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Effect of Impeller Clearance and Multiple Impeller Combinations on Solid Suspension in a Standard Flat Bottom Agitated Vessel

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Abstract : Agitation finds its usage among a wide range of industries like food, cosmetic, chemical, biochemical and pharmaceutical applications. Among chemical applications these include fermentation, crystallization, hydrogenation and catalytic reactions. The determination of critical impeller speed is one of the most important parameter under consideration for mechanical agitators and has been under investigation for quite some time now. However, the effect of impeller clearance for different impellers on solid mixing has not yet been well established. In this work, three impellers have been taken into consideration, namely, Rushton turbine, Rushton turbine with 45^o angle and Pitched blade turbine. An attempt has been done to study the effect of multiple impeller combinations in a standard agitated vessel. The impellers were used individually and in combinations of two and three. The critical impeller speed, optimum impeller clearance and power consumption were observed. Hick's method was used to determine the critical impeller speed and the power consumption was determined by using a piezoelectric ceramic transducer and the experiments were performed in the C/T range of 0.1 to 0.35.The study revealed that at a clearance of T/3 all the three impellers showed lowest critical impeller speed and pitched blade turbine consumes less power compared to other impellers. In two impeller combinations the Rushton turbine at the bottom and pitched blade at the top consumed less power among other two impeller combinations. In three impeller combinations the Rushton turbine at bottom, pitched blade at middle and Rushton turbine with 45^{o} angle at top consumed less power among other three impeller combinations.
Keywords: Solid Suspension, Impeller Clearance, Agitated Vessel, Critical Impeller Speed, Multiple Impellers.

1. Introduction

Different types of impellers are used to suspend solids in an agitated vessel. The suspension is easier and more favorable for an axial flow impeller as compared to a radial flow impeller where it is more difficult to lift up the particles. The impellers inside the agitator vessel can be used in various configurations, i.e. it can be a single impeller system, dual impeller system, or a multiple impeller system, the type of the configuration being used, taking of the height of vessel in to consideration.

The determination of minimum or critical impeller speed (Njs) is one of the most important parameters under consideration for mechanical agitators. Critical impeller speed can be defined as the minimum speed required for achieving complete off-bottom suspension, i.e. a state when the solids are provided with enough agitation to be lifted off the tank bottom completely. It is necessary to take into consideration the effect of impeller clearance on Njs. Zwietering (1958) and Nienow (1968)[1] found that critical impeller speed increases with increase in impeller off bottom clearance with Rushton turbine. S. Sicardi et al. (1979) reported that two different types of flow patterns namely single eight and double eight are produced depending on the clearance employed. Gray (1987)[2] reported that for axial flow impeller the flow transition from single eight to double eight occurs at C/T=0.35 and for radial flow at C/T=0.17. Sharma and Shaikh (2003) identified three different regimes in the critical impeller speed Vs C/T curve. Baldi et al. (1978)[3] showed that Njs remains constant when the stirrer is very close to the vessel bottom. Armenante et al. (1998) [4] have found an empirical correlation for the determination of critical impeller speed, when the impeller is positioned very close to the tank. Aoyi Ochieng et al. (2007) explained the effect of impeller clearance on the velocity field and mixing. At low clearance the suspension of solid particles can be achieved at lower speed, but solid will not be homogeneously dispersed throughout the vessel. Increasing clearance the capability to suspend solid particles will decrease because of change in the flow pattern and decrease in energy available for suspension at the vessel bottom. When the height of final suspension is important higher clearance is desirable. Myers et al explained the influence of clearance on solid suspension performance. B.Pandit et.al (2005) mentioned that variation with Njs with the number of impellers strongly dependent on the spacing between the impellers.

The present work focuses on finding out the optimum clearance for different impellers considered in this study. Also an attempt has been made to find out the best impeller and impeller combination in single and multiple impeller combinations respectively.

2. Materials and Methods

Fig.1. Experimental Setup

The experimental setup is shown Figure 1. It consists of agitated vessel with outer vessel to minimize the optical distortion, motor and speed regulator with display. Figure 2 shows the three types of impellers used in this study namely Rushton turbine, Rushton turbine with 45^o angle and Pitched blade turbine with 45^o angle.

The schematic diagram of agitated vessel is shown in Figure 3. The cylindrical, flat bottom agitated vessel diameter T=290 mm, equal to the liquid height H, equipped with four vertical baffles of width w=T/10. The parameters for Rushton turbine given in Table 1 were same for other two impellers too. The liquid was water at room temperature. The solid phase was sand and glass beads. The physical properties of solid-liquid system are given in Table 2.The impeller clearance was varied from T/2 to T/9.66 and it is given in Table 3.

Fig.2. Impellers

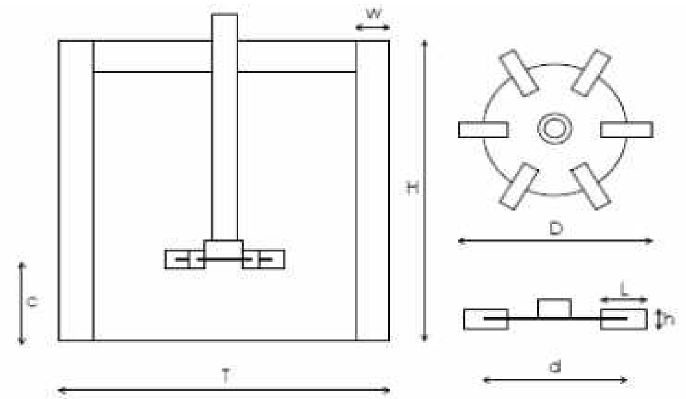

Fig.3. Geometry of the agitation tank

Table 1: Parameters of the impeller

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

Table 2: Physical properties of the solid-liquid system

	Properties	**Liquid**	**Solid**
Study I	Density (kg/m^3)	1000	Sand (2500 kg/m^3)
	Viscosity(Pa s)	1x10^{-3}	-
	Particle diameter (µm)	-	0.575mm, 1.026 mm, 1.3 mm
	Volume fraction (vol%)	-	2%, 3% , 4% , 5%
Study II	Density (kg/m^3)	1000	Glass beads (2500 kg/m^3)
	Viscosity(Pa s)	1x10^{-3}	-
	Particle diameter (µm)	-	2 mm
	Volume fraction (vol%)	-	3%

Table.3: Clearance value used in this study

T/9.66	T/5	T/3.33	T/2.857	T/2.5	T/2.22	T/2
30mm	58mm	87mm	102mm	116mm	131mm	147mm

For sand-water system, only Rushton turbine was used and for glass beads-water system, three impellers were used individually and in dual and triple impeller combinations. Among the various visual methods available for the observation, Hick's method was used to determine the critical impeller speed. It is defined as the speed at which the settled bed height is zero. A further reduction in the speed causes the solids to settle again and form a bed on the vessel bottom.

Power consumption was determined by using a Piezoelectric Ceramic Transducer shown in Fig.4. 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.

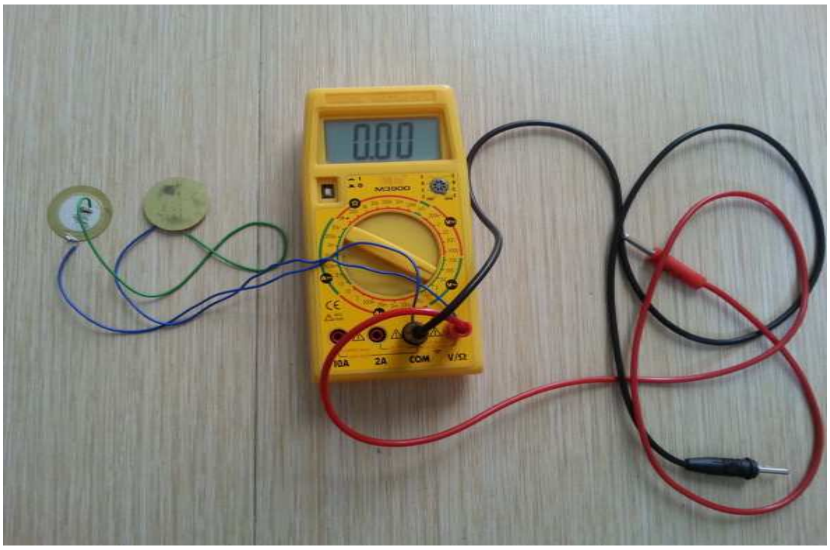

Fig.4. Piezoelectric Transducer

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

(i) $V = d*t*F / \varepsilon\varepsilon' A$ (ii) $P = 2*\pi*Njs*(T_e-T_r)/60$

Where,

Symbol	Name	Formula	Value	Unit
V	Voltage	(i)	-	V
d	Charge coefficient	-	450	-
t	Thickness if 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	36.11	mm^2
P	Power	(ii)	-	W
π	Pi	-	3.14	-
N_{js}	Critical Impeller Speed	-	-	rpm
T_e	Torque	F x r	-	Nm
T_r	Residual Torque	-	0.02	Nm
r	Shaft Radius	-	6	mm
R	Radius of Ceramic Plate	-	11.5	mm

3.Results and Discussion

Study 1: Sand-Water System: In this study sand (2500 kg/m^3) of different diameters (0.575mm, 1.026 mm, 1.3 mm) and various volume fractions (2%, 3%, 4%, 5%) were used and the following observations were made. The effect of solid concentration and clearance on Njs and cloud height were shown in figures 5-7 for different diameter of sand particles in water. It is observed that the critical impeller speed and cloud height increases with increase in concentration for all the particle sizes. It is also observed that the cloud height decreases as the impeller clearance increases. This is due to the reason that higher the clearance the energy available for suspension at the vessel bottom decreases. At clearance of C/T=0.3 optimum critical speed is achieved with highest cloud height.

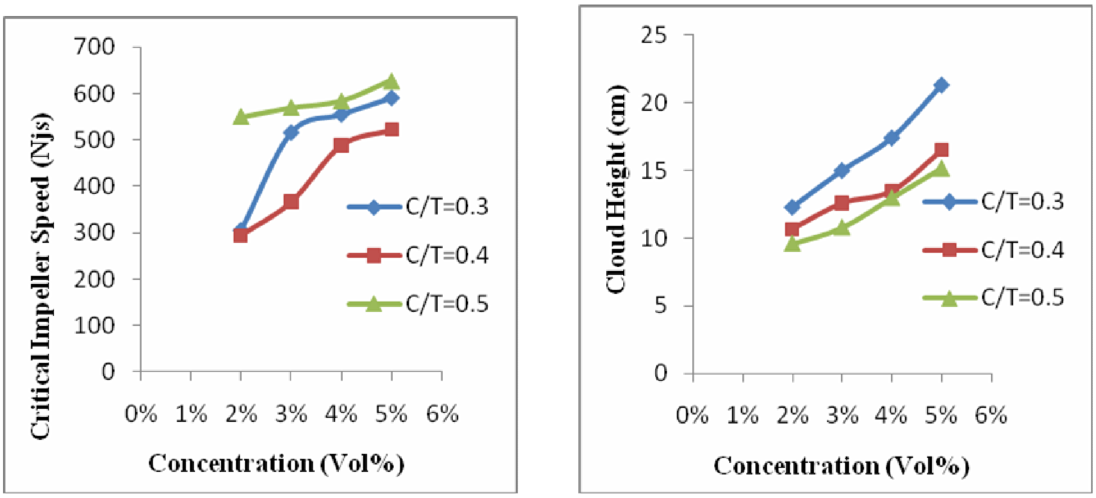

Fig .5 The variation of critical impeller speed and cloud height at various clearances for different concentrations of sand of dp =0.575 mm

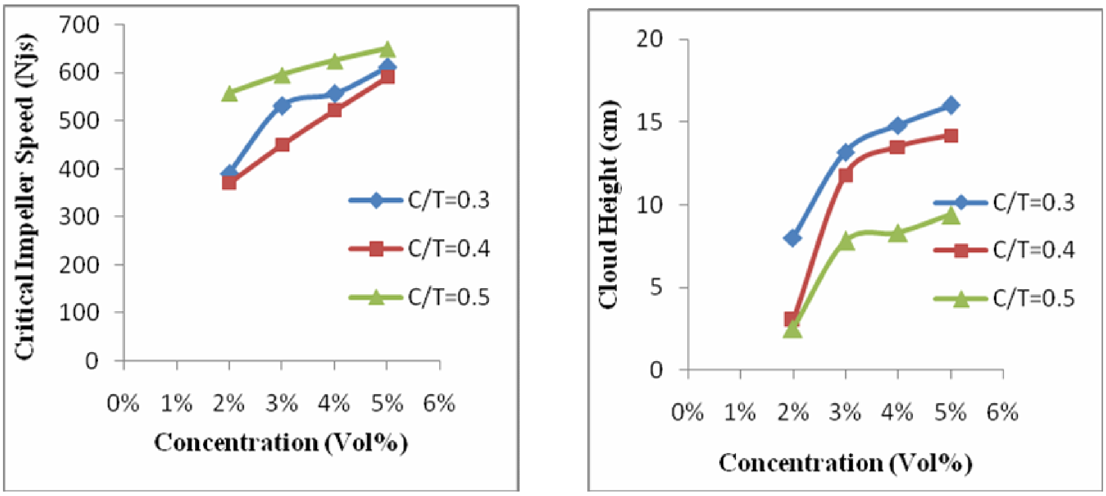

Fig. 6. The variation of critical impeller speed and cloud height at various clearances for different concentrations of sand of dp =1.03 mm

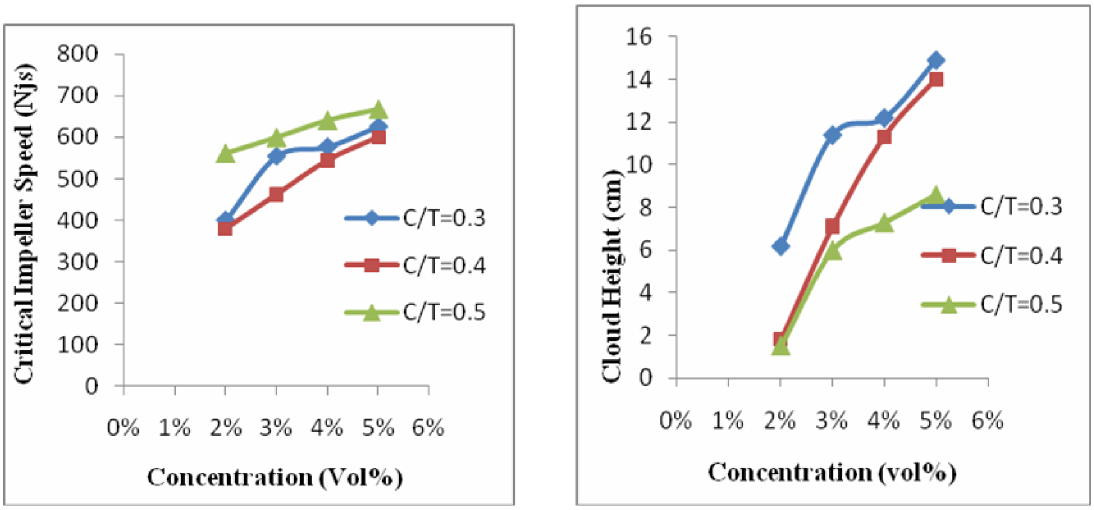

Fig. 7. The variation of critical impeller speed and cloud height at various clearances for different concentrations of sand of dp =1.3 mm

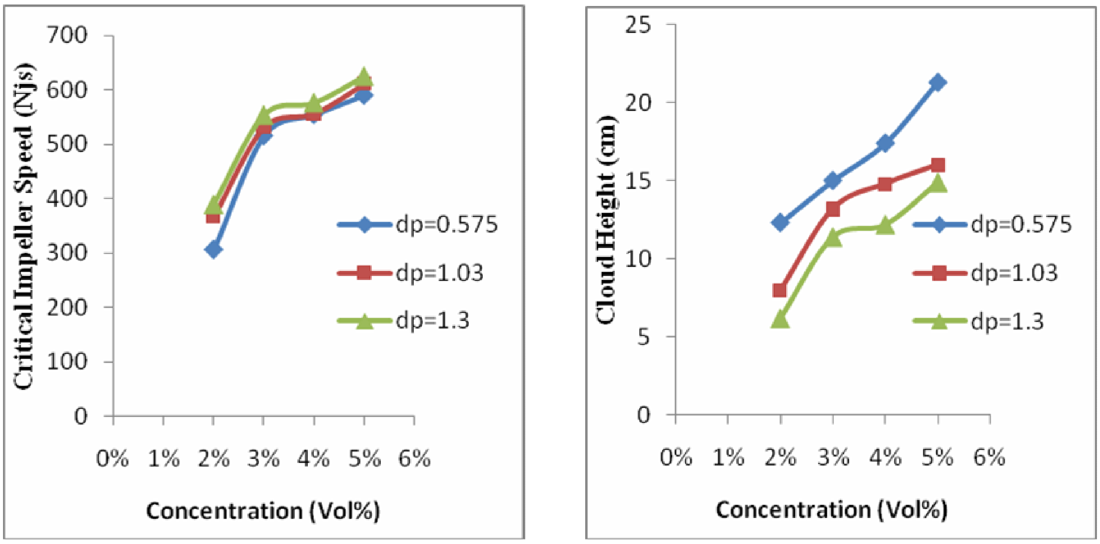

Fig.8. The variation of critical impeller speed and cloud height for different particle sizes

Figure 8 shows the effect of particle size on critical impeller speed and cloud height. It is found that the crtitical impeller speed increases with increase in particle sizes and cloud height decreases with increase in size of particle.

Study 2: Glass Beads -Water System: In this study glass beads (2500 kg/m^3) of 2 mm diameter and 3% volume fraction was used. Three impellers namely Rushton turbine, Rushton turbine with 45^o angle and Pitched blade turbine with 45^o angle were used and the following observations were made.

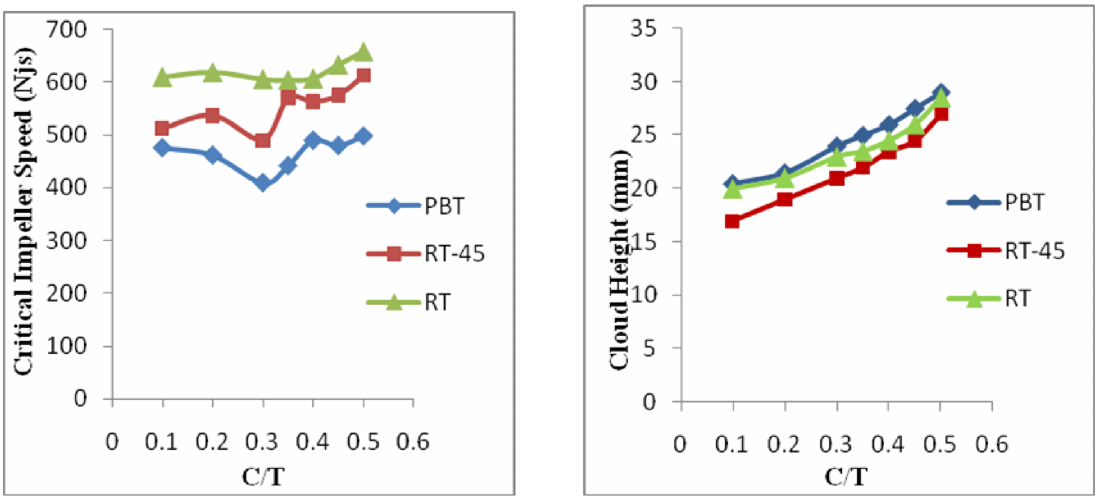

Fig.9. The variation of critical impeller speed and cloud height at various clearances for different impellers.

The variation of critical impeller, cloud height and power consumption for different impellers was shown in figures 9 and 10. It was observed that the critical impeller speed decreases initially as the C/T value increases and reaches a minimum value and increases for all the impeller types. The minimum value is observed at C/T=0.3 for all the impellers and pitched blade turbine displays the lowest critical impeller speed of 400 rpm. Also it was observed that Rushton turbine with 45^{o} angle gives less critical speed compared to the radial flow Rushton turbine. Figure 9 shows cloud height increases with increase in clearance for all the impellers and it is highest for pitched blade turbine.

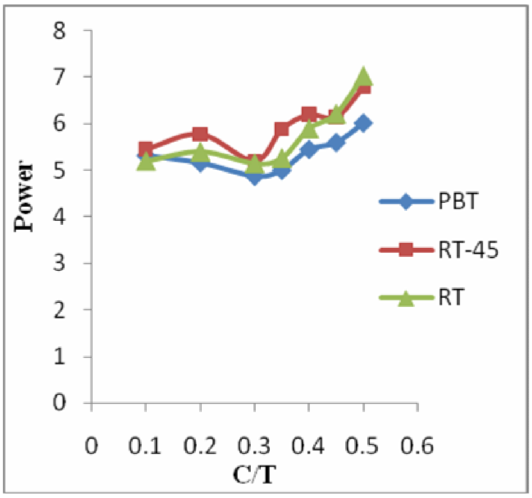

Fig.10. The variation of power consumption at various clearances for different impellers.

Figure 10 shows the variation in power consumption for various clearances and for different impellers. It was found that the minimum power consumption is observed at C/T=0.3 and pitched blade turbine requires the least amount of power to provide a good suspension in a glass bead-water system, whereas the Rushton turbine with 45^{o} requires the maximum power.

In dual impeller system six impeller combinations were studied with the clearance of T/3.33 and impeller spacing of T/2 and T/3.33. The numbers 1 to 6 in table.4 represent the combination number for the following combinations of impellers used.

Table.4. Impeller combinations in dual impeller system

Combination No	1	2	3	4	5	6
Combination						
Bottom	RT-45	RT-45	RT	RT	PBT	PBT
Top	RT	PBT	PBT	RT-45	RT-45	RT

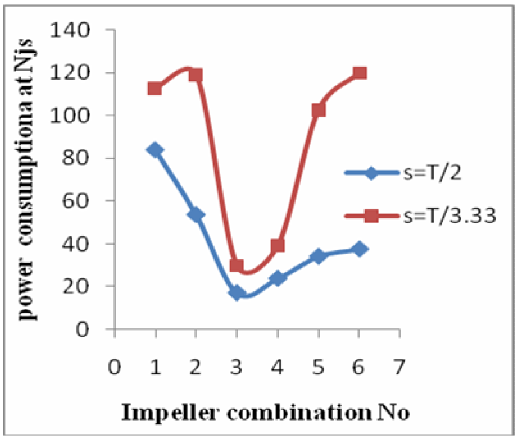

Fig.11. The variation power consumption for dual impeller combinations of impeller spacing T/2 and T/3

Figure.11. shows the power consumption at Njs for dual impeller combinations of impeller spacing T/2 and T/3. It was observed from Figure 11 that the power consumption is less for the impeller spacing of T/2. It notes that Bottom: RT and Top: PBT is the least power intensive configuration for both the impeller spacing of T/3.33 and T/2. This combination consumes power of 17 W at a critical speed of 559 rpm and power of 30 W at a critical speed of 560 rpm for the impeller spacing of T/3.33 and T/2 respectively.

In triple impeller system, six combinations were studied with the clearance value of T/3.33 and the impeller spacing of T/3.33.

Table.7. Impeller combinations in triple impeller system

Impeller Position	**Impeller Combinations Numbers**					
	1	**2**	**3**	**4**	**5**	**6**
Bottom	RT	RT	PBT	PBT	RT-45	RT-45
Middle	RT-45	PBT	RT-45	RT	RT	PBT
Top	PBT	RT-45	RT	RT-45	PBT	RT

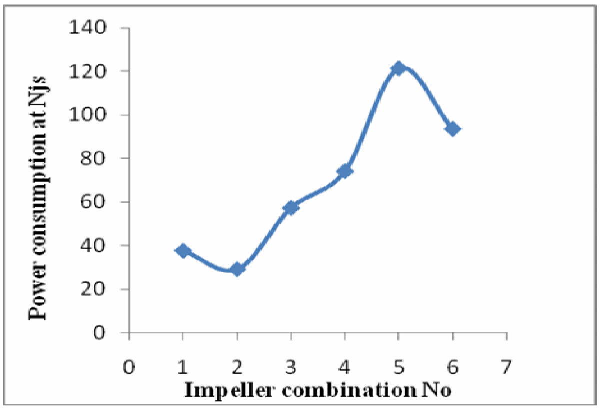

Figure.12. The variation power consumption for triple impeller combinations of impeller spacing T/3.

In Table.7 Numbers 1-7 Is Different Impeller Combinations Used In Triple Impeller System. It Is Found From Fig. 12, That The Best Combination Is Bottom: RT, Middle: PBT And Top: RT-45, With The Least Power Consumption Of 29 W At A Critical Speed Of 515 Rpm. The Second Best Combination Is Bottom: RT, Middle: RT-45 And Top: PBT At 541 Rpm With Power Consumption Of 38 W And The Worst Combination Is Bottom: RT-45, Middle: RT And Top: PBT With A Power Consumption Of 121 W At 1290 Rpm.

4. Conclusion

The Study Revealed That For Sand-Water System The Lowest Critical Impeller Speed And Highest Cloud Height Is Achieved At A Clearance Of T/3 Using Rushton Turbine. In Glass Beads-Water System, Pitched Blade Turbine Is The Ideal Impeller At T/3, As It Consumes 4.98 W As Compared To The Other Impellers Which Consumes 5.2 And 5.15 W Of Power To Achieve A Complete Off Bottom Suspension. An Attempt Has Been Made To Find Out The Best Multiple Impeller Combination In A Standard Agitated Tank. In Dual Impeller System, It Is Observed That The Best Combination Is Bottom: RT, Top: PBT Of Spacing T/3.33 Consumes Least Power Of 17 W At 559 Rpm. In Triple Impeller System The Best Combination Is Bottom: RT, Middle: PBT And Top: RT-45 Which Consumes Least Power Of 29 W At 514 Rpm. It Is Also Noted That The Power Consumption Increases And Critical Impeller Speed Decreases As The Number Of Impeller Increases.

5. Acknowledgement:

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