IOP Conf. Series: Materials Science and Engineering **233** (2017) 012009 doi:10.1088/1757-899X/233/1/012009

Centrifugal pump's impeller optimization using methods of calculation hydrodynamics

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Abstract. The paper features the results of the fluid flow calculation in the channels of varying geometry of the centrifugal pump for the service water in the methanol production chain. Modeling of the flow in ANSYS CFX allowed developing recommendations on adjusting the impeller's profile, significantly decrease the cavitation wear and increase the lifetime by several times.

1. Introduction

The rotational machinery (pumps, compressors, expanders, ventilators, etc.) is the most widespread type of the technical systems, on which the reliability, lifetime expectancy, various technical and economical characteristics, and energy efficiency of the systems in question depend. Given that presently energy, oil, chemical and metallurgical branches of industry are the basic components of the economy of the Russian Federation, the solution of the problem of energy efficient pumps development with active control and high operational characteristics is a quite urgent problem. In order to solve it, either new technologies and techniques have to appear or the existing have to be modernized, which in its turn requires development of the new generation pumps. The present political situation leads to a necessity of replacing the imported pumping equipment used in oil and gas, chemical, metallurgical, pharmaceutical industries. Untimely shortage of imported equipment and its parts can lead to a rapid increase in the number of emergencies and to a decrease in the industrial power. Impossibility of buying new parts from abroad leads to the necessity of import substitution in order to timely repair and replace the parts, which can no longer be bought from the foreign suppliers. Using the example of a pump by 'Egger' (Switzerland) which is installed at the LLC 'Schekinazot' as a part of the drainage cycle of methanol production, a comparative analysis of the technical and economic prospects of import substitution will be given. The price of an imported pump is 5 million RUB; average lifetime is 3 months due to the cavitation wear of the impeller (Figure 1). The price of the parts, i.e. impeller itself, fluid-film bearing and the sealing, is around 3 million RUB. Downtime is unacceptable because its cost in terms of methanol production per day is 6.0 million RUB. It is suggested to optimize the impeller's profile in order to increase the cavitation margin and accordingly the lifetime expectancy up to 10-12 months.

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(a) (b)

Figure 1. General view of the impeller of the Egger's pump before (a) and after 3 months of operation (b).

2. Flow modelling of the original impeller

For the studied model of the centrifugal impeller a 3D model of the flow part was developed (Figure 2).

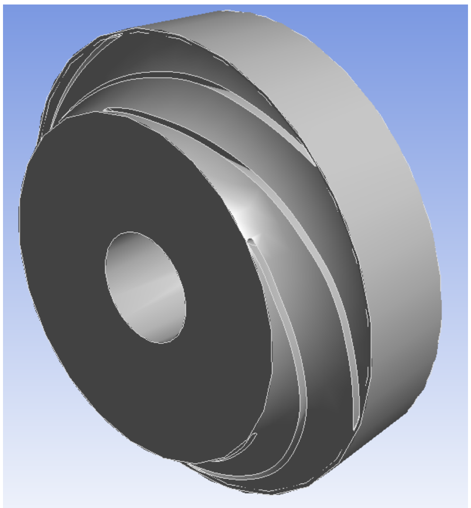


Figure 2. Model of the impeller's flow part.

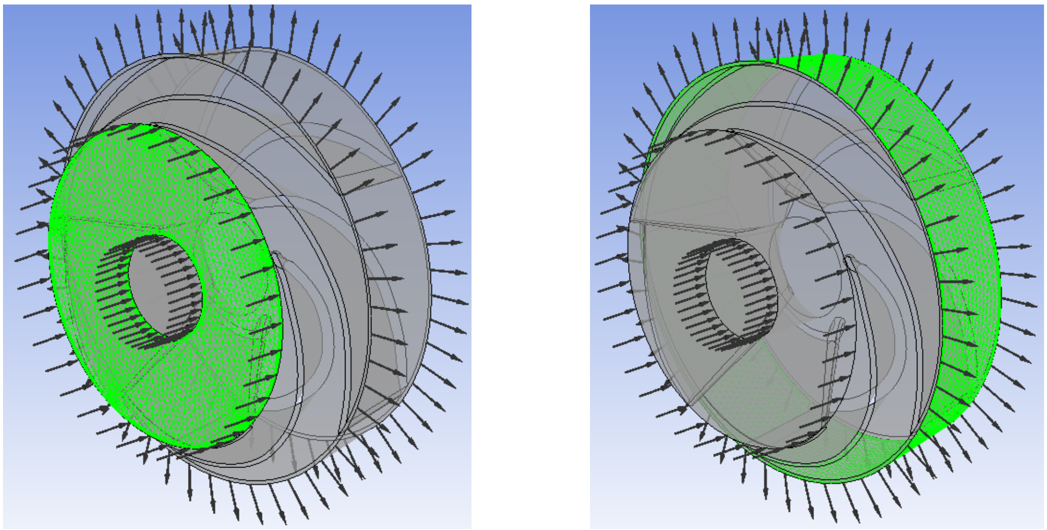
The fluid flow modeling in the impeller was implemented using the numerical solution of the Navier-Stokes differential equations [1]. The method of finite elements was used, which is realized in the CFD software ANSYS CFX. The first step was to analyze flow of the fluid with the following parameters through the impeller:

− fluid density 997 kg/m^3;
− dynamic viscosity 0,0008899 Pa·s;
− angular velocity 1450 rev/min.

The following boundary conditions were used during the calculations:

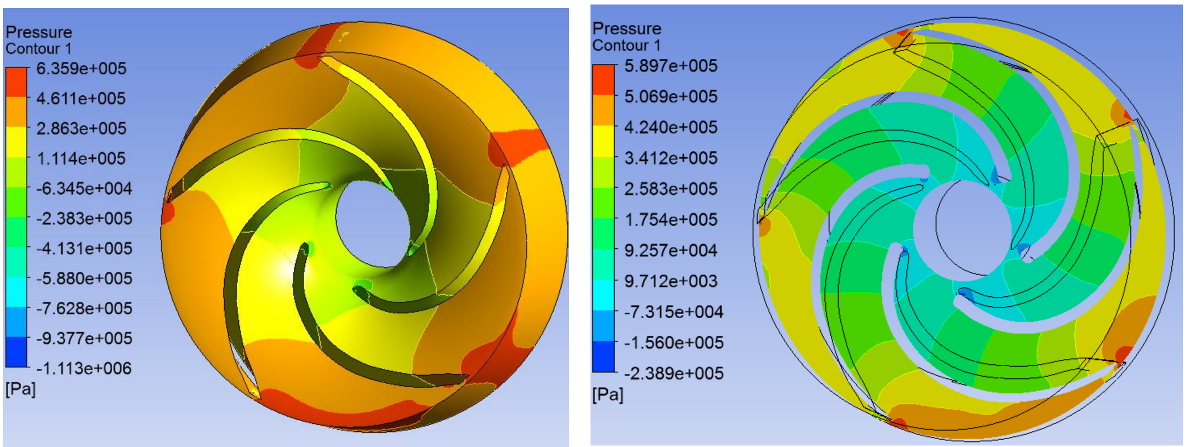
− input relative overpressure (Figure 3(a)) 1 kPa;
− output mass flow (Figure 3 (b)) 1000 kg/s.

The standard k-ε turbulence model was used in the calculations. As a result of the calculation, the pressure in the impeller was 52.38 m. To evaluate the possibility of cavitation excitation the pressure distribution was obtained (Figure 4), the analysis of which showed, that in the area of the blades the cavitation is indeed expected, since these are areas of under pressure.



(a) (b)

Figure 3. Boundary condition: (a) input boundary condition; (b) output boundary condition.



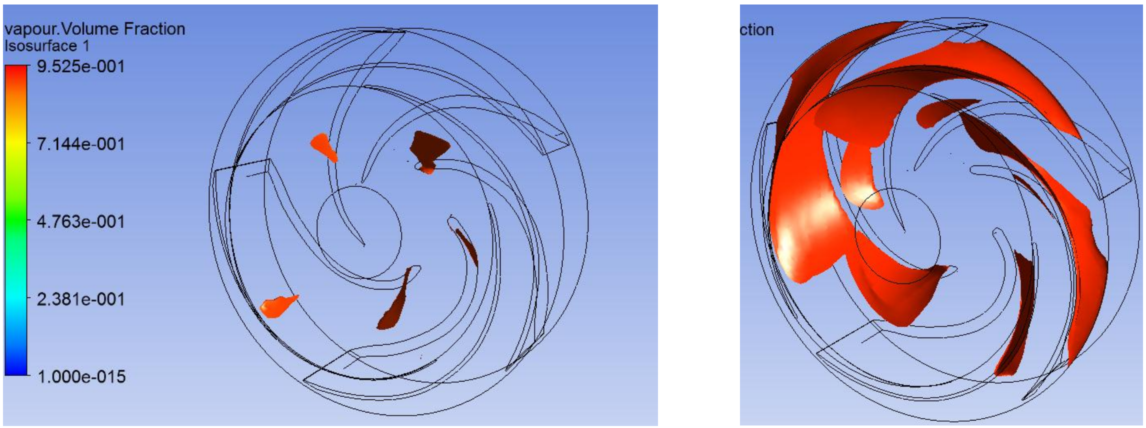
(a) (b)

Figure 4. Pressure distribution on the impeller: (a) impeller's model; (b) cross-sectional area.

In order to study the possibility of cavitation excitation a two-phase fluid flow was analyzed. With the saturated vapor pressure of 3.2 kPa and relative overpressure of 0.1 MPa, average pressure on the impeller is 51.18 m, which indicates the absence of cavitation. This assumption is based on the distribution of volumetric gas content (Figure 5 (a)). However, with the decrease of the pressure to 0.08 MPa the average pressure in the impeller would be 30.11 m, which indicates a cavitational disruption. This assumption is also proven by the distribution of volumetric gas content (Figure 5 (b)). On the basis of the calculation experiments the conclusion can be made that the original impeller of the pump provides the acceptable operation characteristics only in case of the cavitational margin of 10 atm., but with smaller values the impeller is exposed to a significant wear of the impeller's blades.

3. Flow modelling in the modified impeller

The modified profile of the blades of the impeller (Figure 6) is different from the original in oncoming angles, number of blades and the closed design of the impeller. The parameters and the procedures of the calculation experiments are similar to the calculations for the original impeller. According to the results, the average pressure in the modified impeller is 56.44 meters, which is comparable to the original impeller.



(a) (b)

Figure 5. Isosurfaces of the volumetric gas content.

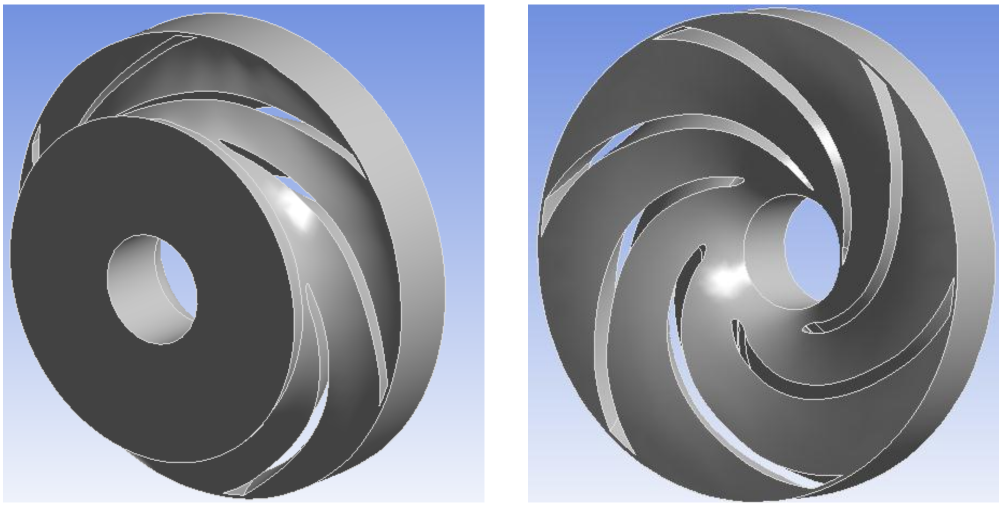


Figure 6. Geometry of the flow area of the modified impeller.

In the Figure 7 the pressure distribution is shown, and it is clear that in a small area on the beginning of the blades there are areas with high disruption and possible cavitation.

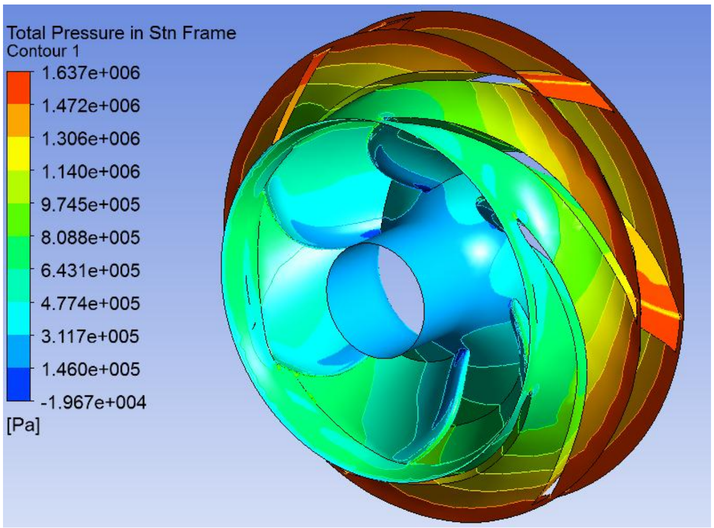


Figure 7. Pressure distribution on the modified impeller.

When analyzing the two-phase fluid flow in the modified impeller it was obtained, that the average absolute pressure on the input is 2.47831 atm., and the average pressure in the impeller is 56.42 m. This indicates the absence of the significant cavitational occurrences, as the drop of the pressure is less than 3% (3% is a widely used value to determine the cavitation tear). This assumption is proved with the distributions of pressure and volumetric gas content (Figure 8).

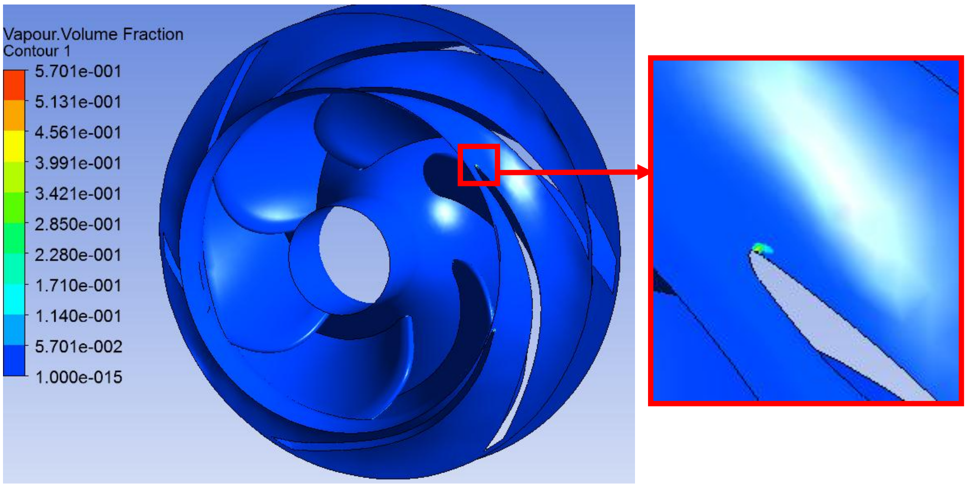


Figure 8. Volumetric gas content distribution.

When the output absolute pressure on the exit drops to 4.8 atm. The absolute pressure on the inlet is 73742 atm., and the average pressure is 55.80 m, which indicates the absence of significant cavitation, as the pressure drop is also less than 3%. This assumption is based on the pressure and volumetric gas content distributions (Figures 9 and 10).

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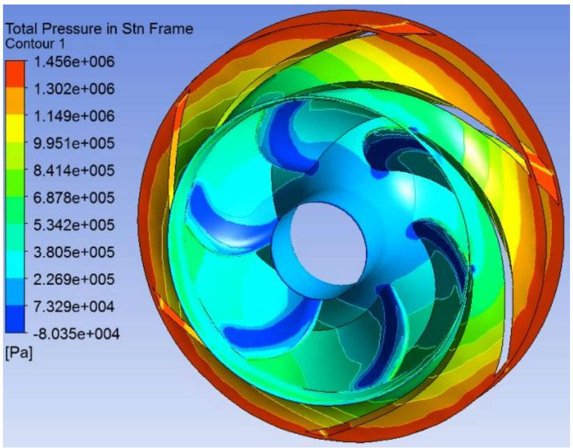

Figure 9. Pressure distribution.

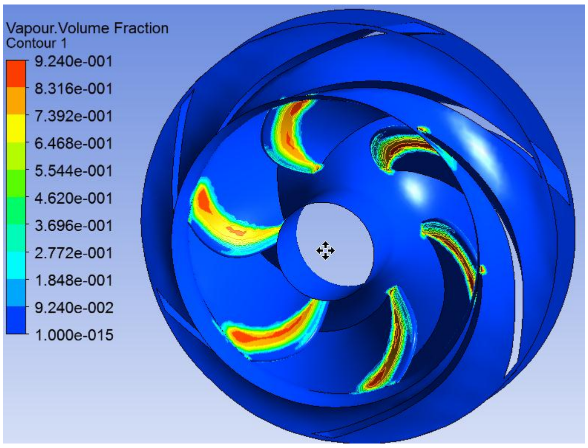

Figure 10. Volumetric gas content distribution.

4. Conclusions

So, it can be concluded, that the modified impeller provides better operational characteristics even with the cavitational margin around -0.26 atm., i.e. with the possibility of suction from the depth 2.6 m. Generally the modified impeller outraces the original design from the point of view of the operational parameters and cavitational margin.

References

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