Study The Effect Of The Shape And Length Of The Baffle On The Hydrodynamic Structure In A Tank Agitated By A Rushton Turbine

Mohammed Foukrach, Mohamed Bouzit

Abstract— in this study, the shape of four square teeth of the baffle was tested with effect of the baffle length L on power consumption for an agitated vessel equipped by a Rushton turbine with six blades. The CFX code was employed for a numerical simulation of the turbulent flows in agited tanks with MRF technique, the Navier-Stokes equations were discretized by the finite volumes method, with a standard k-ε model. Numerical predictions have been compared with literature data and a satisfactory agreement has been found.

Index Terms— Rushton turbine, power comsuption, baffles length, stirred vessel, ANSYS CFX code.

1 Introduction

AGgreat number of operations of chemical industry, biochemical or petrochemical are carried out of tanks or in mechanically agitated engines The fine knowledge of the hydrodynamic structures of the turbulent flows in these systems, also makes it possible to improve the performances of the mobiles of agitation implemented, by the development of the geometrical and operational conditions optimal at the same time ensuring the improvement of the quality of the mixture and the energy saving. The presence and dimensions of the baffles have a considerable effect on the hydrodynamic structure like on the consumption; to note that, for the unbaffled tanks, the report/ratio of the quantity of liquid driven back by the agitator with the consumption, report/ratio which we can call effectiveness of circulation, is higher than in the case of an apparatus provided with baffles. In the literature, the study of the systems of agitation at summer started in several work relating to the characterization of the turbulent flows. As an indication, we can quote work of Deglon and al [1] which studied the influence of the grid on the characterization of the flows generated by a turbine of Rushton with six blades (TR6) in a baffled tank. Turbulent flow inside a cylindrical baffled stirred vessel is studied experimentally for different Reynolds numbers. A set of speed was selected ranging from 100 rpm to 350 rpm. These speeds gave high turbulence but without significant surface vortex formation. Vector field's maps and contours of time averaged velocities, for both radial and axial components in the impeller stream of a vessel stirred by a Rushton turbine, were determined by means of 2D PIV technique Zied Driss and al [2].

Aubin et al [3] used particle image velocimetry (PIV) technique to calculate the effect of the aerated agitator configuration in the mean velocity fields equipped by a pitched blade turbine. Oshinowo et al. [4] performed the CFD study using different turbulence models like, k – ε, RNG k – ε and RSM for the prediction of tangential velocity distribution in a baffled vessel using multiple reference frames (MRF) model.
Arezou. Ghadi, and Azam Sinkakarimi [5] Study the location of interface in a stirred vessel with Rushton impeller by computational fluid dynamic and experimental data was presented. Mean tangential, radial and axial velocities in various points of tank were investigated. Results show sensitivity of system to location of interface and radius of 7 to 10 cm for interface in the vessel with existence characteristics cause to increase the accuracy of simulation.
During recent years, the studies of the power consumption for the impeller-vessel systems of different geometry have been continued by many research workers. Kamien´ski [6], Saito et al. [7] and Ibrahim and Nienow [8] determined power characteristics for new types of the high-speed impellers.
Thus, the practical advantage of the turbine of Rushton, caused many research tasks aiming at the study finalized of the generated flow and the calculation of the consumption (Van' T Riet and Al [9], Van Der Molen and Van Maanen [10], Yianneskis and Al [11], Yianneskis and Whitelaw [12], Dyster and Al [13], Kemmoun and Al [14], Joanna Karcz, Marta Major [15], Stoots and Calabrese [16], Lee and Yianneskis [17], Baccar [18] and Zalc and Al [19])
The turbulent flow field generated in baffled stirred tank was computed by large eddy simulation (LED) and the flow field was developed using the Sliding Mesh (SM) approach. Mixing times and power number have been determined for a vessel agitated by a 6-blade Rushton turbine. The predicted results were compared with the published experimental data. R. Zadghaffari et all [20].

Taghavi et al. [21] experimentally studied mixing power consumption and flow regimes in dual Rushton impeller stirred tank in both single and two phase condition and then performed its CFD analysis. Power consumption of lower impeller blade was found to be more than that of upper impeller blade.
Three-dimensional and steady-state flow has been performed

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using the fully predictive Multiple Reference Frame (MRF) technique for the impeller and tank geometry. Process optimization is always used to ensure the optimum conditions are fulfilled to attain industries' satisfaction or needs (ie; increase profit, low cost, yields, etc). In this study, the range of recommended speed to accelerate optimization is 100, 150 and 200rpm respectively and the range of recommended clearance is 50, 75 and 100mm respectively for dual Rushton impeller. Thus, the computer fluid dynamics (CFD) was introduced in order to screen the suitable parameters efficiently and to accelerate optimization, N. Othman et al [22].

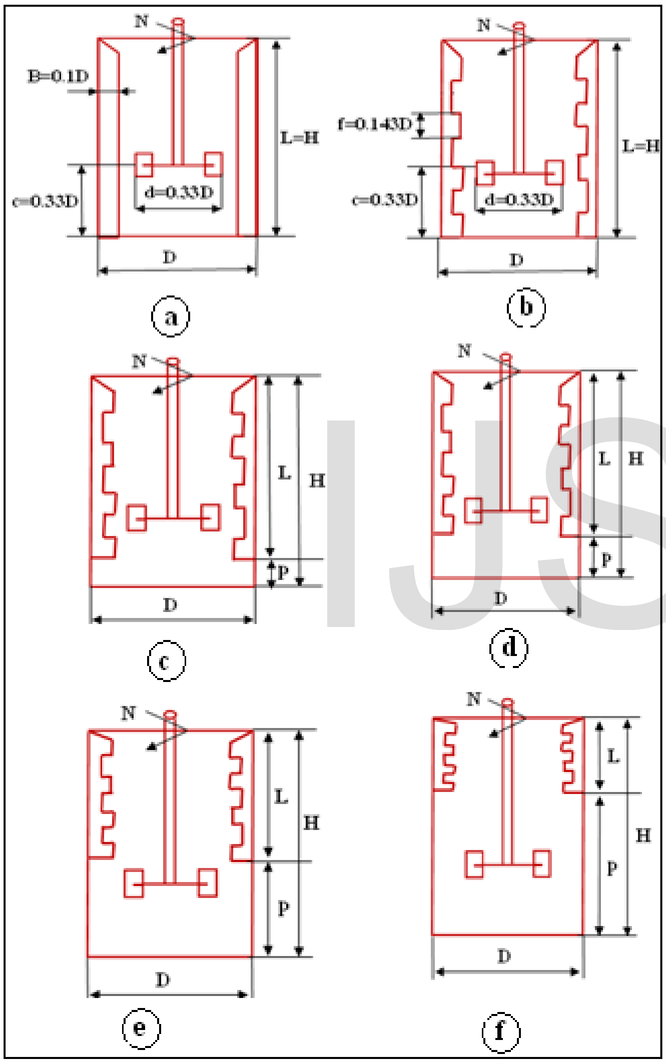


Fig. 1 Arrangement of planar baffles in the agitated vessel; (a) vertical baffles; for (b) to (f) baffles of four square teeth with (b) p/H=0; (c) p/H=0.17; (d) p/H=0.33; (e) p/H=0.5; (f) p/H=0.67.

Baffles called also against blades, these elements fixed at the level of the wall of the tank to avoid the formation of the vortex, induced by the centrifugal force due to the rotation of the agitator. The baffles have a rectangular form most of the time; in our study one changed this form with the shape of four teeth.

This document brings back a data-processing research on the hydrodynamics of cylindrical tank agitated by a turbine of Rushton. Our force was concentrated on the effects the height of baffle with four square teeth on the structures of flow and the power of energy. It relates to the effects of the baffles on the size of the vortexes.

2 MIXING SYSTEM

Effects of the shape of baffles in an agitated tank design are investigated in this paper by realizing two types of baffles: vertical baffles, baffles of four square teeth (Fig. 1.a and b). Each vessel is equipped by a Rushton turbine impeller (Fig. 2) which consists of six blades fixed on a disc with 3mm of thickness. All other parameters are listed in Table 1.The vessel of inner diameter D=0.6 m, filled with the tap water up to height H=D. Four planar baffles of width B=0.1D and different length L were mounted in the vessel with the flat bottom. As Fig.1 shows, the five series of the measurements were conducted for the L/H=1; 0.67; 0.5; 0.33; and 0.17 or p/H=0; 0.33; 0.5; 0.67; and 0.83. The Rushton turbine of diameter d=0.33D, placed at the height c=0.33D from the bottom of the vessel. The vessel was filled with pure water at room temperature 20°C, and dynamic viscosity of density 0.00089 kg/m.s. the numerical simulation was carried out within the turbulent regime of the fluid flow in the vessel (Re=3.10^4; 2.10^5).

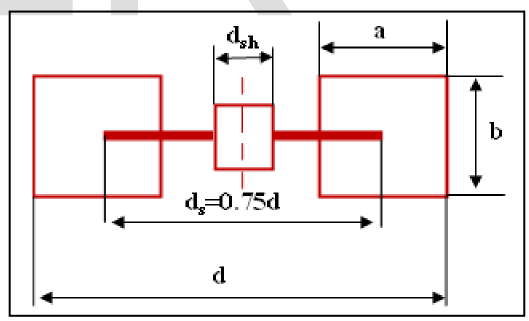


Fig. 2 Geometrical parameters of the Rushton turbine.

TABLE 1
GEOMETRICAL PARAMETERS OF THE AGITATORS USED

Agitator	d/D	a/d	b/d	d_s/d	d_{sh}/d
Rushton turbin	0.33	0 .25	0.2	0.75	0.2

3 MATHEMATICAL BACKGROUND

The conservation of the matter gives:

$$\nabla.\left(\rho u\right)=0$$

Where ρ is the density and u the speed.
The conservation of the momentum is written:

$$\nabla.\left(\rho u\otimes u\right)=\nabla.(\tau+-\rho\overline{u'\otimes u'})-\rho g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Where τ is the shear stress which gives by :

$$\tau=-p\delta+\mu(\nabla u+(\nabla u)^T)$$

The term $-\rho\overline{u'\otimes u'}$, called forced of Reynolds, is the product of the fluctuations speed.

The Reynolds number for flow in a stirred tank is given by the formula:

$$\mathrm{Re}=\frac{\rho ND^2}{\eta}$$

Where N is the wheel rotational speed blade, the η viscosity of the operating fluid.

The power consumption used for mixing, P, can be calculated using two methods. The first one integrates the viscous dissipation energy, Q_v, in the whole vessel volume:

$$P=\eta\int_{vessel\ volume} Q_v\,dv$$

The viscous dissipation energy is given by:

$$Q_v=2\left[\left(\frac{dv_r}{dR}\right)^2+\left(\frac{dv_\theta}{d\theta}\right)^2+\left(\frac{dv_z}{dZ}\right)^2\right]+\left[\frac{dv_r}{d\theta}+\frac{dv_r}{dR}\right]^2+\left[\frac{dv_\theta}{dZ}+\frac{dv_z}{d\theta}\right]^2+\left[\frac{dv_r}{dZ}+\frac{dv_z}{dR}\right]^2$$

The second methodology uses the torque, C, applied on the agitation system as given in the following equation:

$$P=2\pi NC$$

The power numbe, Np, leaves extrapolating power calculations when the diameter of the stirrer and of its speed of rotation N changes. The power number is defined by:

$$N_p=\frac{P}{\rho N^3 D^5}$$

4 NUMERICAL METHOD

The discretization of the flow domain (tetrahedral mesh) has been performed using ICEM- CFD, the CFD solver CFX 12.0, is used to obtain values for the velocity components and pressure at each of the node points. The solver uses a full finite volume formulation to solve the fully-coupled mass and momentum conservation equations. The flow fields are solved with a technique MRF (rotating frame of reference) Houari Ameur [23].

In this study, the Reynolds number is varying from 3.10^4 to 2.10^5. We have used a standard k-ε model is used for modeling the turbulent flow. The standard k-ε model is a semi-empirical model that solves the turbulent kinetic energy (k) and its turbulent dissipation (ε) for fully turbulent flow.

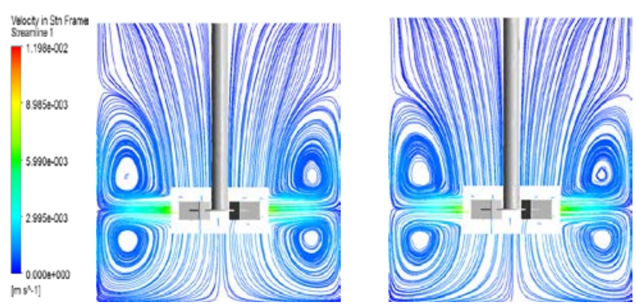
Results were considered converged when a lower level of residual, of the order of 10^{-4}, was reached and the field values were almost identical over the last 4000 iterations. The simulations were run on a Pentium Core i3 with 2 GB of RAM and a typical run time was 12 hours.

5 Results and discussion

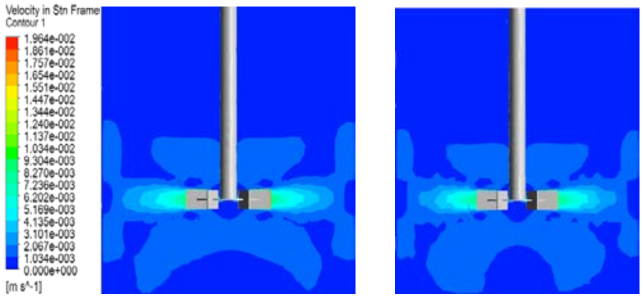
The consumption is a parameter important to describe the performances of a system of mixture; a numerical study was carried out to characterize the agitated cylindrical tank. Specifically, we are interested to determine the variation of the number of power according to the Reynolds number in the case of a baffled tank equipped with a standard turbine of Rushton. To check our results of computer, the figure Np of power were analyzed and compared with the number calculated starting from the code of CFD.

Figure 6 illustrates the number of power obtained in Newtonian fluid for Reynolds number ranging between 10^4 and 2.10^5. We use the same conditions and geometrical parameters. We validate our results of digital simulation of unbaffled cylindrical tanks with experimental result of Joanna Karcz, Marta Major [15]. Good agreement is fond between numerical and experimental values of the power number.

5.1 Effect of baffles shape



(a) ***(b)***

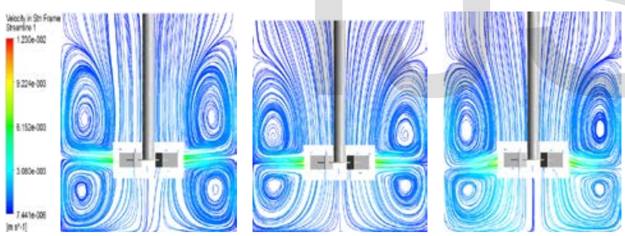


(a) *(b)*

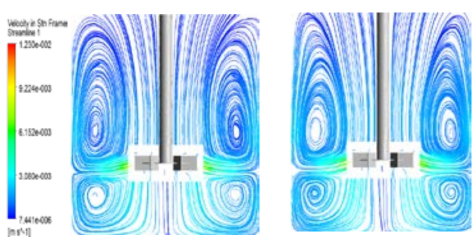
Fig. 3 Flow patterns for Re = 4.10^4: (a) vertical baffle, (b) baffle has four teeth.

Figure 3 present the flow patterns in a vertical plane containing the blade on the two vessels: vertical baffle (a) and baffle has four teeth with the same volume. It can be observed the presence of a radial jet on the level of turbine which changes against the walls of the tanks with two axial flows thus forming two zones of recirculation on the two sides of the turbine, the close zone to the turbine has a high speed that the other. The results are almost identical between the two types of baffles but the baffle with four teeth reduces the sizes of vortex (0.21m) that the vertical baffle (0.24m).

5.2 Effect of the baffle length



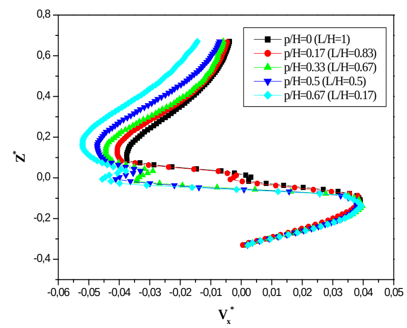
(a) *(b)* *(c)*



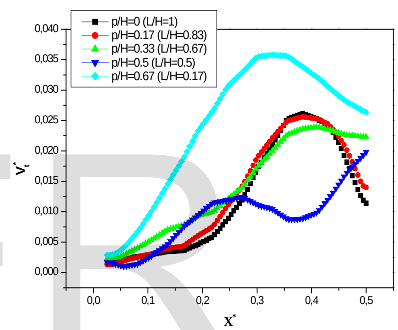
(d) *(e)*

Fig. 4 Current line of the baffles length, (a) p/H=0; (b) p/H=0.17; (c) p/H=0.33; (d) p/H=0.5; (e) p/H=0.67, Re = 4.10^4

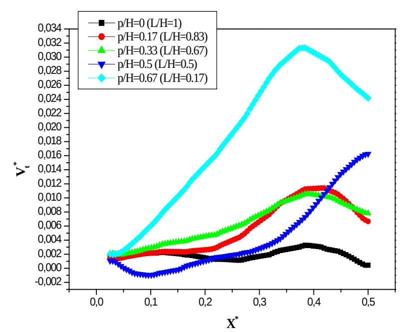
we studied the effect the height of baffle with four teeth on the characteristic hydrodynamics in agitated tank, figure 4 shows the threads of current in various cases length of baffle with (a) p/H=0 (0.21m); (b) p/H=0.17 (0.29m); (c) p/H=0.33 (0.26m); (d) p/H=0.5 (0.38m); (e) p/H=0.67 (0.39m), we notices a major reduction in the size of vortex in the cases (a), (b) and (c) on the other hand the others (d) and (e) an increase in vortex one notices one when the height of baffle decreases the size of vortex thus increases the best case it is (a) p/H=0.



(a)



(b)



(C)

Fig. 5 Velocity profiles for Re = 4.10^4, (a) Axial component at R* = 0.2 (b), (c) Tangential component at Z* = 0.25, 0.433.

The figure (5.a) represents the axial speed various the lengths of baffles studied (p/H=0; p/H=0.17; p/H=0.33; p/H=0.5; p/H=0.67) with Re=4.10^4 and R^*=0.2, in comparison between the various cases, we note that the velocity magnitude is very weak near the free surface of liquid for the vessel with length p/H=0 and p/H=0.17 and gradual increase for the others and maximum at the end of the blades, The minus sign of velocity indicates the existence of a recirculation zone. At the lower part of the vessel, the axial velocity magnitude is intense

At the vessel mid-height (Z* = 0, 25 and 0.433), the tangential velocity component is presented along the vessel radius for the various lengths of baffles of vessel (Fig. 5.b). We remark that the value tangential speed increases when one near the wall to the tank and when the length of baffle decreases

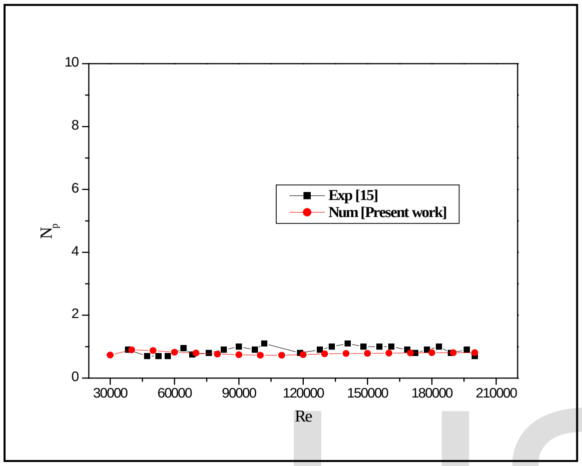


Fig. 6 Power characteristics Np=f(Re) for unbaffled vessels.

Figure (7, 8, 9, 10, 11) are a typical power consumption for agitated vessel with various length of baffles (p/H=0; p/H=0.17; p/H=0.33; p/H=0.5; p/H=0.67) for a vertical baffles and baffles with four square teeth. The x-axis is the Reynolds number as calculated by equation (Re). The y-axis is determined power number by the relation (Np).The plot indicates that at flow turbulent regime ($Re=10^4$ - 2.10^5), the power number varies with the Reynolds number. It can be seen from the plot, which as the Reynolds number is increased from early stages of turbulence to increasingly larger Reynolds numbers, the power number becomes constant. We remark a very significant reduction in the power consumed between the studied chicanes because the tank with baffle for four square teeth (Num (present work)) reduces the power consumption compared with the vertical baffled vessel for different lengths cases studied (Exp [15]).

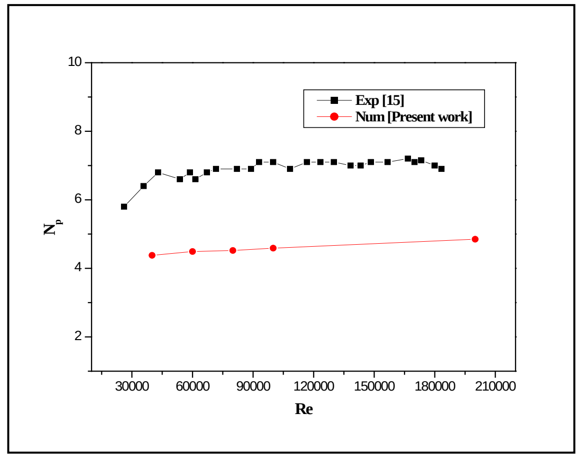


Fig. 7 Power characteristics Np=f(Re) for different baffles and p/H=0 (L/H=1).

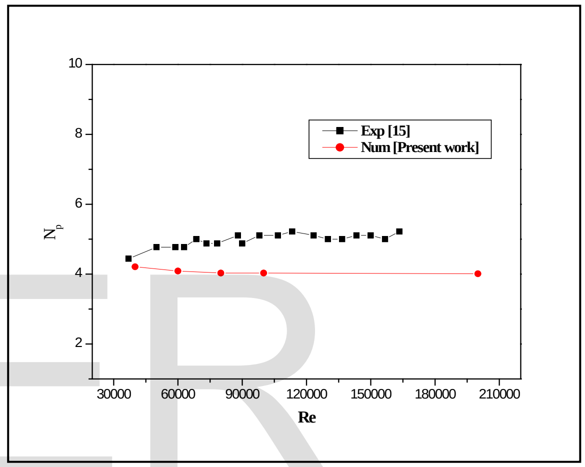


Fig. 8 Power characteristics Np=f(Re) for different baffles and p/H=0.17 (L/H=0.83).

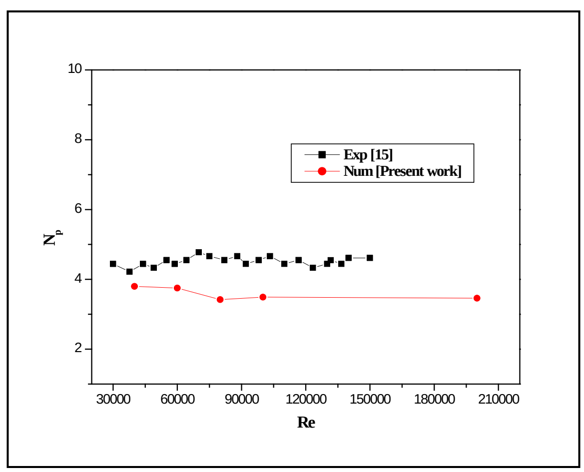


Fig. 9 Power characteristics Np=f(Re) for different baffles and p/H=0.33 (L/H=0.67).

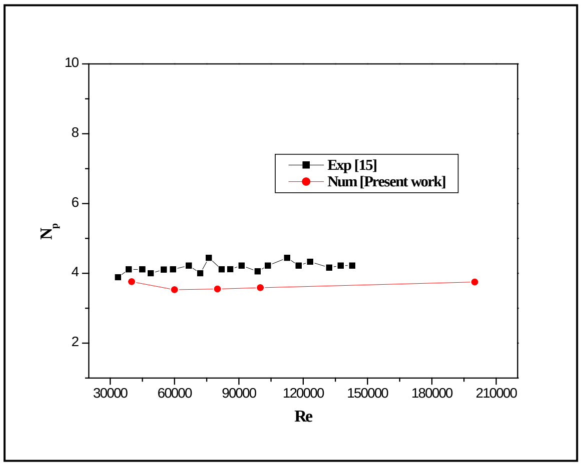


Fig. 10 Power characteristics Np=f(Re) for different baffles and p/H=0.5 (L/H=0.5).

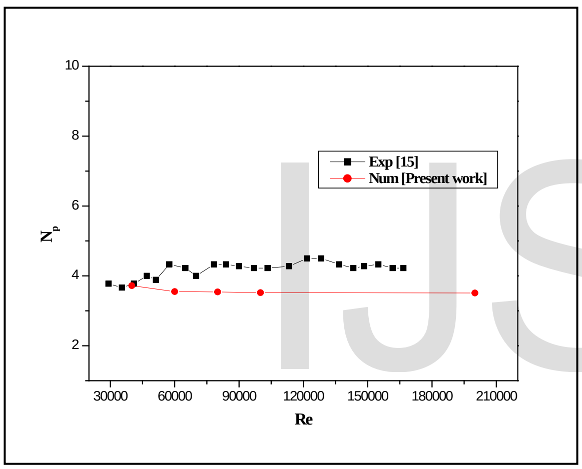


Fig. 11 Power characteristics Np=f(Re) for different baffles s and p/H=0.67 (L/H=0.33).

Table 2 shows the comparison of power numbers for the baffles length tested, we compare ours results (baffle has four teeth) with the experimental (vertical baffle), we remark when we using a vessel with baffle has four teeth can reduce the power consumption.

TABLE 2
COMPARISON OF POWER NUMBERS FOR THE BAFFLES LENGTH TESTED

	Re	p/H					
		0	0.17	0.33	0.5	0.6	1
		L/H					
		1	0.83	0.	0.5	0.33	0
		Np					
Exp. Joanna Karcz (1998)	10^5	6	5.10	4.42	4.28	4.20	0.86
Present work	10^5	4.59	4.03	3.49	3.59	3.52	0.81

6 CONCLUSION

The shape of four square teeth of the baffle has been studded with effect of the baffle length L on power consumption for an agitated vessel equipped by a Rushton turbine with six blades by using computational fluid dynamics with MRF method. A detailed comparison with experimental measurements is presented for power consumption between the simulation (baffles with four square teeth) and experimental results (baffle four vertical baffles). From our results, we deduced that the baffles has four teeth gives a significant reduction in power consumption.

Nomenclatures

a length of the agitator blade, m
B width of the baffles, m
b width of the agitator blade, m
c distance between agitator and bottom of the vessel, m
D inner diameter of the agitated vessel, m
d diameter of the agitator, m
d_s disc diameter, m
d_{sh} shaft diameter, m
f height of baffle has four teeth, m
g gravitational constant, m/s2
H liquid height in the vessel, m
L length of the baffle, m
N agitator speed, s^{-1}
Np power number, dimensionless
P power consumption, W
p distance between lower edge of the baffle and bottom of the vessel, m
Q_v viscous dissipation function, 1/s
R radial coordinate, m
Re Reynolds number, dimensionless
V velocity, m/s
V_z axial velocity, m/s
V_θ tangential velocity, m/s
V_r radial velocity, m/s
Greek letters
τ shear stress, Pa
ρ fluid density, kg/m^3
η viscosity, Pa s
θ

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