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INVESTIGATION OF FLUID FLOW VELOCITY TO REDUCE POWER CONSUMPTION IN A VESSEL STIRRED BY 4-WIDE-BLADE HYDROFOIL IMPELLER

Rajab Atibeni [1]*, Ebrahim Hawaidi [2], Abdelmaged Abdallah [3], Salem Sakal [4]
Assistant Prpfessor[1], Associated Professor[2] , Associated Professor[3], Associated Professor[4]
Department of Chemical Engineering [1,2,3,4]
Faculty of Engineering, Sabratha University, Sabratha, Libya [1,2,3,4]

Abstract: Agitation speed is a determining factor in power consumption and mixing quality, which determines consequently the cost of mixing operation. This study explores the fluid flow velocity and power required for achieving the mixing operation in stirred tank by using PIV technique. The mixing system consists of a cylindrical tank with a flat bottom and an up-pumping 4-Wide-blade Hydrofoil impeller (WHU). The diameter of the vessel, the diameter of the impeller, and the vertical clearance of the bottom were 0.192 m, 0.075 m, and 0.064 m, respectively. Water liquid is used as a working fluid (density ρ = 997 [kg/m3], different shaft positions, (0%, 5%, 10%, and 15%,) away from the center of the tank. Fluorescent particles were also used to measure axial and radial velocities for the liquid phase. PIV measurements showed that the velocity increases by approximately 50% in the tank with the most eccentric shaft that means we can reduce the power consumption 50% in a vessel stirred by 4-Wide-blade Hydrofoil impeller (WHU).

***Index Terms* - Mixing, Stirred tank, Power Consumption, PIV.**

I. INTRODUCTION.

Nowadays mixing is a very common operation in the process industries, usually performed by mechanical agitation, such as in the chemical, biochemical, pharmaceutical, food, paint, wastewater treatment, petroleum and other industries. Stirred tanks are among the most common process equipment used in chemical and other process industries since their good mixing ability and the characteristics for scale-up**[1]**. Power draw is a very important variable in chemical and bioprocess engineering. It is defined as the amount of energy necessary in a period of time, in order to generate the movement of the fluid within a container (e.g. bio- reactor, mixing tank, chemical reactor, etc.) by mechanical agitation[2]. When the power required to carry out the process decreased, at the same time the internal heat generation decreased and the mixing system required a smaller electrical motor, smaller gears, shaft, etc. All of these items minimize investment cost and operating cost. Independent of an industrial process, the main goal has always been to find the most efficient and nondestructive method of mixing which consumes as low amounts of power as possible. For that reason, a large number of research studies have been performed to obtain high-quality mixture usually with low power consumption[3,4,5,6,7]. A few studies have been reported on the effect of shaft eccentricity on the flow field in stirred tank[8,9,10,11]. concluded that the off-centered agitators can change the flow pattern and generate asymmetric flow field structure in the vessel and also the mixing rate and mixing efficiency are affected. Particle image velocimetry, (PIV) are feasible tools for design and optimization of several apparatuses of chemical and process industry, and it is one of the suitable and accurate technique especially for the study of flow velocity in stirred tank in both the absence and presence of floating particle, positive or negative suspension[12]. However, few researches have been reported on how the off-centered impeller would influence on the flow field in a stirred tank. This is an area in which much work is still needed. In this work we investigate the fluid flow velocity by using PIV technology to reduce power consumption in a vessel stirred by 4-Wide-blade Hydrofoil impeller, with the measurement region below the surface and above the bottom of the tank.

2. EXPERIMENTAL SECTION.

Experiments were performed in a Perspex vessel of 0.192m diameter (*T*) with flat bottom, agitated by an up-pumping 4-Wide-blade Hydrofoil impeller, (WH_U). The liquid height (*H*) was kept constant at *H*=*T*. The impeller diameter and off-bottom clearance were 0.075 (0.4*T*), and 0.064 m (0.33*T*), respectively The vessel was immersed in a glass rectangular tank filled with water, in order to minimize the errors produced by the refraction of the water and curved glass of the inner vessel. The eccentricity of an off-centered agitator was defined as *R*/*T* × 100 (%), where *R* is the radial distance from the shaft to the vessel centerline. Eccentricities of 0%, 5%, 10%, and 15% have been used in the present work. We defined those four positions as positions P 1, P 2, P 3, and P 4, corresponding to the eccentricities of 0%, 5%, 10%, and 15%, respectively.

2.1 Measurement technique

Particle Image Velocimetry is an optical, non-invasive technique which is used for velocity flow field measurements. One of the requirements for application of the PIV technique is adding the tracer particles to the volume of stirred liquid. The tracer particles are assumed to faithfully follow the flow dynamics. Fluorescent melamine microsphere suspension powder with density of 1510 kg/m^3 was used as tracer particle. During the measurements the laser light is scattered on the tracer particles, and the scattered light is captured by the CCD Camera, which records two images, I_1 and I_2, in the known interval of time, Δt. In the next step the captured images are divided into small sections called interrogation areas (IA). The cross-correlation operation (1) of corresponding sections of two successive image frames allows determination of the displacement vector of tracer particles, dx , and the velocity vector, **V**, (2).

$$C(s) = \iint_{IA} I_1(\bar{X}).I_2(\bar{X} - s)d\bar{X} \qquad (1)$$

$$\bar{V} = \frac{\Delta\bar{X}}{\Delta t} \qquad (2)$$

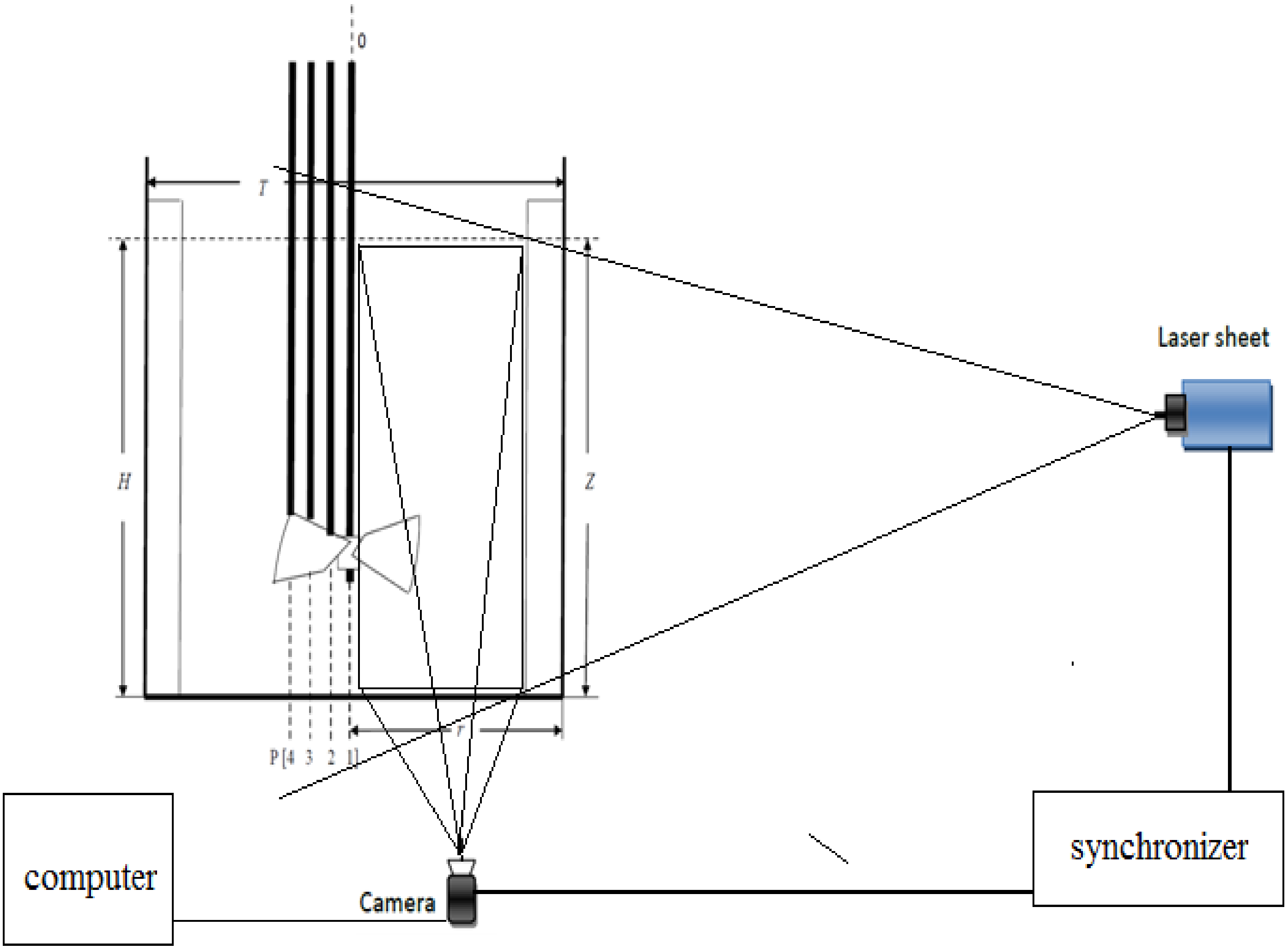


Figure 1. Schematic of the experimental setup

3. EXPERIMENTAL RESULTS AND DISCUSSION.

3.1 PIV velocity vectors for different positions (P1and P4), at the same agitation speed (10 rps).

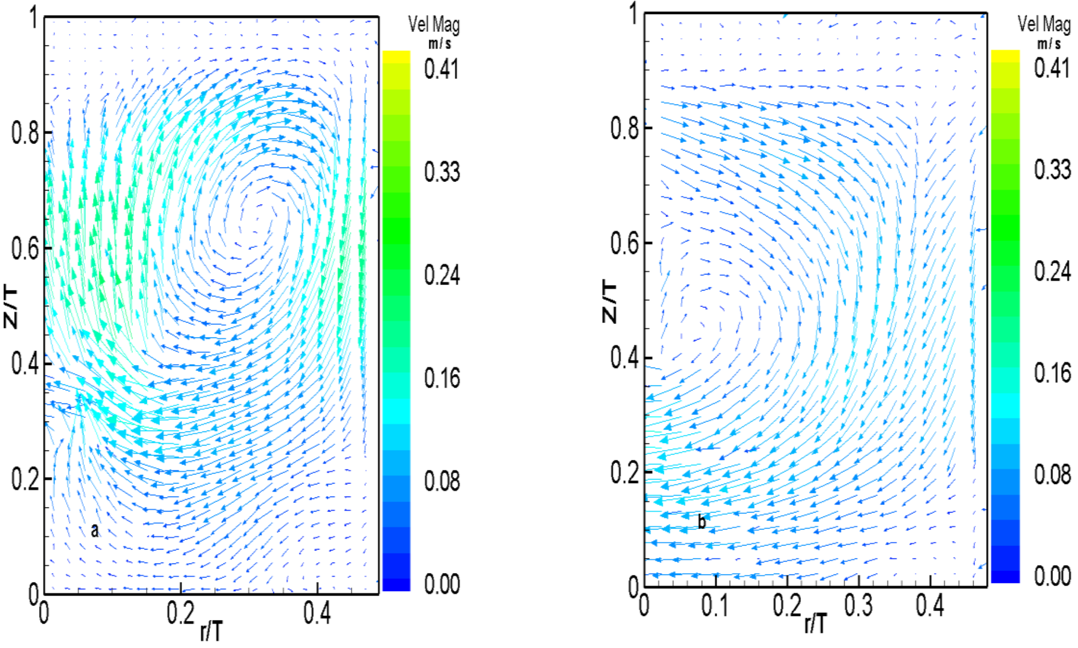
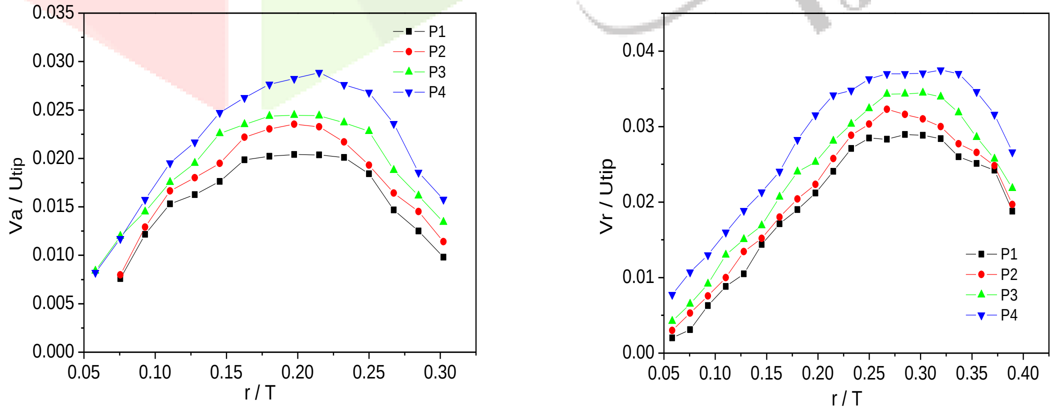


Figure. 2(a,b) PIV vectors for different eccentricity(P1and P4) at N= 10 rps.

Figure. 2(a and b), shows the fluid flow velocity vectors at the measurement plane, as shown in Figure 1 at P1 and P4, respectively. The liquid moves mainly forming a circulation loops in the plane for *PIV* measurement and the flow is characterized by important streamline curvature and strong rotation at P1, put in Position P4, the flow field is characterized by a different structure: together with a prevailing strong radial flow towards the shaft, especially in the bottom of the tank, as revealed by the PIV vector plots. This result is in good agreement with that obtained by G. Montante et al. [9] in unbaffled stirred tanks.

3.2 Radial profiles of the mean axial and radial velocities at Z/T=0.9

Figure 3 (a, and b), shows the radial profiles of the mean radial and axial components of the velocity in the region just below the surface of stirred tank where the liquid flow circulates from the shaft to the tank wall by up pumping impeller for different eccentricities 0%, 5%, 10%, and 15%, respectively. The measurements shows that the axial and radial velocity increases about 50% from Position 1 to Position 4 at constant agitation speed as shown in Table 1. That means off-centered shaft improves the mixing performance in stirred tank by reducing the power consumption about 50% compared to that of the centered shaft case.



a *b*

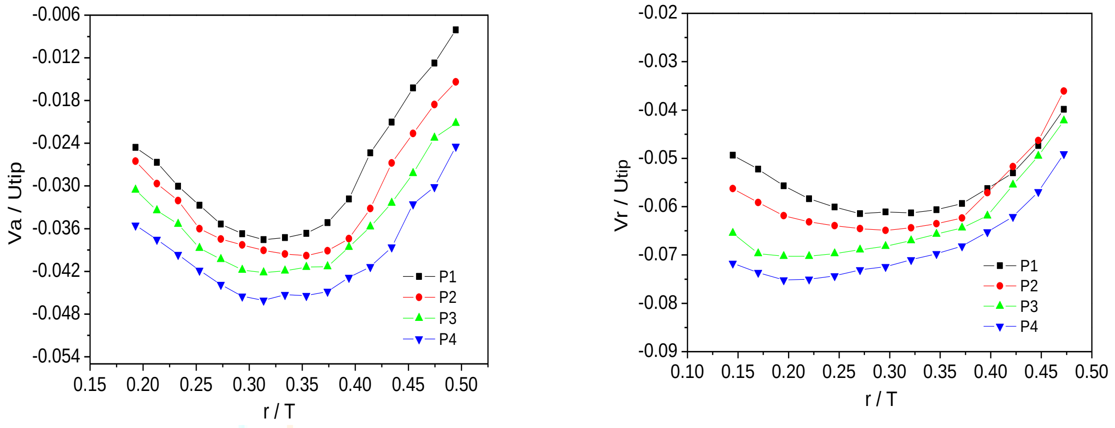
Fig 3. (a, b) Radial profiles of the mean axial and radial velocity at Z/T = 0.9

Table 1

Position	P1	P2	P3	P4	$(V_{P4} - V_{P1}/V_{P1}) \times 100$
Eccentricity	0%	5%	10%	15%	
Average(Va)m/s	0.016	0.0178	0.0198	0.024	50%
Average(Vr)m/s	0.020	0.0230	0.0255	0.0298	49%

3.3- Radial profiles of the mean axial and radial velocities at Z/T=0.15

Figure 4(a, and b), shows the radial profiles of the mean radial and axial components of the velocity below the impeller and above the bottom of stirred tank where the liquid flow recirculates from the wall to the shaft for different eccentricities 0%, 5%, 10%, and 15%, respectively. The measurements shows that the axial and radial velocity increases about 50% from Position 1 to Position 4 at constant agitation speed as shown in Table 2. That means the power consumption can be reduced about 50% compared to that of the centered shaft case.



a *b*

Fig 4.(a, b) Radial profiles of the mean axial and radial velocity at Z/T = 0.15

Table 2

Position	P1	P2	P3	P4	$(V_{P4} - V_{P1}/V_{P1}) \times 100$
Eccentricity	0%	5%	10%	15%	
Average(Va)m/s	-0.028	-0.032	-0.036	-0.042	50%
Average(Vr)m/s	-0.0504	-0.058	-0.063	-0.0752	49%

4- CONCLUSION.

PIV technique has been applied to investigate the fluid flow velocity at different shaft positions to reduce power consumption in stirred tank. All the measurements were taken in the region below the surface and above the bottom of the tank with an upward pumping 4- Wide-blade hydrofoil impeller (WH), D= 0.075 m, and the tank diameter 0.192 m. From the experimental results we are able to see that mean axial and radial velocities increase by approximately 50% when we move the shaft position away from the center, that will reduce the power required to carry out the process about 50%, at the same time the internal heat generation decreased and the mixing system required a smaller electrical motor that will reduce the investment cost and operating cost.

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