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# Shape effect on optimal geometric conditions in surface aeration systems

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**Abstract**−The performance of surface aeration systems, among other key design variables, depends upon the geometric parameters of the aeration tank. Efficient performance and scale up or scale down of the experimental results of an aeration system requires optimal geometric conditions. Optimal conditions refer to the conditions of maximum oxygen transfer rate, which assists in scaling up or down the system for commercial utilization. The present work investigates the effect of an aeration tank's shape (unbaffled circular, baffled circular and unbaffled square) on oxygen transfer. Present results demonstrate that there is no effect of shape on the optimal geometric conditions for rotor position and rotor dimensions. This experimentation shows that circular tanks (baffled or unbaffled) do not have optimal geometric conditions for liquid transfer, whereas the square cross-section tank shows a unique geometric shape to optimize oxygen transfer.

Key words: Aeration, Geometric Conditions, Oxygen Transfer, Rotor, Shape

## INTRODUCTION

In wastewater treatment, aeration is used to provide oxygen to aerobic microorganisms during the stabilization process. Additionally, certain applications use the mixing capabilities of aeration equipment to maintain sufficient agitation within the stabilization reactor to promote the desired level of interaction between the microorganisms and the organic loading to the treatment process. There are many types of aerators used in practice, such as cascade, spray nozzles, diffused or bubble aerators and surface aerators. Among them, surface aerators are popular because of their comparable efficiency and ease in operation [1-5].

American Society of Civil Engineers (ASCE) standard [6] presents a general methodology for the evaluation of aeration systems. While the standard does generally acknowledge significant differences in the operational characteristics of different kinds of aeration systems, it offers only limited guidance with regard to the impact of certain aspects of the testing protocol on the reported performance of surface aeration systems undergoing evaluation in accordance with the published standard. An initial investigation has been conducted with the objective of identifying those aspects of the currently adopted performance evaluation protocol with the potential to influence the reported operational performance of mechanical surface aeration equipment. It is generally understood that the tank geometry employed for the evaluation of an aeration device may influence the reported performance of that device [7]. However, the magnitude of this influence has not been widely investigated [8]. Because of the great variety of treatment process designs, defining a single efficient tank geometry that would conform to the goal of optimal performance for all aeration devices is difficult [6] Generally, two shapes are employed as surface aeration systems, such as square and circular. They may be with or without baffles. Various researchers [9-12] have studied the square surface aeration systems. Rao [10] has developed an optimal geometric condition for square shaped surface aeration systems. There exist numerous references on circular or cylindrical surface aeration systems [13-19]. Rao et al. [18] and Rao and Kumar [19] have adopted the square tank optimal geometric conditions in their experiments. Because of not having certain optimal geometric conditions, researchers have used certain guidelines [15] for the circular baffled and unbaffled systems. These conditions may or may not give the optimal design for efficient surface aeration systems.

In this work, attempts have been made to observe or quantify in a qualitative way the effect of shape on geometric conditions in surface aeration systems.

## MATERIALS AND METHODS

Fig. 1 shows a typical surface aeration tank used for the oxygen transfer studies. Three shapes of tank (equal area, $A=0.5184\ m^2$) have been used in this work: baffled circular tank, unbaffled circular tank and unbaffled square tank.

Aeration studies were conducted according to the standards laid down by the American Society of Civil Engineers [6]. After measuring initial concentration of dissolved oxygen (DO) of water (tap water) in the tank, water was deoxygenated by adding appropriate quantities of cobaltous chloride and sodium sulfite [20]. About 8 mg/*l* of sodium sulfite and 0.1 to 0.5 mg/*l* of cobaltous chloride are to be added to each mg/l of DO present in the water. The chemicals were mixed thoroughly to complete the deoxygenation. When deoxygenation occurred, i.e., when the DO concentrations came down to almost 0 mg/*l*, the experiment was started by setting the required speed of the rotation of the rotor. Three experiments for each case were conducted at the same speed. The variations in the experimental measurements in $K_La_{20}$ were 0.5 to 1%. Dissolved oxygen (DO) was measured and recorded over time by a Thermo Orion 5 Star Meter. The DO meter was calibrated with the modified Win-

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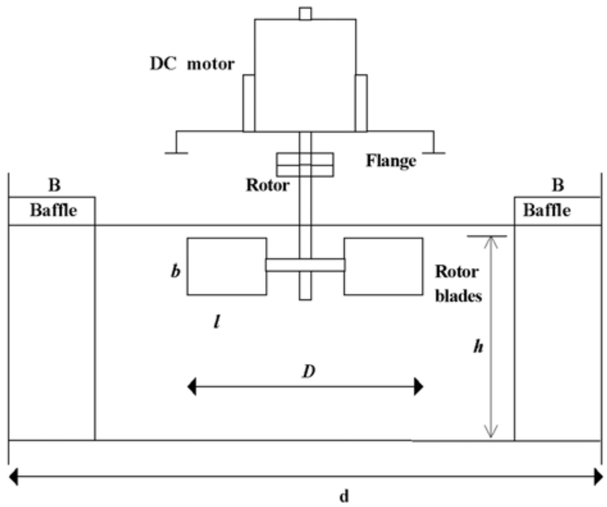


**Fig. 1. Schematic diagram of a surface aerator.**

kler's method [20]. The volumetric mass transfer coefficient $K_La_T$ was estimated by using the ASCE DO parameter estimation program (http://fields.seas.ucla.edu/research/dopar/). The temperature correction factor $\theta$ given by Van't Hoff Arrhenius was used to convert the $K_La_T$ value to standard conditions, 20 °C. The various factors affecting the aeration process can be grouped as geometric variables and dynamic variables and expressed as:

$$K_La_{20}=f(H, D, l, b, h, n, N, g, \rho_a, \rho_w, \nu) \quad (1)$$

where H is the water depth, h is the distance between the horizontal bottom of the tank and the top of the blades, D is the diameter of the rotor and N is rotational speed of the rotor. b and $l$ are the rotor's blade width and length respectively. n is the number of blades fitted to the rotor. The physical variables include density of air ($\rho_a$), density of water ($\rho_w$), and the kinematic viscosity of water ($\nu$). After dimensional analysis using Buckingham $\Pi$-Theorem [16], Eq. (1) is expressed in non-dimensional form as:

$$k=f(H/D, l/D, b/D, h/D, n, \rho_a/\rho_w, R, F) \quad (2)$$

where, $R=ND^2/\nu$ is the Reynolds number, $F=N^2D/g$ is the Froude number and where $k=K_La_{20}(\nu/g^2)^{1/3}$ is the non-dimensional oxygen transfer parameter. The first five non-dimensional parameters represent the "geometric-similarity" of the system and the last parameter represents the "dynamic-similarity." In the present study, experiments were conducted by using a modified version of disc turbine fitted with six blades in symmetrical manner following some of the previous investigations [21-24]. Therefore, the number of blades, n was constant; also the parameter $\rho_a/\rho_w$ was invariant as only tap water was used in all the experiments. $l$/b ratio also was kept constant in the experiments; thus only one of the rotor dimensions had to be studied. Thus, these parameters were omitted in the analysis. The functional relationship of Eq. (3) can now be expressed as,

$$k=f(H/D, h/D, l/D, R, F) \quad (3)$$

or it can be written as:

$$k=f(H/D, h/D, l/D, X) \quad (4)$$

where $X=F^{4/3}R^{1/3}$ [7,8] and is called the theoretical power per unit volume. For baffled circular tanks, two additional parameters are that the number of baffles ($N_b$) and width of the baffle (B) should be included in dimensional analysis. However, in the present work, the effect of shape was analyzed on the optimal geometric conditions of the first three parameters of Eq. (3) on the same dynamic conditions, which is generally shown by the parameters X.

## RESULTS AND DISCUSSIONS

Scale-up is an inherent part of process development; in fact the terms are virtually synonymous for many people. Scale-up has been successfully achieved when yields and productivities, previously demonstrated on a small scale, have been produced in larger capacity units. Two basic approaches to scale-up are available: extrapolation of model experiments based on the principles of similitude, and mathematical analysis of the complete (or controlling) mechanism [25, 26]. To scale-up by similitude, one must first establish some functional relationship between the various dimensionless parameters which can be used to characterize the system. Fluid mechanics and geometry are key points to understanding mixing. The fluid mechanics transports the material about the tank, whereas the geometry determines the fluid mechanics. In fact, the geometry is so important that the processes can be considered geometry specific. As discussed earlier and given in the Eq. (3), results are presented here, and the effect of shape on optimal geometric conditions has been analyzed.

### 1. Effect of Shape on Optimum Position of Rotor (h/D)

Position of rotor submergence defines the surface aeration systems. Experimental observations are plotted in the Fig. 2. Repeatability of the experiments is required to establish any result. As shown in Fig. 2, three different experimental results for one tank have been shown to check the repeatability of the experimental results. As can be seen from Fig. 2, initially oxygen transfer rate increases with an increase in h/D, and after reaching an optimal position (the point at which oxygen transfer rates are maximum), the oxygen transfer rates decreases with further increment in h/D. This trend is visible in all the three types of tank. The optimal value obtained for the baffled

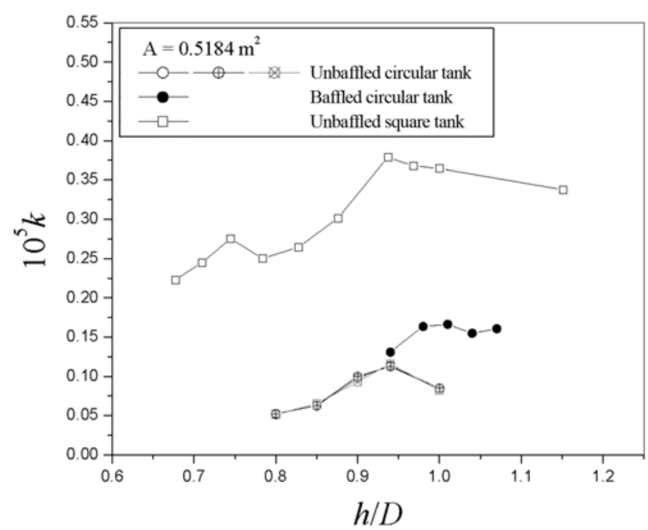


**Fig. 2. Effect of shape on the optimal position of h/D.**

circular tank is 1.0 and for the unbaffled circular tank and square is 0.94. Fig. 2 shows that without baffles, there is no effect of shape on the optimal position of the rotor. With baffles, the nature of the phenomenon is the same but the optimal point has been shifted to some higher value.

**2. Effect of Shape on Optimal Rotor Blade Dimensions (*l*/D)**

The rotor blade is the most critical part of a surface aeration system since it determines the type of flow pattern, pumping and circulation flow rates [27]. Thus, it is needed to find the optimal geometry of the blade. In the present experimental investigation, the ratio of $l$/b has been maintained constant (=1.25) as given by the Udayasimha [21]. Experimental results are plotted in Fig. 3 where it can be seen that maximum aeration occurs at $l$/D=0.3 for all the three types of tank. This shows that rotor dimensions are independent of the shape of the tank.

**3. Effect of Shape on Optimal Depth of Water (H/D)**

Experimental result for finding shape effect on H/D shows some surprising results as shown in Fig. 4. It can be seen from Fig. 4 that

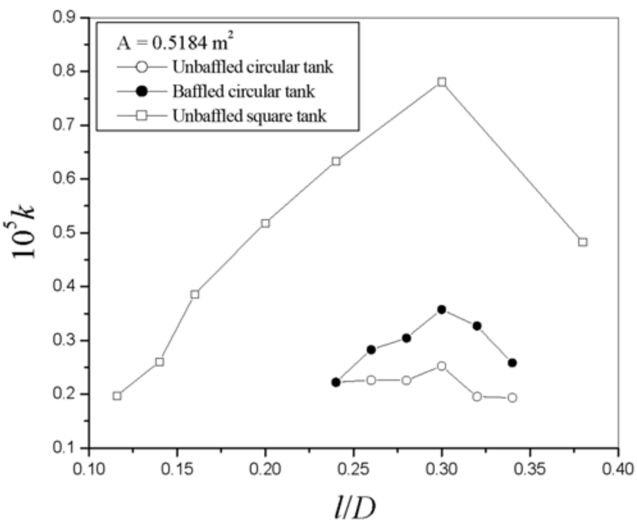


**Fig. 3. Effect of shape on optimal rotor blade dimensions.**

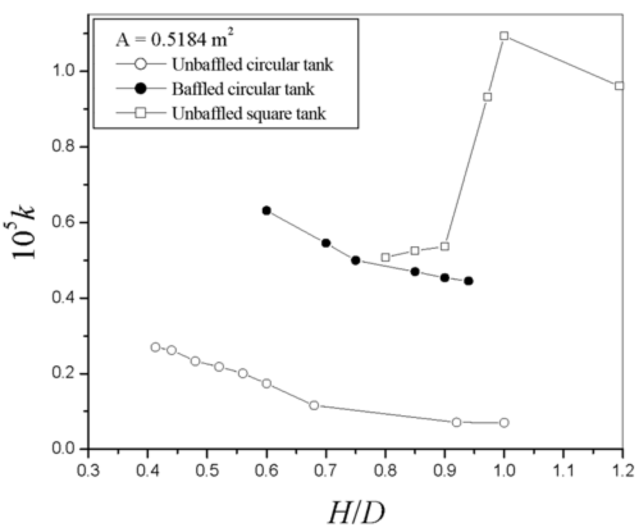


**Fig. 4. Effect of shape on optimal depth of water.**

for square tanks, there is an optimal point; which is not the case of the circular tank with and without baffles. Circular tanks do not show any optimal value for H/D. The overall trend in circular tanks is that the oxygen transfer rate decreases with an increase in H/D. The cause of this behavior may be attributed to the symmetry of flow, which exists in the circular tank. It can be said that such symmetry should not exist in a circular tank with baffles. Here, with baffles also, there exists some symmetry which makes it different from the square tank.

## CONCLUSIONS

We experimentally investigated the effect of shape of an aeration tank on optimal geometric conditions. Optimal geometric conditions are required for scale down or scale up of the laboratory experimental dimensions. It is concluded that tank shape has no influence on the optimal geometric conditions of rotor dimensions and immersion depth of the rotor. Thus the same optimal geometric conditions for rotor dimension and immersion depth can be taken for different shaped surface aeration systems. The depth of liquid in the aeration tank with respect of rotor diameter gets affected by the aeration tank shape. It is found that in circular with and without baffles, there is no optimal position for the liquid depth, whereas in square tanks the oxygen transfer rates show optimality.

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## NOMENCLATURE

B : width of baffle
b : width of the blade [m]
D : diameter of the rotor [m]
F : $N^2D/g$, Froude number
H : depth of water in an aeration tank [m]
h : distance between the top of the blades and the horizontal floor of the tank [m]
k : $K_La_{20}(\nu/g^2)^{1/3}$, non-dimensional oxygen transfer coefficient
$K_La_T$ : overall oxygen transfer coefficient at room temperature T ºC of water [1/minute]
$K_La_{20}$ : overall oxygen transfer coefficient at 20 ºC [1/minute]
$l$ : length of the blade [m]
$N_b$ : number of baffles
N : rotational speed of the rotor with blades [1/minute]
R : $ND^2/\nu$, Reynolds number
X : $N^3D^2/(g^{4/3}\nu^{1/3})=F^{4/3}R^{1/3}$
$\nu$ : kinematic viscosity of water [m²/s]
$\rho_a$ : mass density of air [kg/m³]
$\rho_w$ : mass density of water [kg/m³]
$\theta$ : 1.024

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