Journal of Energy, Mechanical Engineering and Transport
Volume 1 (2024), Issue 3, 41-46

https://doi.org/10.51301/jemet.2024.i3.08

Determination of centrifugal pump efficiency based on cradle cad evaluation experiment

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Abstract. Kazakhstan is a country with a significant resource base, a favorable location and a unique opportunity to supply fossil fuels to Europe and to dynamically developing Asian markets, including China. The article provides brief information on the indicators of pipeline transport in Kazakhstan. The development of energy conservation determines the importance of improving the efficiency of equipment that uses most of the energy consumed. Pumping equipment is one of the most significant consumers of electrical energy. In Kazakhstan, the share of the transport component in the cost of production is large. Kazakhstan's commitment to sustainable development goals creates the need for more economical energy consumption. As a rule, a sixth of the cost of oil transportation is the cost of electricity, which is spent on driving pumping equipment. Therefore, work on the creation of energy-efficient pumps is relevant. The paper proposes a new impeller configuration (with variable vane curvature) for double suction centrifugal pumps with higher efficiency. The head and efficiency of the centrifugal pump were compared with different vane screens. The proposed changes in the design of the centrifugal pump result in an increase in static pressure and relative velocity, which leads to an increase in hydraulic and overall efficiency, and the kinetic energy of turbulence reduces its pulsation. At the same time, the operating point of the pump is shifted towards a decrease in supply by 1.5%.

Keywords: *main pipelines, oil transportation, centrifugal pump with double suction wheel*.

1. Introduction

Global energy demand will continue to grow in the long term due to improving living standards in developing countries. But the market expects a significant change in the structure of energy demand due to a decrease in the role of hydrocarbon energy sources and an increase in the share of renewable energy sources. In the long term, the undisputed dominance of fossil fuels will remain, the share of oil and gas in the global consumption of primary energy will remain practically unchanged (53.6% in 2010 and 51.4% by 2040). [2].

According to the World Energy and Climate Statistics published by Enerdata in 2024, harmful emissions from the burning of fossil fuels continue to rise. In 2023, a new record was recorded for the number of CO2 emissions generated from the combustion of fossil sources, in the amount of 34626 million tons. The distribution of CO_2 emissions by fossil fuel is as follows: 47% of total CO_2 emissions are emitted from coal combustion; oil products – 31%; Gas accounted for 22% of emissions [3].

Crude oil production in 2023 increased by 1%, with production growth in the United States, Brazil and Iran offsetting production cuts by OPEC+ countries. The leading position in terms of fossil fuel production is occupied by oil (39% of total production). Figure 1 shows the ranking of countries with the highest oil production. Kazakhstan occupies the 13th position in this rating.

Based on the analysis of statistical data and forecast estimates, it can be concluded that pipeline transport will be further developed. Kazakhstan's pipeline transport infrastructure plays a key role in the country's economy, ensuring the transportation of oil both to the domestic market (31%) and for export (69%). The main routes include the Atyrau-Samara, Atasu-Alashankou and Kenkiyak-Kumkol oil pipelines. These pipelines connect major oil fields to refineries and export terminals.

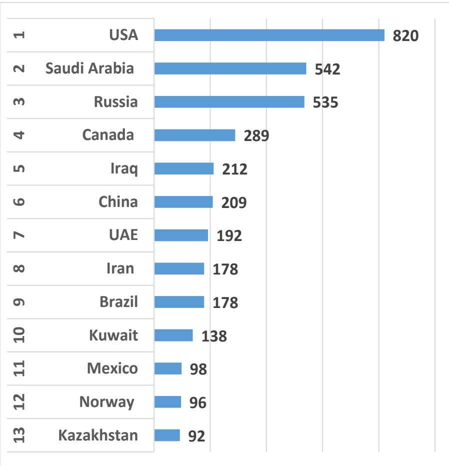


Figure 1. Ranking of countries with the maximum oil production in 2023 (million tons) [3]

The total length of trunk pipelines in Kazakhstan is more than 31 thousand km. The dynamics of the development of pipeline transport infrastructure is shown in Figure 2 (compiled on the basis of data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan).

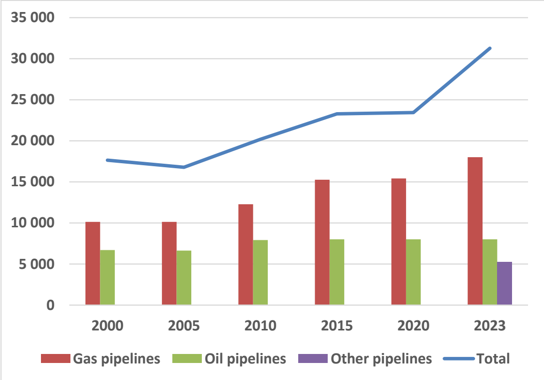


Figure 2. Length of Kazakhstan's main pipelines (km)

In oil transportation, attention is paid to reducing operating costs and improving the efficiency of routes. One of the goals of sustainable development is the innovative development of transport infrastructure. In this article, the object of research is a centrifugal pump with a double-suction wheel, the subject of research is the improvement of the design of a centrifugal pump to improve the efficiency of pipeline transport infrastructure.

The efficiency of oil transportation through pipelines is determined by the pumping mode obtained as a result of combining the characteristics of the pump and the pipeline. These characteristics change when the properties of the pumped oil change, as well as when any structural changes are made in the pipeline or in the pump [4].

In the paper [1], the factors that affect the energy consumption of transfer pumps are considered. Let's list these factors:

- the amount of oil pumped;
- pressure drop created by the centrifugal pump;
- density and viscosity of oil;
- variable loading of the oil pipeline, frequent changes in the pumping mode;
- operation of the main equipment in the field of non-optimal efficiency;
- dissipation of mechanical energy and its transition first into vortex energy, and then into thermal energy.

In the paper [4], a relationship was established between the specific consumption of electricity and the efficiency of the pumping unit.

Analysis of these factors shows that it is possible to increase the energy efficiency of the oil transportation process by upgrading centrifugal pumps.

Centrifugal pumps with a double-suction wheel are widely used in various industries due to their high efficiency and reliability.

These pumps are often used to convey clean liquids, viscous liquids and low-concentration fibrous slurries. They ensure a stable flow and minimal pulsation, which is especially important in production processes.

Due to their design, such pumps are used to pump oil and other liquids in pipelines, providing high performance and durability and low operating costs.

Centrifugal pumps with a double-suction wheel have a number of design features that make them ideal for pipeline transport, especially in the oil industry [5-7]:

Impeller: Two-way suction ensures an even distribution of fluid flow, minimizing radial forces and vibration. This allows the pump to operate with high efficiency even when the flow volumes change.

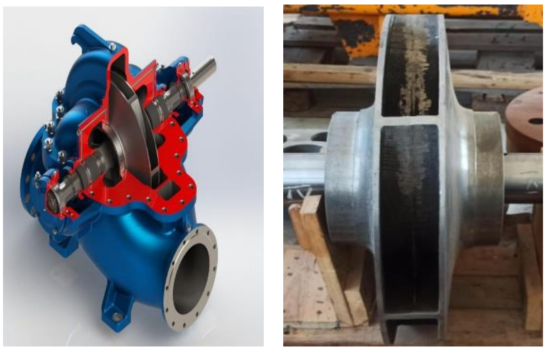
Axial Connector Housing: This design makes maintenance easy, as internal components can be accessed without disconnecting the piping.

Guide vane: Mounting the guide vane behind the impeller allows for maximum efficiency over a wide flow range, ensuring head stability.

Materials: The use of corrosion-resistant and wear-resistant materials such as duplex stainless steel increases the service life of the pump and reduces maintenance costs.

The flow rate of a double-suction centrifugal pump is about twice that of a single-suction centrifugal pump of the same diameter, and the axial force of the first pump is theoretically balanced [5-7].

The object of the study is the design of a centrifugal pump with a double-suction wheel CNP 630-90 (Figure 3), the technical characteristics of the pump are shown in Table 1.



a) b)

Figure 3. CNP 630-90 pump: a) general view of the pump; b) two-way entry impeller

Table 1. Specified design parameters of the pump being upgraded

№	Name value	Meaning
1	Nominal positive displacement pump, Q_H, m^3/h	630
2	Pump head H_H, m	90
3	Rotation speed n_H, r/min	1450
4	Permissible cavitation margin $\Delta h_{доп}$, m	14

The two main components of a centrifugal pump are the impeller and the casing.

Other components are the suction nozzle, exhaust nozzle, shaft, bearing, wear-resistant rings, gland and mechanical seal.

A dual-suction impeller is essentially no different from two single-suction impellers placed close to each other on a horizontal shaft and supported by supports on both sides. This design allows you to increase productivity without increasing the diameter of the impeller. This type allows fluid to enter the impeller eye on both sides. This action can be symmetrical with respect to the center line of the double suction impeller.

The symmetry of the impeller greatly improves its hydraulic balance or does not create an axial traction force. A central spring serves both impellers and leads through a single diffuser to the outlet flange.

Pressure fluctuations in the pump impeller can cause a high amplitude of vibration in dual-suction centrifugal pumps, but the influence of impeller geometry is still not well understood. The task of the study was to simulate the flow of fluid in a wheel with different variants of blade geometry.

2. Materials and methods

To determine the level of pressure fluctuations and its effect on the efficiency of the pump, Cradle software was used. The Cradle program is a series of software solutions for computational fluid dynamics (CFD) engineering analysis and multidisciplinary modeling [8,9]. Impeller and continuum mesh were created using the ICEM CFD mesh generator. It allows you to forcibly adjust the density of the mesh, thickening it in the necessary places (for example, on the inlet and outlet edges of the blades) and enlarging it where high mesh density is not required. This approach allows you to save computer resources and obtain a sufficient density of the mesh in the studied part of the computational domain. Prior to the study, a check of grid independence was performed. For this purpose, nets with different densities were built. Figure 4 shows the stages of mesh generation.

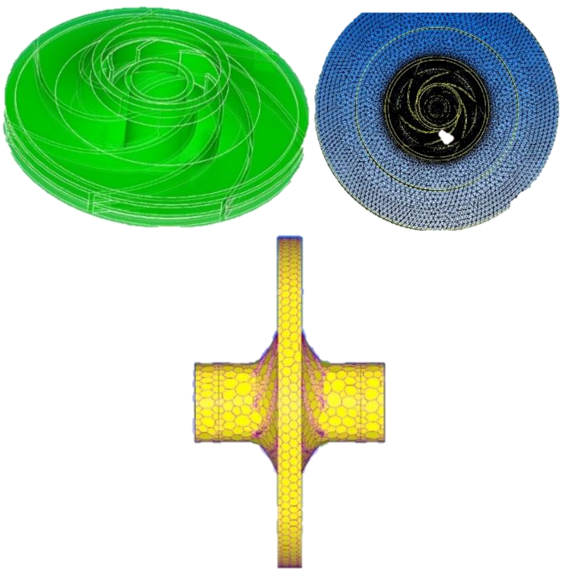
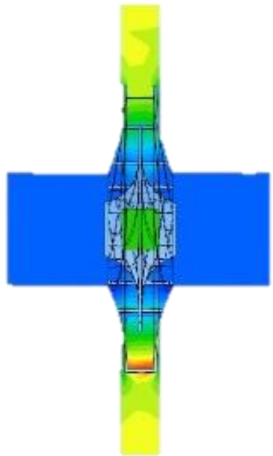


Figure 4. Stages of mesh generation

The impeller subregion was covered with a uniform unstructured mesh of tetrahedral cells, and the elbow subregion was covered with a regular hexagonal mesh. Adaptation of the mesh was not carried out, because, firstly, the use of standard wall functions does not require too small a mesh (min + y = 30 ÷ 60), and secondly, the lack of computational resources hindered further improvement of the solution. Computational grids with 600 thousand, 800 thousand and 1 million cells were built. The analysis of integral values obtained from the results of numerical research for grids with different densities showed that with the number of cells over 700 thousand, the results differ by no more than 1%. This result indicates grid independence. Further numerical research was carried out for grids with approximately 700 thousand cells. The value of the variable y+, which characterizes the thickening of the mesh near the walls, was within 20< y+ <60 units.

Boundary conditions were set on the wall of the wheel: zero tangent velocity (the condition of «adhesion» to the wall), zero velocity of the wall itself relative to the rotating coordinate system (i.e., the wall moves synchronously with it). On the elbow wall – Wall: zero shear velocity (the condition of «adhesion» to the wall), zero velocity of the wall itself relative to the absolute inertial coordinate system (i.e. the wall is stationary).

Algorithm verification. The above algorithm is used for numerical simulation, the above algorithm is used to numerically simulate the internal flow of the original centrifugal pump and the optimized centrifugal pump. To verify the validity of the algorithm used, calculations were made for the pump working area according to the experimental data in Figure 5 from 0.5Q to 1.25 Q.



a)

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=== TURBOMACHINERY OUTPUT ===

 (PUMP)                          IN             OUT
 AREA           :      6.133618E-02     1.358585E-01
 VOLUME FLOW    :      1.740000E-01    -1.739630E-01
 DENSITY        :      9.782000E+02     9.982000E+02
 TOTAL PRES     :     -6.827984E+05     4.578261E+05

 THRUST         :     -3.439847E+02
 TORQUE         :     -2.073163E+03
 HEAD           :      9.666001E+02
 SHAFT POWER    :      3.147966E+05
 EFFICIENCY(T)  :      6.824664E+01
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b)

Figure 5. Simulation results: a) wheel pressure distribution; b) results file

The results of the pressure characteristics of the pump, obtained by calculations in the CRADLE/Sflow program and experimental from the factory, were summarized in a comparative diagram shown in Figure 6.

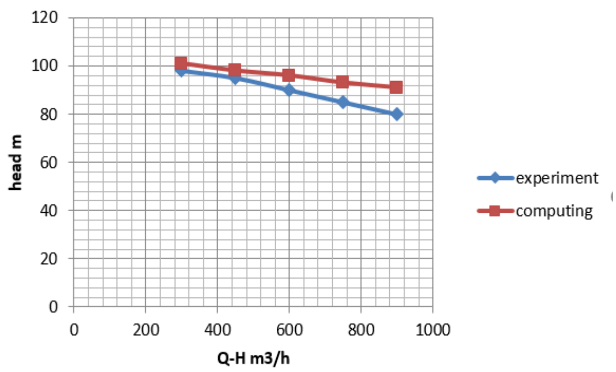
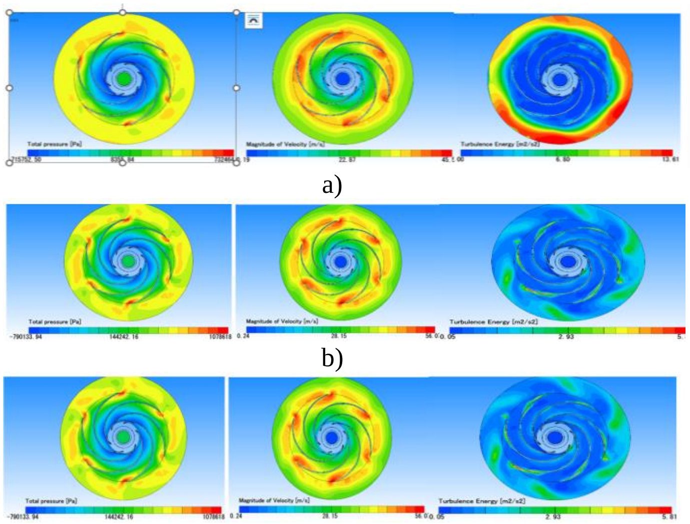


Figure 6. Comparative graph of computational and experimental values

Analyzing the integral characteristics obtained on the experimental bench and comparing them with the results of numerical simulation (Figures 7, 8), it can be concluded that the discrepancy in the head results is about 4%.

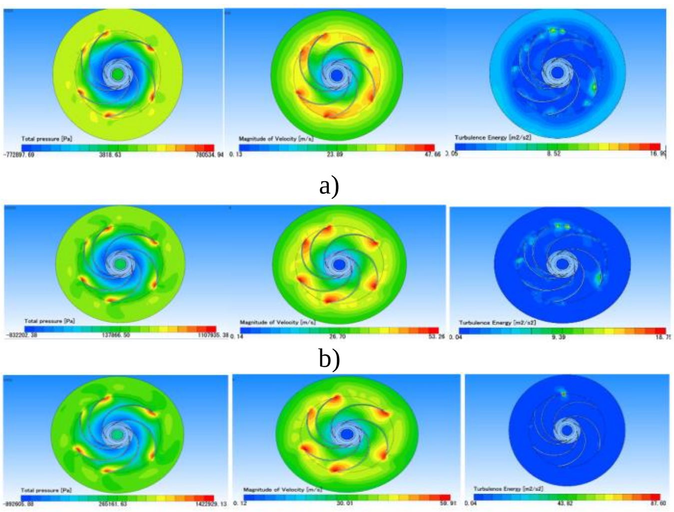


a)

b)

c)

Figure 7. Results of simulation of flow kinematics in a homogeneous lattice wheel: a) low flow, 0.5 Q and 0.7 Q; b) rated flow rate 1.0 Q; c) and high flow rate and 1.5 Q



a)

b)

c)

Figure 8. Results of kinematics modeling: a) low flow, 0.5 Q and 0.7 Q; b) rated flow rate 1.0 Q; c) and high flow rate and 1.5 Q

Analyzing the fact of the mismatch of characteristics, it can be assumed that the most probable cause of this behavior of curves is the discrepancy between the geometric model of the blade systems used in the calculations and those actually manufactured.

In particular, this applies to the shape of the inlet and outlet edges, the roughness of the flow path, etc., as well as the error of physical measurements, but the difference is quite acceptable, which confirms the adequacy of the computer model of the wheel.

In order to measure the effect of variable curvature vanes on centrifugal pump performance, changes in static pressure, relative velocity, and kinetic energy turbulence in the middle part of the impeller were analyzed under typical flow conditions (low flow rate of 0.5 Q and 0.7 Q, rated flow rate of 1.0 Q and high flow rate and 1.5 Q).

3. Results and discussion

Based on the results of the simulation, the general law of static pressure change is that the static pressure in the different channels of the wheel is evenly distributed. The static pressure drops for the original wheel are 0.36 MPa to 0.528 MPa and for the wheel with variable curvature blades from 0.44 MPa to 0.63 MPa at all the studied feed modes. As shown in Figure 8. At the impeller inlet, the static pressure was the lowest.

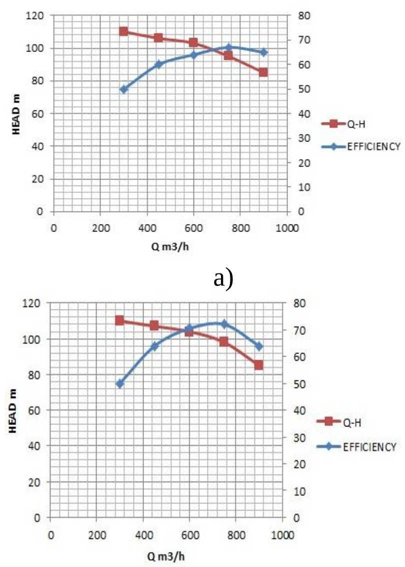
The static pressure at the outlet of the impeller was the highest. For all impellers, the static pressure as a whole increased with increasing flow rate. Under the condition of 0.7 Q, the increase in static pressure was more pronounced. At the outlet, the static pressure reached its maximum value under the condition of 1.5 Q.

Visualization of the pressure distribution gradient shows a decrease in the low-pressure zones in the modified wheel, i.e. a decrease in the occurrence of reverse currents in the wheel with a heterogeneous grid. The volume of distribution gradually decreased as the flow rate increased.

The speed diagrams made it possible to observe an increase in the relative speed in the upgraded wheel, so at a minimum feed the speed in the original wheel is 45 m/s, in the upgraded 47 m/s and at a maximum feed of 56 m/s for the original wheel and 59 m/s for the upgraded wheel, the increase in relative speed will affect the hydraulic efficiency.

The diagram of the distribution of turbulent kinetic energy under low flow velocity conditions in the original wheel has a large surface area colored blue, which indicates a higher turbulence value, and behind the wheel there are pronounced red areas of maximum flow vortex values, which naturally leads to a decrease in efficiency in this mode of pump operation. And only locally do vortices appear. Pump losses at low feeds are greater in the original wheel.

Based on the results of efficiency and pressure characteristics obtained by the method of computational fluid dynamics, graphs were built in the CRADLE system (Figure 9).



a)

b)

Figure 9. Pressure and energy characteristics of the pump: a) for a pump with a reference wheel; b) for a pump with a modified wheel

In the diagrams, the intersection of the Q-H curve and the efficiency curves that were plotted from the results of the calculations correspond to the operating points of the pump. Obviously, although the efficiency of the modified pump decreased at the nominal supply, the operating point and the average integral efficiency increased by 2%, and the operating point shifted towards a decrease in the supply by 1.5%.

4. Conclusions

In this article, the influence of the geometry of the wheel blade system of a centrifugal pump on the pressure-energy characteristics was investigated. Numerical simulation of flows in a centrifugal pump with homogeneous and heterogeneous vane grate wheels at low flow, nominal flow and high flow was carried out. The main conclusions are as follows: the redesigned wheel has increased static pressure and relative speed, which leads to higher hydraulic and overall efficiency, the kinetic energy of turbulence has less pulsation, and the operating point of the pump has shifted. Despite the fact that the average integral efficiency in the modified pump has increased, the operating point of the pump is shifted towards a decrease in supply by 1.5%. The theory of a blade system with variable curvature was tested by computational methods.

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Орталықтан теңгерілген насостың тиімділігін cradle cad жүйесінде есептеу әдісін пайдалана отырып анықтау

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Аңдатпа. Қазақстан - айтарлықтай ресурстық базасы, қолайлы орны және Еуропаға қазба байлықтарын жеткізудің бірегей мүмкіндігі бар және Азия нарықтарын, соның ішінде Қытайды да қарқынды дамып келе жатқан ел. Мақалада Қазақстандағы құбыр көлігінің көрсеткіштері туралы қысқаша ақпарат берілген. Энергия үнемдеуді дамыту тұтынылатын энергияның көп бөлігін пайдаланатын жабдықтардың тиімділігін арттырудың маңыздылығын айқындайды. Сорғы жабдығы электр энергиясын аса маңызды тұтынушылардың бірі болып табылады. Қазақстанда өндіріс құнындағы көлік құраушысының үлесі үлкен. Қазақстанның орнықты даму мақсаттарына бейілділігі энергияны неғұрлым үнемді тұтыну қажеттілігін туғызады. Әдетте мұнай тасымалдау құнының алтыншы бөлігін электр энергиясының құны құрайды, ол айдау жабдығын жүргізуге жұмсалады. Сондықтан энергия тиімді сорғылар құру жөніндегі жұмыстар өзекті болып табылады. Қағазда тиімділігі жоғары қос сору центрифугалық сорғылар үшін импельдердің жаңа конфигурациясы (ауыспалы вана қисаюы бар) ұсынылады. Орталықтан тепкіш сорғының басы мен тиімділігі әр түрлі ване экрандармен салыстырылды. Орталықтан тепкіш сорғы конструкциясының ұсынылып отырған өзгерістері статикалық қысымның және салыстырмалы жылдамдықтың артуына әкеледі, бұл гидравликалық және жалпы тиімділіктің артуына әкеледі, ал турбуленттіліктің кинетикалық энергиясы оның импульсін төмендетеді. Бұл ретте сорғының пайдалану нүктесі берілімді 1.5%-ға төмендету жағына ауысады.

Негізгі сөздер: *құбыр конвейері, мұнай тасымалдау, қос сору дөңгелегі бар ортадан тепкіш сорғы.*

Определение эффективности центробежного насоса на основе эксперимента по оценке cad-системы cradle

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Аннотация. Казахстан является страной со значительной ресурсной базой, выгодным расположением и уникальной возможностью поставлять ископаемое топливо в Европу и на динамично развивающиеся азиатские рынки, включая Китай. В статье приведена краткая информация о показателях трубопроводного транспорта Казахстана. Развитие энергосбережения определяет значимость повышения эффективности оборудования, которое использует большую часть потребляемой энергии. Насосное оборудование является одним из самых значительных потребителей электрической энергии. В Казахстане велика доля транспортной составляющей в себестоимости продукции. Приверженность Казахстана целям устойчивого развития создает необходимость более экономичного расхода энергоносителей. Как правило, шестая часть затрат на транспортировку нефти — это затраты на электроэнергию, которая тратится на привод насосного оборудования. Поэтому актуальны работы по созданию энергоэффективных насосов. В статье предложена новая конфигурацию рабочего колеса (с переменной кривизной лопаток) для центробежных насосов двойного всасывания с более высокой эффективностью. Было проведено сравнение напора и КПД центробежного насоса с различными лопастными решетками. Предложенные изменения в конструкции центробежного насоса приводит к увеличению статического давления и относительной скорости, что ведет к повышению гидравлического и общего КПД, а кинетическая энергия турбулентности снижает свою пульсацию. При этом рабочая точка насоса смещается в сторону уменьшения подачи на 1.5%.

Ключевые слова: *трубопроводный транспорт, транспортировка нефти, центробежный насос с колесом двухстороннего всасывания.*

Received: 07 June 2024
Accepted: 15 September 2024
Available online: 30 September 2024