Short Communication

STIRRED TANK WITH ARROWHEAD IMPELLER - INFLUENCE OF SUBMERGENCE DEPTH ON POWER CONSUMPTION

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Abstract: Impeller submergence governs the performance of mixing tanks employed in chemical and biochemical operations. Present work experimentally investigates the effect of impeller submergence depths on power consumption when arrowhead impeller has been used in the process. Arrowhead impeller performs better than the conventional Rushton impeller. It has been found that at higher range of impeller submergence, mixing processes consume less power. Optimal range of submergence depth is 0.8 to 0.9 times the impeller diameter.

Keywords: *arrowhead impeller, mixing tanks, power consumption, rotational speed*

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1. Introduction

Power consumption is a basic integral quantity in a stirred tank, which determines the other processes involved in aeration phenomena such as 'mass transfer rates', 'gas hold up' etc [1–4]. The power usage in mass transfer operations is very important in judging the aeration performance of the aerator. Power draw influences heat and mass transfer processes, mixing and circulation times. Power draw has been used as a criterion for process scale-up and bioreactor design [5]. The costs associated with power draw contribute significantly to the overall operation costs of industrial plants. Therefore, it is desired that the mixing process is performed efficiently and with a minimum expense of energy required to achieve the objective established a priori [4].

Effect of various parameters on the flow behavior and mixing characteristics in stirred tanks has been studied extensively. Nagata [6] presented a relationship between the number of baffles and mixing time for a single four- and six-blade flat-paddle impeller. Nagata [6] also defined the product of mixing time and power drawn by the impeller as mixing energy as an index to characterize the mixing in a mechanically agitated vessel. Lu et al. [7] studied the effects of width and number of baffles in mechanically agitated vessels with standard Rushton turbine impellers. Karcz and Major [8] investigated the effect of the baffle length on power consumption in agitated vessel equipped with short baffles. Montante et al. [9] investigated the effect of the impeller clearance on the flow and turbulence fields in a fully baffled vessel stirred by a Rushton turbine. Chapple et al. [10] examined the sensitivity of the power number to changes in blade thickness and impeller diameter. The performance of surface aerators is known to depend on the impeller submergence, which indicates the position of rotor in stirred [11]. According to Oldshue [1], there is not only one optimal or unique design for each kind of process. Several designs may satisfy the process specifications [1]. In order to simplify design and minimize costs, standard reactor designs are usually good enough for most processes. Generally impeller position has been fixed at 1/6 to 1/2 of tank diameter [6]. Backhurst et al. [12] has found that the mass-transfer rate per unit power consumption was optimum at an impeller clearance of twice the impeller diameter. Takase et al. [12] has reported different effects of impeller clearance. Patil et al. [11] has conformed the observations reported by Backhurst et al. [13]. For a pitched blade down flow turbine and standard disk turbine, optimality has been observed when an impeller clearance is twice the impeller diameter [12].

The geometry of an impeller of stirred tank plays major role in optimum design of stirred tanks [14, 15]. Sufficient published literature is available based on Rushton turbine of stirred tank [2–4, 14, 15]. The study based on the arrowhead impeller is found very less in literature as compared with familiar Rushton turbine. Formation of distinct recirculating zones (characteristics of Rushton turbine) is an obstacle to fluid transport. Slow recirculating flow patterns are invariably developed in stagnate (dead) zones of the vessel that must be eliminated as they are a barrier to mixing; this translates into a need of employing other type of radial impeller. The concave blade shape of arrowhead impeller is mainly to resemble the contour of gas cavity during agitation thus minimizes the drawbacks of Rushton turbine by decreasing the gas cavities dimension as well as reducing gassed power drop with its improved gas handling performance.

The economics of stirred tanks, particularly operating costs, are contributing much more heavily to system selection [16, 17]. Because of the widespread applications of

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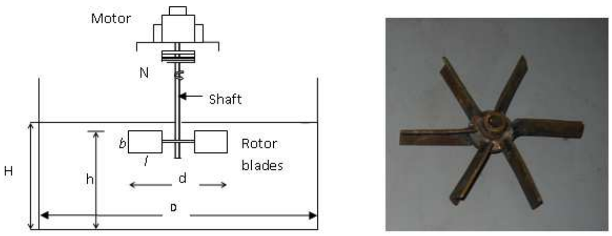

Figure 1: Experimental Setup and Impeller used

Table 1: Impeller geometrical properties

Rotor diameter (d) (mm)	Blade length (mm)	Blade width (mm)	Blade thickness (mm)
80	20	16	0.8
60	15	12	0.6
45	11.25	9	0.45
40	10	8	0.4
30	7.5	6	0.3

stirred tanks in the process industry, even a small reduction in the operational costs of these vessels can result in major cost savings. In order to develop design guidelines for arrowhead impeller, present work investigates the effect of impeller position has been investigated in the present work for optimal power consumption.

2. Experimentation

Experiment has been carried out with an objective to find the effect of impeller position on power consumption. Two sizes (cross-sectional area, A = 0.0314 m^2 and 0.01766 m^2) of unbaffled stirred tanks have been used in the experimentation. Diameter of the tanks (D) is 200 mm and 150 mm respectively. Tap water has been used in the tank. Figure 1 show the experimental setup used in the present study.

The various geometric dimensions of the aerator are: D (tank diameter), H (water depth), h (impeller submergence or distance between the horizontal bottom of the tank and the top of the blades) and d (diameter of the rotor). Standard geometry of impeller (Rushton turbine) has been documented well in the literature [5]. Thus the impeller used in the present study is arrowhead impeller. In the application of high energy agitation and high gas rates, arrowhead impeller will significantly improve the mass transfer rates [18]. Geometric parameters of the impeller have been given in the Table 1.

Liquid level is maintained as equal to impeller's diameter. When a single impeller is to be used, a liquid level equal to the diameter is optimum, with the impeller located at the center for an all-liquid system [6, 19]. The power available at the shaft was calculated as follows. Let P_1 and P_2 are the power requirements under no load and loading conditions at the same speed of rotation. Then the effective power available to the shaft, $P_{\text{eff}} = P_2 - P_1 - \text{Losses}$. Reproducibility of measurements has been found to be ±5%. The main advantages of the estimation of power draw by electrical measurements are: (1) It is a simple method, (2) little instrumentation is required and (3) high investment is not required.

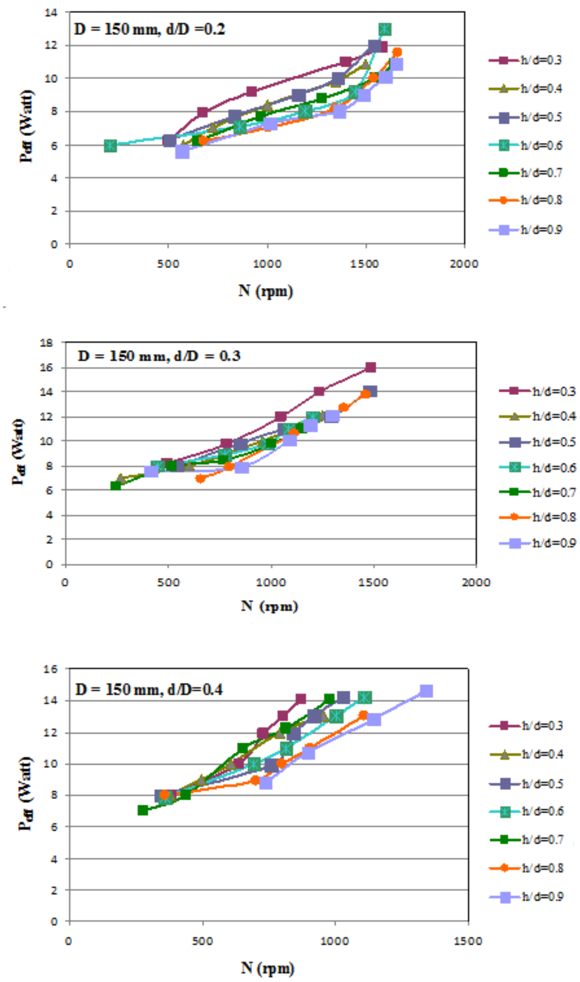

Figure 2: Influence of Submergence Depth at Power Consumption (150 mm Tank)

3. Results and Discussion

The performance of stirred tank is known to depend on the impeller submergence. Therefore, the effect of impeller submergence has been investigated systematically. Figure 2 illustrates observations made on power consumption with different submergence depths of impeller. The value of h/d varies from 0.3 to 0.9. Power consumption is strongly dependent on the gas holdup near the impeller i.e., the local gas hold-up in the vicinity of the impeller [20]. As the size of this region increases, impeller rotates in progressively increasing liquid free region thereby decreasing the power consumption. This fact can be seen from the Figure 3. It can be seen from the Figure 3, the value of h/d=0.9 consumes less power in most of the cases. Overall these observations suggest that a range of 0.8 to 0.9 is optimal as far as power consumption is concerned. The less power consumption at higher value of h/d may be attributed to the fact that blades are exposed to the air. Exposure of blades decreases the drag resistance. This decrease in drag results in lower power draw or consumption.

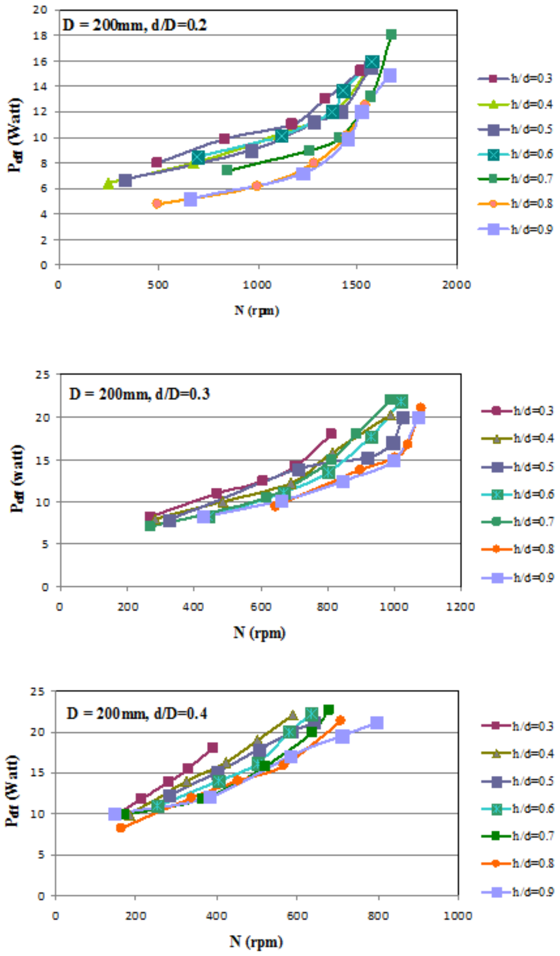

Figure 3: Influence of Submergence Depth at Power Consumption (200 mm Tank)

4. Conclusions

Generally standard guidelines for submergence are being followed for designing the stirred tanks for desired process, which can far from being an optimal point. Slight change in submergence depth can cost much when optimal performance is required. In particular, there is practically no published information which stipulates the optimal submergence depth of impeller. Present work experimentally investigates the influence of submergence depth on power consumption for arrowhead impeller. It can be concluded that h/d=0.9 can be taken as optimal point.

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