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Study about Flow Rate of the Impellers Used for Solid Particles Suspension Realization

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Abstract

A new mathematic model for the flow rate of the impellers with axial discharge was deduced due to the methods of dimensional analysis. Through experimental determinations the general calculation relation was particularized for the case of the six 45^o- pitched blade turbine. Research results are presented by graphics, depending of impeller's parameters: speed, diameter and width of blades. Experimental data are used for establishing a general relation of impeller flow rate, taking into account the liquid density and viscosity.

Key words: *mixing, agitation, impeller, flow rate, pitched blade turbine.*

Introduction

The resultant motion of liquid in a cylindrical vessel with rotational mechanical impeller can be decomposed in an axial flow, a radial flow and a tangential flow, in accordance to the rectangular system with the vertical axis in direction of the vessel revolution axis. Usually, in the aim of axial and radial flow intensification, is decreased the tangential current through the use of baffles [1]. Thus, the fundamental studies considering the mixing in vessels with baffles directed to the two types of impellers: impellers with radial discharging flow pattern and impellers with axial discharging flow pattern.

But apart from the circulation flow of liquid, it must be taken into account the turbulence which is created through the impeller action, this turbulence being characterized by highly cutting tensions. So, because the aims of mixing processes are very varied, the impeller must chose in such kind that to assure an optimum ratio between circulation and the turbulence [2, 3]. With this end in view, the impellers were classified depending on the size of ratio among the power number and the pumping number, N_p/N_q:

$$N_p = \frac{N}{\rho \cdot n^3 \cdot d^5}, \tag{1}$$

$$N_q = \frac{q}{n \cdot d^3}, \tag{2}$$

in which: q is the impeller's flow rate, n – speed of impeller, d – diameter of impeller, ρ – density of liquid and N – power input.

The impellers with a big value of ratio N_p/N_q are so called “cutting impellers”, for instance the disc-turbine and the impeller with six right blades which present a radial discharging flow pattern. The impellers with a small value of ratio N_p/N_q are so called “recirculation impellers”, for instance the propeller with six blades and the six 45^0 – pitched blade turbine which present an axial discharging flow pattern.

Many researchers [4, 5, 6] have shown that for solid particles suspending, mixers with downward axial discharge are more effective than upward axial discharge mixers or radial discharge mixers.

This observation leads to the conclusion that the suspension of solid particles is controlled by the movement and not by turbulence of environment. In other words, to obtain a stable suspension of solids is necessary a certain minimum speed to flow, intuitively linked to a solid particle settling velocity.

Although the experimental researches revealed that the propeller mixer showing the best features for operations to achieve suspensions of solid particles, in practice there is the tendency of replacing propeller with blades inclined impellers, because their construction is less complicated. Some authors place the impellers with inclined blades among the so – called “mixed impellers”, which generates both axial and radial flow patterns; however for an angle of blade inclination lower than 45^0, the radial flow is insignificant [7, 8].

Theoretical Considerations

The purpose of this paper is to establish a relationship for calculating the axial flow rate of the six 45^o- pitched blade turbine. We chose this type of impeller because, as seen in the above, has a simple construction and at the same time has high performances in the processes of achieving the suspensions of solids particles.

Because of the complexity of hydrodynamic process which is in progress in vessels with mechanical mixing devices, the deduction of the mathematical model has been realized with help of the conventional method of dimensional analysis, completed then through experimental determinations.

Thus, faithful to the Buckingham method, which is based on the produces theorem, anything complete relation:

$$f\left(A_1, A_2, A_3 \dots A_p\right) = 0 \tag{3}$$

between the physical sizes $A_1, A_2, A_3 \dots A_p$ which cause a phenomenon, can be written in the form:

$$\varphi\left(\pi_1, \pi_2, \pi_3 \dots \pi_{p-m}\right) = 0 \tag{4}$$

or

$$\pi_1 = k \cdot (\pi_2)^a \cdot (\pi_3)^b \dots \left(\pi_{p-m}\right)^r, \tag{5}$$

where $\pi_1, \pi_2, \pi_3 \dots \pi_{p-m}$ are dimensionless produces, free between them, realized with sizes A_1, A_2, A_3… A_p, and m is the degree of dimensional matrix.

Taking into account the results published in the specialty literature it can be asserted that the parameters which can influence the flow rate of the impellers with radial discharging flow pattern are: n –speed of impeller, d - diameter of impeller; h – impeller’s width of blades, μ - dynamic viscosity of working liquid; ρ - density of working liquid; g – gravitational acceleration.

Among these parameters it was not included the number of blades of the impeller, because the researches were limited about impellers with six blades. So, taking into account the parameters which can influence the studied phenomenon the following dimension matrix can be formed:

	q	*d*	*h*	*n*	*μ*	*ρ*	*g*
L	3	1	1	0	-1	-3	1
M	0	0	0	0	1	1	0
T	-1	0	0	-1	-1	0	-2

(6)

The degree of matrix is m = 3, because the determinant of the three order formed of the elements of the columns 5, 6 and 7 is non-zero. As initial sizes are selected μ, ρ and g, and on their basis we drew up the four one dimensionless produces (p- m= 7-3 =4):

$$\begin{aligned}\pi_1 &= \mu^{a_1} \cdot \rho^{b_1} \cdot g^{c_1} \cdot q \\ \pi_2 &= \mu^{a_2} \cdot \rho^{b_2} \cdot g^{c_2} \cdot d \\ \pi_3 &= \mu^{a_3} \cdot \rho^{b_3} \cdot g^{c_3} \cdot h \\ \pi_4 &= \mu^{a_4} \cdot \rho^{b_4} \cdot g^{c_4} \cdot n\end{aligned} \tag{7}$$

Further on, for the determination of exponents of dimensionless produces it is necessary to obtain first the dimensional equations:

$$\begin{aligned}L^0M^0T^0 &= L^{-a_1}M^{a_1}T^{-a_1}L^{-3b_1}M^{b_1}L^{c_1}T^{-2c_1}L^3T^{-1} \\ L^0M^0T^0 &= L^{-a_2}M^{a_2}T^{-a_2}L^{-3b_2}M^{b_2}L^{c_2}T^{-2c_2}L \\ L^0M^0T^0 &= L^{-a_3}M^{a_3}T^{-a_3}L^{-3b_3}M^{b_3}L^{c_3}T^{-2c_3}L \\ L^0M^0T^0 &= L^{-a_4}M^{a_4}T^{-a_4}L^{-3b_4}M^{b_4}L^{c_4}T^{-2c_4}T^{-1}\end{aligned} \tag{8}$$

and the final forms of dimensionless produces are:

$$\begin{aligned}\pi_1 &= \mu^{-\frac{5}{3}} \cdot \rho^{\frac{5}{3}} \cdot g^{\frac{1}{3}} \cdot q \\ \pi_2 &= \mu^{-\frac{2}{3}} \cdot \rho^{\frac{2}{3}} \cdot g^{\frac{1}{3}} \cdot d \\ \pi_3 &= \mu^{-\frac{2}{3}} \cdot \rho^{\frac{2}{3}} \cdot g^{\frac{1}{3}} \cdot h \\ \pi_4 &= \mu^{\frac{1}{3}} \cdot \rho^{-\frac{1}{3}} \cdot g^{-\frac{2}{3}} \cdot n\end{aligned} \tag{9}$$

Taking into account the expressions (9), the relation (5) becomes:

$$\frac{q\rho^{\frac{5}{3}}g^{\frac{1}{3}}}{\mu^{\frac{5}{3}}} = k \cdot \left(\frac{\rho^{\frac{2}{3}}g^{\frac{1}{3}}d}{\mu^{\frac{2}{3}}}\right)^a \cdot \left(\frac{\rho^{\frac{2}{3}}g^{\frac{1}{3}}h}{\mu^{\frac{2}{3}}}\right)^b \cdot \left(\frac{\mu^{\frac{1}{3}}n}{\rho^{\frac{1}{3}}g^{\frac{2}{3}}}\right)^a \tag{10}$$

whence it results, finally, the relation of calculus for the radial flow rate of impellers:

$$q = k \cdot d^a \cdot h^b \cdot n^c \cdot \mu^e \cdot \rho^f \cdot g^i, \tag{11}$$

where

$$e = \frac{-2a - 2b + c + 5}{3};\ f = \frac{2a + 2b - c - 5}{3};\ i = \frac{a + b - 2c - 1}{3}. \tag{12}$$

Experimental Procedure

The relation (11) represents the general expression of flow rate for the impellers with axial discharging flow pattern, which is the same for all type of impellers. The particular forms of this relation depend on values of coefficient k and of exponents a, b, c, e, f and i, which will be experimentally determinated for the researched type of impeller, respectively the six 45°-pitched blade turbine (fig. 1).

In order to achieve this aim the experimental set-up shown in Figure 2 has been used. As it can be seen, the impeller has been positioned on the bottom of the draft tube 2. Thus, the impeller can be powered only by the pipe 6 and the fluid from draft tube is pumped in the vessel 5 and then, is collected in the gutter 3.

The purpose of the experimental researches has been the identification of influence for all parameters from relation (11) about the axial flow rate of impeller. Thus, the speed of impeller, the impeller's diameter and the width of blades were varied, but in the same time the others parameters were maintained constantly. The flow rate of liquid pumped of the impeller is determined measuring the volume of liquid evacuated through the pipe 4 in the clock unit.

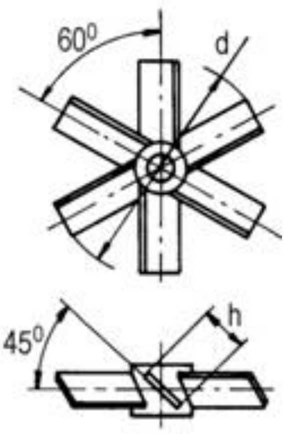

Fig. 1. The six 45°- pitched blade turbine.

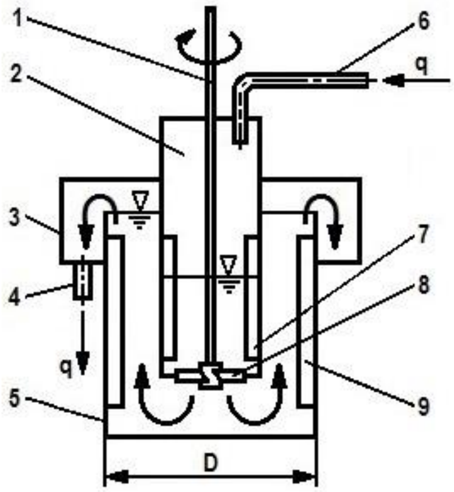

Fig. 2. Experimental set-up: 1- impeller's shaft; 2- draught tube; 3- gutter; 4- drain pipe; 5- vessel; 6- supplying pipe; 7- baffles; 8- impeller; 9- baffles.

In the frame of experimental determinations five constructive variants of impeller have been used, presented in Figure 2, with the width of blades h = 15, 20 and 25 mm and with the diameters $d = D/4$, $D/3$ and $D/2$; the diameter of vessel D = 250 mm. The values determinated on this path were represented in the charts, in logarithmic coordinates, as shown in Figures 4-6.

Results and Discussions

The graphical processing of results from diagrams presented in Figures 3-5, put in evidence the following proportionality relations:

$$q \sim n;\ \ q \sim d^3;\ \ q \sim h. \tag{13}$$

In this way has been founded the exponents a, b and c from the relation (11): a = 3; b = 1; c = 1; the others exponents can be deduced with the help of equations (12): e = –0.666; f = 0.666; i =0.333. Through the assemblage of results it is obtained the following relation:

$$q \sim n \cdot d^3 \cdot h \cdot g^{0.333} \cdot \left(\frac{\rho}{\mu}\right)^{0.666}. \tag{14}$$

Confronting the experimental results with the values obtained through the application of relation (14), we arrived at the conclusion that the average value of coefficient k is 7.5 10^{-4}. Thus, the final form of this equation is:

$$q = 7.5 \cdot 10^{-4} \cdot n \cdot d^3 \cdot h \cdot g^{0.333} \cdot \left(\frac{\rho}{\mu}\right)^{0.666}. \quad (15)$$

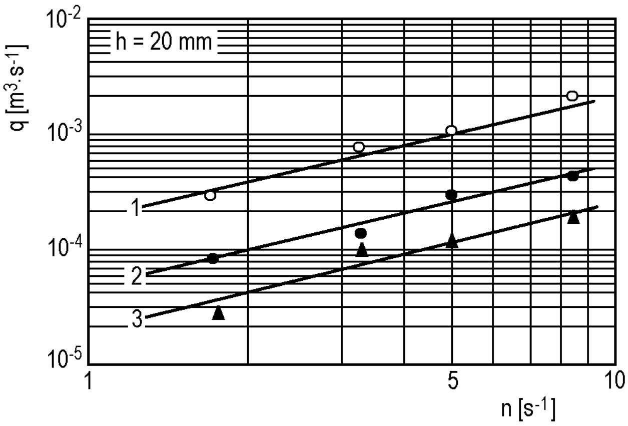

Fig. 3. Influence of impeller's speed about axial flow rate of six 45°- pitched blade turbine: 1 - *d* = *D*/2; 2 - *d* = *D*/3; 3 - *d* = *D*/4.

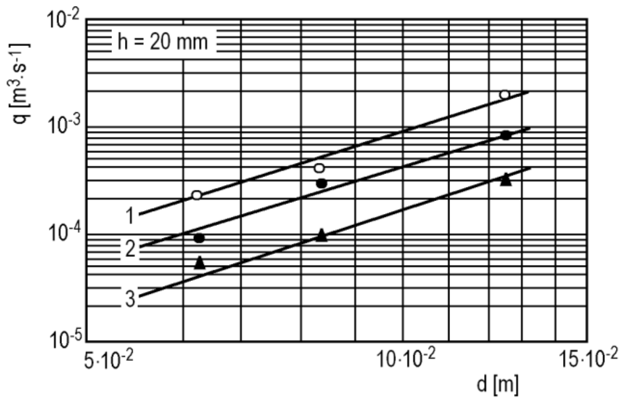

Fig. 4. Influence of impeller's diameter about axial flow rate of six 45°- pitched blade turbine: 1 - *n* = 500 rot/min; 2 - *n* = 300 rot/min; 3 - *n* = 100 rot/min.

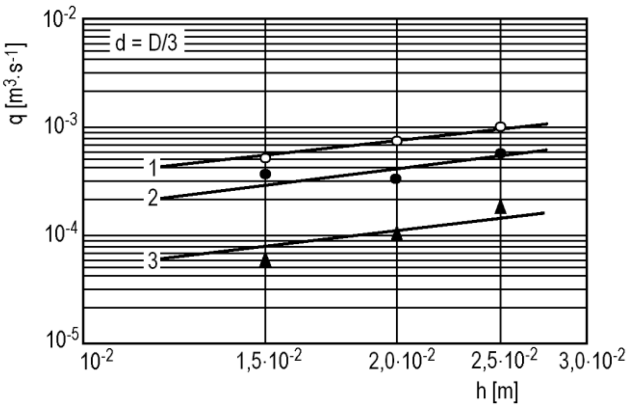

Fig. 5. Influence of blade's width about axial flow rate of six 45°- pitched blade turbine: 1 - *n* = 500 rot/min; 2 - *n* = 300 rot/min; 3 - *n* = 100 rot/min.

Conclusions

Based on the strength of the methods of dimensional analysis, we deduced a new mathematical general model for the flow rate of impellers with axial discharge [relation (11)]. With the help of experimental determinations this general relations were personalized for the case of six 45^o-pitched blade turbines [relation (15)].

It must be specified that the relation proposed is valuable only if the conditions of geometrical similitude are respected, as well as the scale-up rules, in the case of its applications to industrial equipment.

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Studiu privind debitul amestecătoarelor folosite pentru realizarea suspensiilor de particule solide

Rezumat

Cu ajutorul analizei dimensionale, a fost dedus un nou model matematic pentru debitul amestecătoarelor cu refulare axială. Prin determinări experimentale, relația generală de calcul a fost particularizată pentru cazul amestecătorului cu șase brațe înclinate la 45^0. Rezultatele cercetării sunt prezentate sub formă grafică în funcție de parametrii amestecătorului: turație, anvergură și lățimea brațelor. Datele experimentale sunt folosite pentru stabilirea relației generale de calcul a debitului amestecătorului, ținând cont de densitatea și vâscozitatea lichidului.