SURFACE AERATION FOR WATER TREATMENT AGITATED TANK
MIXING TIME, POWER CONSUMPTION AND HYDRODYNAMICS

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Abstract. A surface aeration and agitation system used for water treatment was studied under both aerated and non-aerated conditions to explain the influencing parameters on the mixing time. The power consumption measurement and lower propeller pumping capacity by applying (LDV) are performed. A dimensionless mixing time number model is made to correlate the most affecting factors for the system.

Keywords: surface aeration, agitated tank, mixing time, pumping capacity, dimensional analysis

1. INTRODUCTION
Aeration process in water and wastewater treatment has an important function of delivering the needed oxygen to the aerobic micro-organisms for respiration. Also it ensures well mixed condition for whole treatment tank through maintaining the microbial flocs in continuous state of agitated suspension by the accompanied mixing in order to achieve maximum contact surface area between the flocs and wastewater [1]. Mixing plays an important role when an attempt is made for scale up of batch reactor system such as the surface aerator system [2]. The objective of this study is to interpret the flow characteristics created by the impellers, the power consumption, mixing time for the system in different cases of applied geometry.

2. MATERIALS AND METHOD
The experimental runs are carried out in a cylindrical flat bottom vessel placed in a larger cubic vessel in order avoid the laser beam diffraction for LDV application. All the vessels are made of fibre glass. The cylindrical vessel is equipped with aeration and mixing system which consists of an aerator (turbine of conical overturned shape with 15° pitched blades) placed at the water surface with mixing assembly positioned below the turbine (see fig. 1); the mixing assembly is composed of four 45° pitched blade propeller placed inside a draft tube (for geometric details see table 1). The experiments are performed for different operation conditions; the dual phase (air-water) condition (air bubble formation occurs) with turbine alone or whole system are employed. The single liquid phase condition, when mixing assembly alone is employed in order to clearly understand the performance of each part. The experimental runs involved testing of mixing time, also the pumping capacity and flow rate in the vicinity of lower propeller and draft tube accesses without any external effect, for both aeration (up pumping) and mixing (down pumping) flow conditions. The mixing time is determined by applying the decolouration method of (iodine- thiosulfate) method, which includes colouring the water with iodine solution and then decolourize it with sodium thiosulfate solution. The hydrodynamic characteristic such as the pumping capacity of lower propeller was determined by applying the LDV (Laser Doppler Velocimetry) technique with two beams (green-blue) Dantec fiber...
flow device, which depends on the reflected scattering beams by previously added tracer particles to the water. The acquisition area is chosen for the control volume increment was the external plane enveloping the vicinity of the propeller and near the accesses of the draft tube. The acquisition conducted for both up and down pumping conditions and with and without draft tube.

The power consumed was measured for most of the experimental sets and the effects of the water level on mixing time of aerated condition for different rotational speed were tested. The operating fluid was the tap water.

<table>
<thead>
<tr>
<th>Table 1. Geometric configuration details.</th>
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<tbody>
<tr>
<td>Diameter (m)</td>
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<tr>
<td>Vessel</td>
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<tr>
<td>Turbine</td>
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<tr>
<td>Draft tube</td>
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<tr>
<td>Propeller</td>
</tr>
<tr>
<td>Cone</td>
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<tr>
<td>Baffles</td>
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<tr>
<td>Draft tube baffles</td>
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<tr>
<td>Impellers spacing</td>
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<tr>
<td>Water level height</td>
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</tbody>
</table>

3. RESULTS AND DISCUSSIONS

3.1 Mixing Time

3.1.1 Single Phase Condition. The mixing time experiments were performed for different conditions to determine the mixing assembly performance, where the system is operated without the turbine at the top, where the process contains only liquid (water) agitation and mixing. The measurements by the decolouration method were conducted at given geometrical configuration and propeller rotational speed (N) levels of (1.67 - 3.33 rps) where the flow regime always kept in the turbulent state. The investigations were applied for two modes of agitation: the up flow pumping and down flow pumping. To understand the effect of draft tube, the system tested for two configurations, where in one of them the draft tube is removed (see fig. 2). The position of decolorizing solution is always chosen to be at the surface of water to measure correctly the mixing time achieved due to the circulation of air bubbles entrapped from the water surface. Generally the experimental results showed that, mixing time is decreased with increasing the rotational speed, which refers that the
The relationship between mixing time and the agitation of water is reversibly proportional that agrees with [2, 3, 4, 5]. It’s observed that the mixing dimensionless number ($t_mN$) stays somehow constant for each case that indicates the geometrical configuration can be characterized by its mixing number (see fig. 3). Figure (2) shows also that mixing time with up-flow pumping is slightly higher for with draft tube than down flow conditions that agrees with [6] but for (C/T < 0.33). This result can be explained by the up flow is enhanced due to the existence of cone at the vessel bottom, where it contribute to redirect the flow upward to propeller intake and also it removes the dead zone below the propeller [7]. The mixing time of down flow pumping for without draft tube condition was higher than with draft tube, these results agree with [8,9,4,10]. The ($t_m$) is decreased with longer draft tube as [9]. It’s observed also the mixing time is higher for without draft tube condition than with draft tube for down-flow, while $t_m$ is lower with draft tube for up-flow pumping. The low values of mixing time in non-aerated condition relied on low ratio of ($d/T = 0.15$), which leads to weak interaction between the propeller and the walls and the bottom of the vessel.

### 3.1.2 Dual Phase Condition.

**The Turbine Alone:** The mixing time investigation carried out for various rotational speeds (N), where both the draft tube and the propeller removed. Figure (4) shows the mixing time is highly effected by the elevation of (N), the mixing time is lessened, when the speed is doubled (1.67-3.33).

**The Whole System:**

**The Effect of Rotational Speed:** Figure (4) represents the plot for the mixing time relation versus the (N), same with turbine alone case, wherein the mixing time appears to be very dependent on the elevation of (N). As a consequence this indicate the mixing time in aerated condition is highly

![Figure 2. Relation between rotation speed and mixing time (non-aerated condition).](image)

![Figure 3. Relation between rotation speed and mixing time (non-aerated condition).](image)

![Figure 4. Relation between rotation speed and mixing time, (Whole syst., Turbine alone), Aerated condition.](image)

![Figure 5. Effect of water level on the mixing time.](image)
effected by the flow pattern and the bubble presence in the liquid phase, and it’s quite clear for adapted rotation speed (1.67 -3.33 rps). Mixing time always in this condition has values lower than of the turbine alone case, by the comparison between these two cases the participation of lower positioned mixing assembly (propeller and draft tube) can be determined within the lessened values mixing time, where the performance of the mixing assembly can be evaluated by its assistance to the above turbine to achieve homogenization in entire vessel within shorter mixing time (more details in next section). The power consumption relationship with (N) for this case of aeration is illustrated in figure (6), where with propeller and draft tube the power consumed is slightly elevated due to their performance.

The Effect of Liquid Level: Generally the liquid level in the surface aeration is just at the upper edge of the aerator blades (100% submergence of aerator blades). To investigate the effect of liquid level ratio (h/T) on the mixing time, different liquid levels are tested (0.34, 0.35 and 0.36). The highest (h/T) employed the lowest $t_{\text{mix}}$ is accomplished (see figure 5), that agrees with [11].

3.2 Hydrodynamics. The measurements are performed with LDV by acquisition of mean velocity components the radial and axial around the propeller plane area and draft tube inlets. The propeller pumping number ($N_{Qp}$) is calculated by measuring the mean velocities created by propeller blades for both up-pumping and down-pumping directions. The pumping capacity is calculated according to the resultants for volumetric flow rate balance around the considered area of propeller vicinity, the applied calculation of volumetric flow rate depends on the direction of each velocity component entering and leaving the acquisition plane area. The pumping capacity is represented as a dimensionless factor known as pumping number ($N_{Qp}$) pursuant to the fact that pumping capacity is proportional to the rotational speed [12]. Table (2) shows the measured values of ($N_{Qp}$) for all pumping directions for both conditions with and without draft tube. The up and down flow values of pumping number relatively have close values in each case of with and without draft tube, [13] figured out same results. Also in table (2) it’s noticed that the pumping capacity slightly improved with presence of draft tube. The flow also identified of the propeller at other areas in the draft tube to demonstrate the relative importance of flow pattern created by the same propeller to compare it with propeller pumping capacity [13]. Table (2) shows the determined pumping numbers at the draft tube inlet and outlet positions, where by comparing between them it can be noticed the pumping number keeps its value. The draft tube wall function assists to redirect the flow and lessen the radial flow and small loops formation.
Table 2. Pumping numbers at propeller vicinity and draft tube inlets.

<table>
<thead>
<tr>
<th></th>
<th>Up flow with draft tube</th>
<th>Down flow with draft tube</th>
<th>Up flow without draft tube</th>
<th>Down flow without draft tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_Qp ) (At propeller vicinity)</td>
<td>( 0.56 )</td>
<td>( 0.55 )</td>
<td>( 0.51 )</td>
<td>( 0.49 )</td>
</tr>
<tr>
<td>( N_Qp ) (At draft tube inlets)</td>
<td></td>
<td>( 0.54 ) (Up flow at draft tube upper outlet)</td>
<td>( 0.55 ) (Up flow at draft tube lower inlet)</td>
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</tbody>
</table>

Figure (7) illustrates the axial mean velocity at the draft tube accesses for up-pumping direction. At the lower inlet of draft tube, the effect of the cone positioned at the vessel bottom is quite clear. The velocity is highly redirected up-ward the mean axial velocity has its maximum value at the close point to the cone surface for each the right and left side of the inlet acquisition line. At the upper draft tube outlet acquisition line the discharge flow by the propeller can be observed with mean axial velocity \( (V_z) \) profile (see fig.7).

3.3 Mixing Time Correlations

Many previous attempts to build a model of mixing time were dealt with aerated condition of agitated tank, but generally the surface aeration has not taken in account. The flow pattern created by the impellers here is different, the existed developed mixing time models are generally correlate to the mixing time with power consumption and diameter ratio (impeller/tank) for non-aerated condition [15, 11], whereas the mixing time with geometrical parameters and the power consumption [16] or with process parameters [3] or/and with flow characteristics [17] has been correlated.

In this study the attempt to build a mixing time correlation depends upon the performance criteria for the surface aeration system, in depending upon experimental observation, where the various affecting parameters that can be taken in account are; operational parameters like, rotational speed, acceleration of gravity and flow passing through the lower propeller blades, the property parameters; water density and viscosity, the geometrical configuration parameters, such as the water height level \( (h) \).

By applying Buckingham II of dimensional analysis theory, the general influencing factors may affect the mixing time in surface dual phase (aerated) condition can represented as:

\[
t_m = f (N_P, N_{Fr}, N_{Re}, d/D, h/D, N_{Qp})
\]

this approach agrees with[17], equation (1) is reduced as the geometric ratio \( (d/D) \) kept constant in the experimentation, the \( (N_{Qp}) \) for the lower propeller is relatively constant for utilized of pitched blade propeller type [15] and since all experimental runs are performed within turbulent regime so \( N_{Re} \) is eliminated, after rearranging the derived equation is solved to determine the values of the constants by applying multiple non-linear regression, the coefficient of determination \( (R^2) \) of (0.90) comparing with experimental results, the model will have the following form:

\[
t_m = 27.66 (N_P)^{0.945} (N_{Fr})^{-0.628} (h/D)^{0.299}
\]

4. CONCLUSION

Mixing time showed obvious dependence upon the variation of rotation speed, liquid level, in both aerated (dual phase) and non-aerated (single phase) conditions with different influence intensity. The power consumption was varied in agreement with mixing time achieved for different conditions applied. The lower propeller pumping capacity was generally constant for both up and down flow and it’s mildly improved with draft tube presence.
A model was built to interpret the mixing time number \( t_m N \) behaviour related to more affecting parameters in the surface aerated agitated tank, the model is applicable for the scale-up within the limits; \((1.67 \leq N \leq 3.33 \text{ rps}), (0.34 \leq h/T \leq 0.36)\) and \((30 \leq P/V \leq 200 \text{ watt/m}^3)\).

**NOMENCLATURES:**

- \( d_d \): draft tube diameter, (m).
- \( d \): propeller diameter, (m).
- \( D \): turbine diameter, (m).
- \( Q_p \): flow rate by propeller \((\text{m}^3/\text{s})\).
- \( g \): acceleration of gravity, \((9.8\text{m}^2/\text{s})\).
- \( h \): water height level, (m).
- \( P \): power consumed, (watt).
- \( N \): rotation speed, (rps).
- \( N_{Fr} \): Froude number, \((\text{ND}^2/\text{g})\).
- \( N_p \): power number, \((P/\rho N^3 D^5)\).
- \( N_{Re} \): Reynolds number, \((\rho ND^2/\mu)\).
- \( N_{Q_p} \): pumping number, \((Q_p/\text{ND}^3)\).
- \( r \): radial coordinate (m).
- \( R \): draft tube radius (m).
- \( S_p \): spacing between two impellers, (mm).
- \( t_m \): mixing time (s).
- \( T \): vessel diameter, (m).
- \( V \): water volume \((\text{m}^3)\).
- \( V_{sp} \): propeller blade tip speed \((\text{m/s})\).
- \( V_z \): mean axial velocity \((\text{m/s})\).
- \( \rho \): water density, \((\text{kg/m}^3)\).
- \( \mu \): water viscosity, \((\text{Pa.s})\).

**REFERENCES:**