearly shows that pitched blade turbine achieves higher decomposition in lower time as compared to Rushton turbine. It is observed that a highest degradation of 63.2% is obtained by using Pitched blade turbine.

4. Conclusion:

The first study, adsorption of eosin dye by granular activated charcoal (GAC) shows a major application in wastewater treatment around the world. Hence a study of this application, wherein agitation was carried out at N_{js} , showed good results. When scaled up to an industrial scale, power requirement was reasonable. The second study was the use of activated TiO_2 to decompose methylene blue. This is an important application in textile industry during disposal of methylene blue dye, which is carcinogenic. Hence the decomposition of this dye can curb this health hazard. Experimentation was carried out at N_{js} for varying volume percentages and exemplary results were achieved degrading the dye from absorbance values of 0.499 to 0.190. It shows that higher decomposition is achieved with pitched blade turbine in lower time as compared to Rushton turbine. The cost of TiO_2 , which proves to be expensive. However expensive, this is an important requirement in the textile industry.

5. Nomenclature:

D-Diameter of impeller, m

d- Diameter of disc, m

D_{hub} -Diameter of hub, m

L- Length of impeller, m

h- Height of impeller, m

t_{disc} -Thickness of disc, m

C- Clearance, m

T- Tank diameter, m

RT- Rushton turbine

PBT- Pitched blade turbine

6. Acknowledgement:

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