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Investigating the impact of drilled impellers design of rotodynamic pumps on the efficiency of the energy transfer process

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ABSTRACT

Drilled impellers represent an alternative approach to the construction of impellers of centrifugal pumps, operating within the specific speed of nq < 10. Their construction is very simple and can be achieved by employing machining methods. This paper presents the impact of the basic construction parameters of drilled impellers on the efficiency of the process of energy transfer into liquid. The main focus is on testing the efficacy of using additional side holes. The main testing method involves computational fluid dynamics (CFD) simulations. The selected impeller constructions are made with the SLS (rapid prototyping) method and tested with a test rig. The paper presents a comparison of numerical and experimental results. Based on the obtained results the author makes recommendations on the construction of drilled impellers.

1. Introduction

The chemical industry often requires the use of pumps with very low specific speed (nq < 10), operating with a relatively low flow rate ($Q < 10\,m^3/h$). For such parameters, classical rotodynamic pumps with centrifugal impellers are rarely used due to very low efficiency (Fig. 1) [1], which normally does not exceed 40%. Drilled impellers, where passages are created by drilling holes in the solid body of the impeller, represent an alternative to standard centrifugal impellers (Fig. 2). Such constructions are known and described in the literature [2,3] but it is hard to find information on design or the flow phenomena inside the structures. Certain results and recommendations on the impact of construction features of drilled impellers on the energy transfer process can be found in some papers by the present author [4] leads to the version of a standard drilled impeller presented in Fig. 2. This solution allows for a more uniform distribution of velocity and pressure along the circumference of the impeller outlet area, and therefore provides better working conditions for the pump stator, which should result in improved efficiency.

In order to design drilled impellers in a conscious and sensible way, one should ask how individual construction features of the impeller impact the achieved operating parameters and efficiency. This paper presents the influence of key geometrical parameters of a drilled impeller on the achieved operating parameters (total head H) and hydraulic efficiency η_h. The main intentions of the project, however, were to verify the efficacy of using additional side holes in drilled impellers, to identify the flow phenomena in such impellers and to stipulate the rules of their design. The applied methodology involved CFD flow analyses and experimental tests on impeller models made with a 3D print method.

2. Impact of construction features

A standard drilled impeller has a very simple construction and can be made by machining (turning + drilling). The geometry of the passages can be basically described with the following two parameters (Figs. 2 and 5):

1. Number of passages z. This parameter impacts the diameter of the passages d_m. If the total outlet area A_o = const., when the number of passages is reduced, their diameter is increased, or when the number of passages is increased, their diameter is reduced.
2. The angle of inclination of the passages γ. The parameter mainly determines the inlet angle β_1.

The paper [5] presents the results of analyses of the impact of the aforementioned parameters on the efficiency (η) and head (H) of drilled impellers. These results can be summarized with the following construction recommendations:

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Nomenclature

A_o impeller inlet cross-section (m^2)
d_m diameter of main passages (mm)
d_a diameter of impeller side passages (mm)
e_H relative error of the discretization for head (%)
e_M relative error of the discretization for momentum (%)
H total pump head (m)
g gravity (m/s^2)
M_t total moment on the internal surfaces of the impeller passages (Nm)
n rotational speed (rpm)
n_q kinematic specific speed (rpm)
p_{co} total pressure in the pump outlet section (Pa)
p_{ci} total pressure in the impeller inlet section (Pa)
P_h hydraulic power (W)
P_w power on a pump shaft (W)
Q flow rate (m^3/h)
z number of the main passages
z_a number of the side passages
β_1 inlet angle of the main passage (deg.)
β_2 outlet angle of the main passage (deg.)
β_{1a} inlet angle of the side passage (deg.)
β_{2a} outlet angle of the side passage (deg.)
γ angle of inclination of the main passage (deg.)
γ_1 angle of inclination of the side passage (deg.)
η total efficiency
η_h hydraulic efficiency
η_v volumetric efficiency
η_h mechanical efficiency
ρ density
ω angular speed (rad/s)

- The optimum number of passages is four. Further increasing of the number of passages results in reducing the flow diameter d_m, and leads to a resultant increase in the resistance of flow. A reduction in the number of passages to less than four causes a more non-uniform velocity in the stator and leads to a decrease in the efficiency.

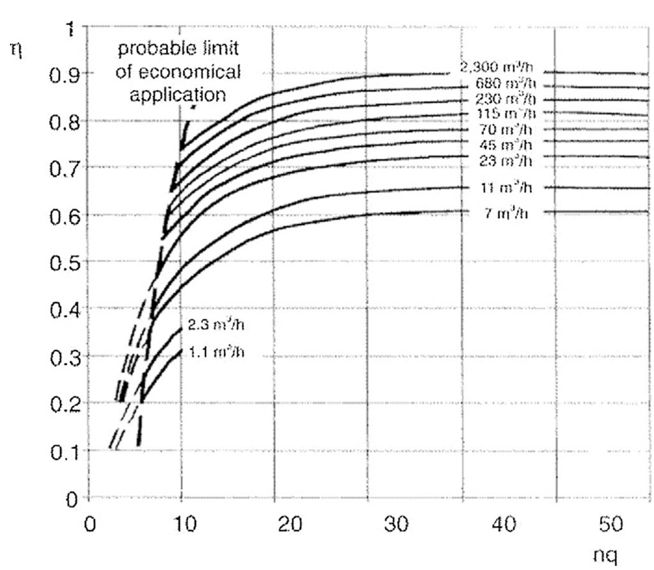

Fig. 1. Relationship between the efficiency of rotodynamic pumps and specific speed and flow rate [1].

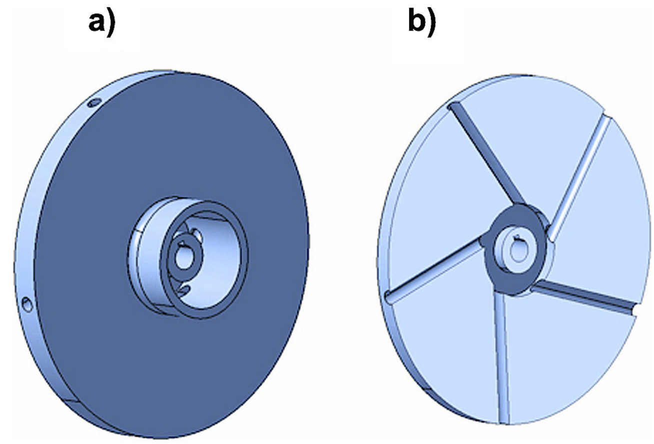

Fig. 2. Drilled impeller: (a) overview and (b) cross-section with the plane perpendicular to the impeller axis of rotation.

- The optimum angle of inclination of the passages γ is the angle that results in the inlet angle β_1 value between 40 and 50°. Research concerning the impact of the inlet angle on the parameters of centrifugal pumps impellers has revealed a positive impact of large inlet angles within the range of low specific speed values [7,8]. The optimum values of inlet angles are however slightly lower for drilled impellers than for traditional blade impellers.

Experimental tests on drilled impellers in the configurations five passages and four passages confirmed the abovementioned recommendations. The tests were carried out with a test rig described in detail in Ref. [9]. The impellers were made using the rapid prototyping SLS (selective laser sintering) method. The measurement results are presented in Fig. 4.

Analysing Fig. 4, one can claim that a reduction in the number of passages has hardly any impact on the course of the flow characteristics $H = f(Q)$, while it has a positive impact on the efficiency improvement, which confirms the abovementioned recommendations.

3. Impact of extra side holes on a drilled impeller operation

In [6], one can find an interesting concept of a drilled impeller construction, namely adding some extra side holes, which

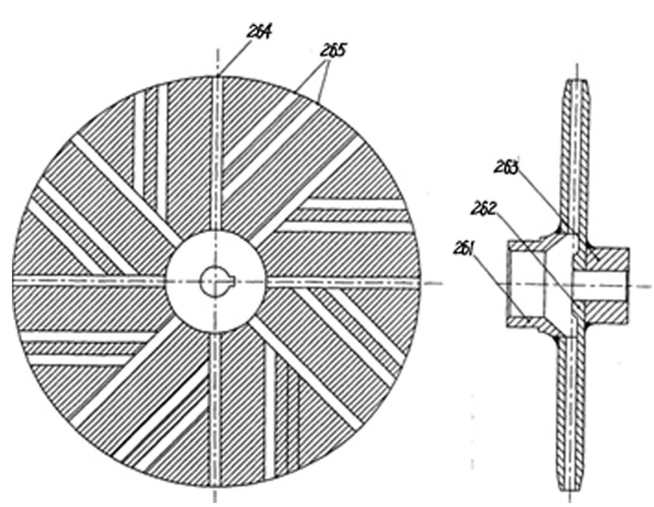

Fig. 3. Drilled impeller with additional side holes [6].