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SUBSTANTIATING THE DESIGN OF EQUIPMENT FOR PREPARING OIL AND GAS FIELD PRODUCTS FOR TRANSPORTATION

Tetiana Nesterenko
Corresponding author
PhD, Associate Professor*
E-mail: tnesterenko2021@gmail.com
ORCID: https://orcid.org/0000-0002-2387-8575

Ivan Nazarenko
Doctor of Technical Sciences, Professor
Department of Machinery and Equipment of Technological Processes
Kyiv National University of Construction and Architecture
Povitrianykh Syl ave., 31, Kyiv, Ukraine, 03037
ORCID: https://orcid.org/0000-0002-1888-3687

Mykola Nesterenko
PhD, Associate Professor
Department of Industrial Mechanical Engineering and Mechatronics**
ORCID: https://orcid.org/0000-0002-4073-1233

Oleksandr Shevchenko
PhD Student*
ORCID: https://orcid.org/0009-0005-0478-7060

Andrii Khyzhniak
Doctor of Philosophy (PhD), Associate Professor*
ORCID: https://orcid.org/0009-0003-5518-0723

Iryna Bernyk
Doctor of Technical Sciences, Associate Professor
Department of Processes
and Equipment of Agricultural Production Processing
National University of Life and Environmental Sciences of Ukraine
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041
ORCID: https://orcid.org/0000-0002-1367-3058

Artur Onyshchenko
Doctor of Technical Sciences, Professor***
ORCID: https://orcid.org/0000-0002-1040-4530

Roman Moshkivskyi
PhD Student***
ORCID: https://orcid.org/0009-0006-8172-1329

*Department of Oil and Gas Engineering and Technology**
**National University "Yuri Kondratyuk Poltava Polytechnic"
Vitaliia Hrytsaienka ave., 24, Poltava, Ukraine, 36011
***Department of Bridges and Tunnels and Hydrotechnical Structures
National Transport University
Mykhaila Omelianovycha-Pavlenka str., 1, Kyiv, Ukraine, 01010

This study investigates processes that separate gas-liquid flows and purify formation water in the equipment for oil and gas field production preparation units.

At the late stage of field development, the efficiency of separation depends on the ability of the equipment to operate under conditions of waterlogging, an increase in the content of mechanical impurities, and a decrease in formation pressure. Under such conditions, conventional separation equipment does not provide the required quality of hydrocarbon separation and purification of formation water.

The task addressed in this work has been solved by improving the internal structural elements in the three-phase separator and a cyclone in the hydrocarbon preparation unit. Hydraulic losses were within permissible values; no secondary removal of drops into the gas stream occurred. That was confirmed by the results of thermodynamic and CFD modeling. This is a feature of the approach in comparison with those reported in which studies of new design solutions were not comprehensively conducted.

The issues of hydraulic losses and secondary removal of drops into the gas stream remained open. The design solutions proposed in this work affected the separation efficiency – the volume of the selected condensate increased while the total hydraulic losses did not exceed 0.037 MPa. It has been proven that new structural solutions for separation elements provide a more uniform distribution of speeds and form local zones with reduced speeds.

The results are explained by a change in the flow structure, an increase in inertial deposition of drops, and a decrease in low-mobility zones in the flow part of the separation elements. The findings could be implemented in the reconstruction of oil and gas treatment plants, in the design of internal separation elements, and when choosing structural solutions for cyclones in order to purify formation water

Keywords: oil and gas fields, hydrocarbon transportation, hydrocarbon preparation, formation water, thermodynamic modeling

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1. Introduction

The main purpose of preparing formation fluids of oil and gas fields for further transportation and use is to obtain marketable products with quality indicators that are regulated by related documents and standards. One of the basic stages in preparation is separation, which makes it possible to separate various components of the gas mixture, in particular liquid fractions of hydrocarbons, associated formation water, and other impurities.

Oil and condensate that have undergone the first stage of purification from formation water and associated petroleum gas are transported from hydrocarbon preparation plants to processing plants. At the same time, natural gas from preparation plants that has undergone several stages of purification is brought to transport quality indicators and sent to the main pipeline. Bringing natural gas to such quality indicators as dew point temperature for moisture and hydrocarbons is not always possible since the existing hydrocarbon preparation plants in the fields, which have been operated for more than a dozen years, have low efficiency and require reconstruction.

When preparing hydrocarbons, the question of disposal, purification, or reuse of associated formation water always arises. Since the fields under consideration are those that have been in operation for a long time, it is possible to reuse associated formation water for further injection into the formation and maintaining formation pressure. Associated formation water has increased mineralization and mechanical impurities, and when injected into the formation it could lead to its clogging; therefore, special attention should be paid to the purification of associated formation water.

Modern technologies and engineering solutions provide new opportunities for improving separation processes and devices. One of the promising approaches is the application of purification process modeling, which allows for more accurate prediction of equipment efficiency and optimization of its parameters. Complex modeling of separation processes provides a deeper understanding of the process of component distribution, taking into account various influence parameters and determining optimal conditions for equipment operation.

Therefore, studies aimed at substantiating the design of equipment for preparation for transportation of hydrocarbons are relevant as they make it possible to improve the quality of marketable products and reduce hydrocarbon losses, especially at the later stages of development. Under the current conditions of the energy crisis in Ukraine, the issue of increasing the volume of marketable products is particularly important.

2. Literature review and problem statement

Research in the field of preparation of field products for transportation is based on the use of classical technologies, such as gravitational, filtration, and inertial methods of hydrocarbon preparation, as well as on supersonic and membrane technologies. Paper [1] reports the generalized results of the study on gravity separators. It is shown that their advantages are simplicity of design and relative ease of maintenance. However, issues related to the large overall dimensions of this equipment and the inability to gravitationally deposit droplets smaller than 100 microns remain unresolved. A likely reason is difficulties associated with the physical limitations of gravitational phase separation. An option for overcoming these difficulties may be the use of filtration separators at the next stage of separation.

In [2] it is shown that for droplets larger than 4 μm, the separation efficiency in a filtration separator can reach 98–99.8%, and the pressure drop is 250–500 Pa. However, the issues of secondary capture of liquid droplets and deposition of mechanical particles that can block filter screens remain unresolved. The solution to this problem may be the use of new materials and technologies, such as membranes and membrane modules. The use of membranes, as presented in [3], is proposed to be implemented for the purification of natural gas from CO_2, H_2S, and N_2 after its purification from mechanical impurities, liquid hydrocarbon fraction, and water. This ensures that natural gas meets the requirements for further transportation and use. However, there are still disadvantages associated with insufficient resistance of polymer membranes to plasticization, the high cost of inorganic membranes, interfacial defects in mixed-matrix membranes and physical aging of carbon molecular sieve membranes. The issue of ensuring simultaneously high permeability, selectivity and durability of the membrane also remains open. An option for solving this issue is to improve the methods of manufacturing such membranes, use new materials for membranes, in particular 2D structures, as well as design universal membranes for the simultaneous removal of CO_2, H_2S, and N_2. This is the approach used in [4, 5]; however, the resistance of this type of membrane to aggressive environments and the possibility of large-scale industrial production are not considered.

Papers [6, 7] report the results of research on the supersonic method of natural gas purification. The main element of the technology is a supersonic separator, which makes it possible to realize the gas velocity above the speed of sound in a gas medium. Such acceleration makes it possible to achieve intensive condensation and separation of target natural gas fractions. The gas-dynamic method of separating gas mixtures is based on providing the gas flow with supersonic velocity to create a temperature that is lower than the braking temperature at the inlet to the apparatus. It is shown that this technology is promising for the condensation and removal of H_2O, heavy hydrocarbon fractions, as well as H_2S and CO_2 impurities from produced natural gas. However, a number of problems have not yet been solved, in particular, significant pressure losses, which are especially undesirable at the late stage of field development, the difficulty of ensuring the stability of process efficiency, and the accurate selection of operating parameters.

The issue of significantly reducing pressure losses could be solved by installing inertial separators with improved geometry of louver packages. The main elements of inertial separators are louvered packages, which have the shape of a sinusoid, triangular or trapezoidal shape. In the louvered, the flow smoothly changes direction, and particles of the dispersed phase under the influence of centrifugal forces settle on the inner surfaces and flow down them. In works [8, 9], a new geometry of the louvered packages of the inertial separator is proposed and the results of CFD modeling are reported. The efficiency of the separator with such a louvered package design is much higher than that of the louvered packages of the classical triangular shape. However, the problem of pressure drop and liquid re-entrainment when using such types of louvered packages in inertial separators requires further research.

One of the options for separation equipment used in complex hydrocarbon preparation plants is cyclone separators, which are used to purify natural gas and associated formation water. In this case, the permissible content of mechanical impurities in formation water should be 3 mg/dm^3, and oil products – 5 mg/dm^3 [10]. In work [11], the results of optimizing the design of a cyclone separator for use in well testing conditions are shown. To determine the optimal parameters, the authors use simulation modeling and experimental studies. It was established that the diameter of the hole for oil product discharge and the angle of the conical chamber are factors that affect the performance of the cyclone separator. However, the problem of significant hydraulic losses and reduced performance at a high concentration of fine impurities has not been completely resolved. In [12], simulation modeling of the process of separating an oil-water emulsion using a hydrocyclone separator is considered. A feature of this cyclone is a porous membrane wall. The effect on the efficiency of the cyclone of the following parameters was studied: particle size, flow rate, and characteristics of the membrane itself. It was shown that the use of such types of porous membranes increases the efficiency of oil removal from associated formation water, but the issue of frequent periodic maintenance and replacement of membranes is not considered. Paper [13] gives an overview of modern technological solutions for the purification of associated formation water. The authors emphasize that classical hydrocyclones are effective for removing oil products and mechanical impurities but the problem of reducing their efficiency with emulsified contaminants has not been completely resolved.

Thus, the focus of the cited papers is the design of separation equipment using either thermodynamic modeling or CFD simulation methods. However, there are no studies on the efficiency of equipment for hydrocarbon preparation plants with complex thermodynamic and CFD modeling. An option for overcoming relevant difficulties is given in work [14]. In it, the authors emphasize that to verify the efficiency of the proposed new design solutions, it is necessary to conduct modeling that combines thermodynamic modeling and CFD simulation. However, this type of modeling is not performed in that work, and the study generalizes papers by other authors.

All this allows us to state that it is advisable to conduct a study aimed at improving the structure of separation elements in three-phase separators and hydrocyclones and which would comprehensively model related processes.

3. The aim and objectives of the study

The purpose of our study is to substantiate the design of the separation elements in a three-phase separator and a hydrocyclone in preparation for the transportation of oil and gas field products with complex thermodynamic and CFD simulation of processes. This will make it possible to reduce the removal of the liquid phase of hydrocarbons into the gas stream, improve the purification of associated formation water, and substantiate rational design parameters for separation elements.

To achieve the goal, the following tasks were set:

– to perform the calculation of the three-phase separator and evaluate the efficiency of phase separation in terms of the removal of light and heavy hydrocarbon fractions;

– to determine the main design parameters of the louver elements of the three-phase separator, in particular the required area of the louver packages and hydraulic losses when installing the louver packages;

– to investigate the influence of the design of the louver packages on the flow of natural gas and evaluate the efficiency of the improved structure of the louver packages with additional C-shaped elements;

– to perform modeling of the process of purification of associated formation water as an element of the technological scheme for the preparation of hydrocarbons of an oil and gas condensate field, to determine the content of mechanical impurities, and compare these values with the maximum permissible ones;

– to investigate the influence of the proposed design solution of the cyclone separator on the distribution of velocities, pressure, and flow turbulence.

4. The study materials and methods

The object of our study is the processes of separation of gas-liquid flows and purification of formation water in the equipment of oil and gas field production preparation units. The nature of the movement of liquid and gaseous phases, the possibility of formation of zones of reduced velocity and the trajectory of droplet moisture movement were considered. Therefore, the following research hypothesis was adopted in the work: rational design solutions for a three-phase separator and a hydrocyclone separator justified by thermodynamic and CFD simulation could increase the efficiency of separation of droplet moisture, mechanical impurities, and heavy hydrocarbon fractions.

The assumptions adopted in the study are:

– the gaseous phase can be considered a Newtonian compressible fluid, which has known thermodynamic properties;

– the thermodynamic properties of the gas phase are determined according to models in the SolidWorks Flow Simulation (France) and Aspen HYSYS (USA) software;

– the droplets of the liquid phase are spherical in shape and move according to the dispersed phase model;

– the distribution of light and heavy liquid droplets in the incoming gas stream is calculated using the Rossin-Rammler distribution methodology;

– the k–ω SST (Shear Stress Transport) turbulence model was used.

The study accepted the following simplifications:

– chemical interaction between phases and foaming were not considered;

– liquid properties were assumed to change insignificantly within the operating temperatures; therefore, they can be considered constant.

The study of equipment for preparing the transportation of formation fluids of gas and oil fields was carried out using the example of a complex oil and gas preparation plant. The complex preparation plant operates according to the following scheme. From the inlet manifold, gas with a temperature of –10°C…+30°C at a pressure of 2.0…6.0 MPa enters the three-phase separator V-270 through an emergency shut-off valve through the high-pressure production manifold. In the V-270 separator, gas is separated with the separation of gas condensate, formation water, and purification from mechanical impurities. The separated gas from the upper part of the separator, through the gas metering unit, the pressure control valve, enters the low-temperature separation unit. Gas condensate from the separator through the control valve enters the condensate degasser, with a temperature of +10…+20°C at a pressure of 0.3…0.4 MPa, for further degassing. Formation water from the separator through the control valve enters the settling tank for storing formation water. Then, the associated formation water is pumped by pumps for purification into pressure hydrocyclones (overpressure more than 100 kPa). In the hydrocyclones, mechanical impurities are separated and discharged into the bunker. Then, through thin-layer settling tanks, the associated formation water enters the hydrocyclones for cleaning from condensate. After the hydrocyclones, the water is fed to fine filters and can be directed into wells to maintain formation pressure (Fig. 1).

Confirmation of the effectiveness of using internal louver devices with various design solutions is considered using the example of an existing production three-phase separator V-270.

The initial data for the calculation were taken from the technological regulations for the oil and gas preparation plant: flow temperature 10°C, pressure 6 MPa, and well production flow rate 61800 m^3/day. The component chemical composition of natural gas is given in Table 1.

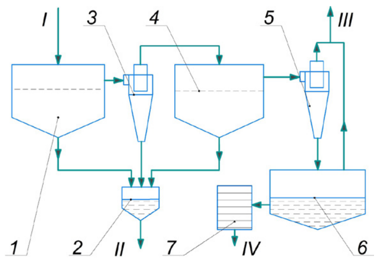


Fig. 1. Scheme of purification of associated formation waters: 1 – settling tank, 2 – sediment collector, 3 – cyclone for separation of suspended solids, 4 – thin-layer settling tank, 5 – cyclone for separation of oil, 6 – settling tank, 7 – fine filter, I – associated formation water, II – sediment, III – petroleum products, IV – purified water into the reservoir pressure maintenance system

Table 1

Component chemical composition of natural gas

Components	Molar fraction of component % mol.	Components	Molar fraction of component % mol.
Methane	92.424	n-Pentane	0.049
Ethane	3.110	i-Pentane	0.059
Propane	0.865	Hexane+higher	0.066
i-Butane	0.118	Nitrogen	2.862
n-Butane	0.197	Carbon dioxide	0.241
neo-Pentane	0.004	Oxygen	0.006

The calculation methodology of the three-phase separator and cyclone separator in the AspenHYSYS software package (USA) consisted of the following [7, 15]:

– input of initial data: component composition of the flow, temperature, pressure, and flow rate at the inlet to the separators;

– construction of a calculation scheme for the three-phase separator and cyclone separator;

– input of the design parameters of the separator;

– calculation separately for light and heavy fractions of hydrocarbons;

– determination of the total removal of liquid into the gas was carried out as the sum of removal of light and heavy fractions of hydrocarbons;

– comparison of the results of calculations for different variants of the design of separators and internal elements.

Research into the effectiveness of the proposed design solutions of the louver packages of the three-phase separator and cyclone separator was carried out in SolidWorks Flow Simulation (France). The calculation methodology involved the following:

– construction of a three-dimensional model of louvered packages of the basic (triangular) design and packages with additional c-shaped elements placed between corrugated plates and models of cyclone separators with various design solutions;

– assignment of the calculation area corresponding to the flow part of the louvered element, with the dimensions selected so as to ensure the appropriate movement of natural gas in the space of the louvered package;

– assignment of boundary conditions at the inlet was performed in accordance with the operating parameters of the separators;

– assignment of boundary conditions at the outlet was carried out based on the static pressure condition, which reproduced the real mode of gas movement through the louvered package and associated formation water through the cyclone separator;

– determination of the properties of the wall material of the louvered package – stainless steel AISI 316L;

– construction of a calculation grid for the separators;

– numerical calculation;

– analysis of modeling results – distribution of gas and liquid velocity in the channels of the louver package and in the cyclone separator and pressure fields to assess local loss zones and the influence of the design on the value of hydraulic resistance;

– comparison of flow uniformity, gas flow velocity, and conditions for the deposition of droplet moisture for the basic and improved design of the louver package and cyclone separator.

5. Results of investigating processes in a three-phase separator and a hydrocyclone separator

5. 1. Results of calculating a three-phase separator in Aspen HYSYS

The results of research in AspenHysys were obtained for a separator without additional louvered packages and with louvered packages for a three-phase separator that separates mixtures into gas, condensate, and water. It was determined whether liquid droplets were trapped by the gas, and whether their number would decrease when using louvered packages. It was also determined whether the separation devices were able to prevent the corresponding removal.

Fig. 2 shows the results of the calculation of a three-phase separator in Aspen HYSYS with an indication of the temperature, pressure, and volume (or mass) of natural gas, condensate, and associated formation water. The value of the volume of purified gas is $56.03 \cdot 10^3$ m^3/day, condensate – 9.876 t/day, and associated formation water – 0.293 t/day. The obtained values for the flow confirm the possibility of using this separator model to assess phase separation.

Tables 2, 3 give the results from calculating the removal of the liquid phase of light hydrocarbon fractions and heavy hydrocarbon fractions into the gas stream, respectively.

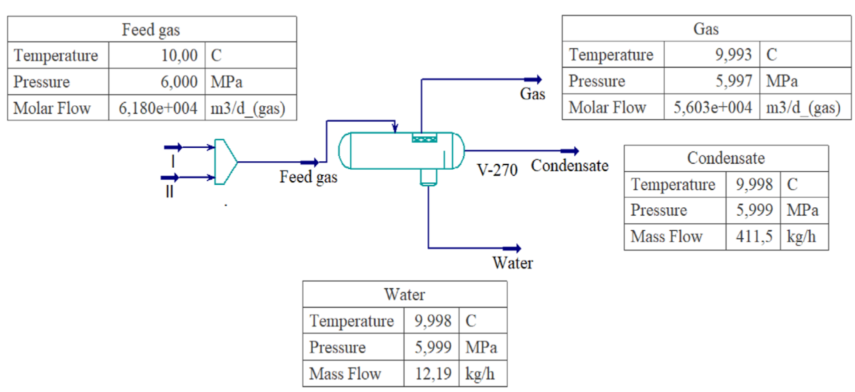


Fig. 2. Calculation results for a three-phase separator

Table 2

Dispersion in a gaseous stream (light fraction)

Light hydrocarbon fraction		
Drop diameter, mm	Weight, kg/h	
	without louvered packages	with louvered packages
$4.97 \cdot 10^{-3}$	0.0001	0.0001
$1.00 \cdot 10^{-2}$	0.0014	0.0011
$1.57 \cdot 10^{-2}$	0.0126	0.0063
$2.22 \cdot 10^{-2}$	0.0651	0.0155
$2.94 \cdot 10^{-2}$	0.1229	0.0078
Total, kg/h	0.20206	0.03076

Table 3

Dispersion in a gaseous stream (heavy fraction)

Heavy hydrocarbon fraction		
Drop diameter, mm	Weight, kg/h	
	without louvered packages	with louvered packages
$1.22 \cdot 10^{-2}$	$5.82 \cdot 10^{-6}$	$2.80 \cdot 10^{-6}$
$2.46 \cdot 10^{-2}$	$1.70 \cdot 10^{-5}$	$4.44 \cdot 10^{-7}$
Total, kg/h	$2.28559 \cdot 10^{-5}$	$3.23953 \cdot 10^{-6}$

Table 2 demonstrates that the use of a louvered package reduces the total removal of the liquid phase of light hydrocarbon fractions from 0.20206 to 0.03076 kg/h, that is, more than 6 times. The greatest reduction in removal is observed for droplets with a diameter of $2.22 \cdot 10^{-2}$ mm and $2.94 \cdot 10^{-2}$ mm.

The total removal of the liquid phase of heavy hydrocarbon fractions also decreases – from $2.28559 \cdot 10^{-5}$ kg/h to $3.23953 \cdot 10^{-6}$ kg/h (Table 3). The absolute values for the removal of heavy liquid are significantly lower than for the light phase, but the use of a louvered package also affects the quality of separation.

Thus, the use of louvered packages in a three-phase separator reduces the removal of the liquid phase of carbohydrates into the gas stream.

5. 2. Calculation of the design parameters of louvered package

The calculation of the required area of the louvered package should be carried out based on the critical gas velocity under given conditions and the volumetric gas flow rate according to formulas (1) to (3).

Required calculated area of the louvered elements, m^2

$$F = \frac{q}{w}, \quad (1)$$

where the critical gas velocity under given conditions $P = 6$ MPa, $T = 283$ K

$$w = C_t \cdot C_e \cdot k \cdot \sqrt[4]{\frac{\sigma \cdot g^2 \cdot (\rho_L - \rho_g)}{\rho_g^2}}, \quad (2)$$

$C_t = 1$ is the coefficient that takes into account the effect of temperature on the critical gas velocity in the separation element; $K = 0.76$ – coefficient of stability of the gas-liquid mixture motion regime, $K = f(P)$; $C_e = 0.983$ – coefficient that takes into account the initial liquid content on the critical gas velocity in the separation element, $C_e - f(e_0)$.

Gas volume flow rate, m^3/s

$$q = \frac{Q_{max} \cdot P_0 \cdot T \cdot z}{86400 \cdot (P + P_0) \cdot z_0 \cdot T_0}, \quad (3)$$

P, T, z – pressure, temperature, and gas compressibility coefficient under operating conditions; P_0, T_0, z_0 – pressure, temperature, and gas compressibility coefficient under normal conditions; Q_{max} – separator capacity, m^3/h.

Then the required area of the louver elements is 0.2546 m^2.

As is known, when installing additional separating elements, hydraulic losses in the separator increase

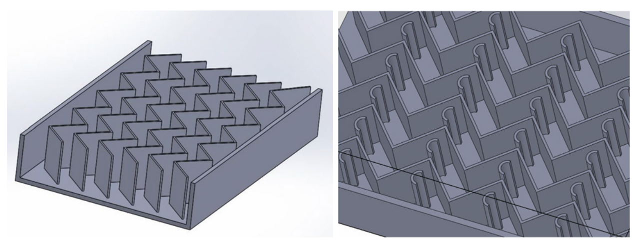
$$p = p_{in} + p_{out} + p_{div}, \quad (4)$$

p_{in} – hydraulic losses at the gas inlet to the separator, kPa; p_{out} – hydraulic losses at the gas outlet from the separator, kPa; p_{div} – hydraulic losses at the separation devices, kPa.

According to our calculations, the total hydraulic losses are 0.037 MPa and do not exceed the permissible value for louvered separators of 0.05 MPa, which indicates the possibility of installing louvered packages.

5. 3. Results of CFD simulation of louvered packages in SolidWorks Flow Simulation

Next, for a given three-phase separator, we consider modeling in Solid Works Flow Simulation with louvered packages of a classical triangular shape (Fig. 3, *a*); louvered packages consist of a number of closely spaced parallel, corrugated plates. We also propose an improved design solution (Fig. 3, *b*) with c-shaped elements installed in the gap between the corrugated plates. For further studies on the separation efficiency, we shall use the separated part of the louvered package.



a *b*

Fig. 3. Separated part of the louvered element: *a* – classic-shaped louvered package; *b* – louvered package with c-shaped elements

As a result, diagrams of gas pressure and velocity distribution were constructed for both variants of louver packages (Fig. 4, *a*, *b*).

In a louver package with a classic design, the main gas flow moves in the central part of the channel with local zones of increased velocity, while in a louver package with c-shaped elements, additional redistribution of the flow and a decrease in velocity are observed in the central part of the inter-louver space (Fig. 4).

The same modeling of the natural gas flow was carried out for a separate pair of rounded corrugations of a louver package with c-shaped elements Fig. 5, 6.

The installation of c-shaped elements in the inter-louvered space in rounded corrugations led to the formation of additional velocity reduction zones, which in turn increased the degree of settling of liquid droplets on the inner surfaces of the corrugations (Fig. 6).

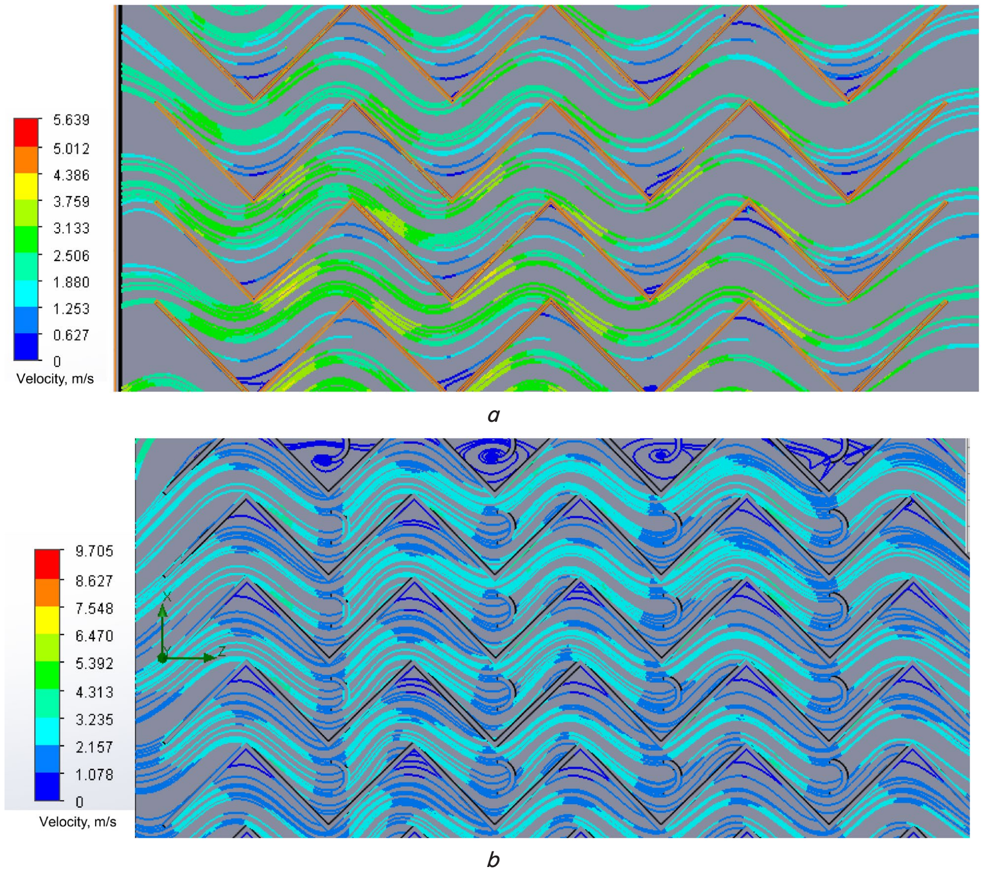


Fig. 4. Gas velocity distribution in a louvered package:
a – louvered package of classical form; *b* – louvered package with c-shaped elements

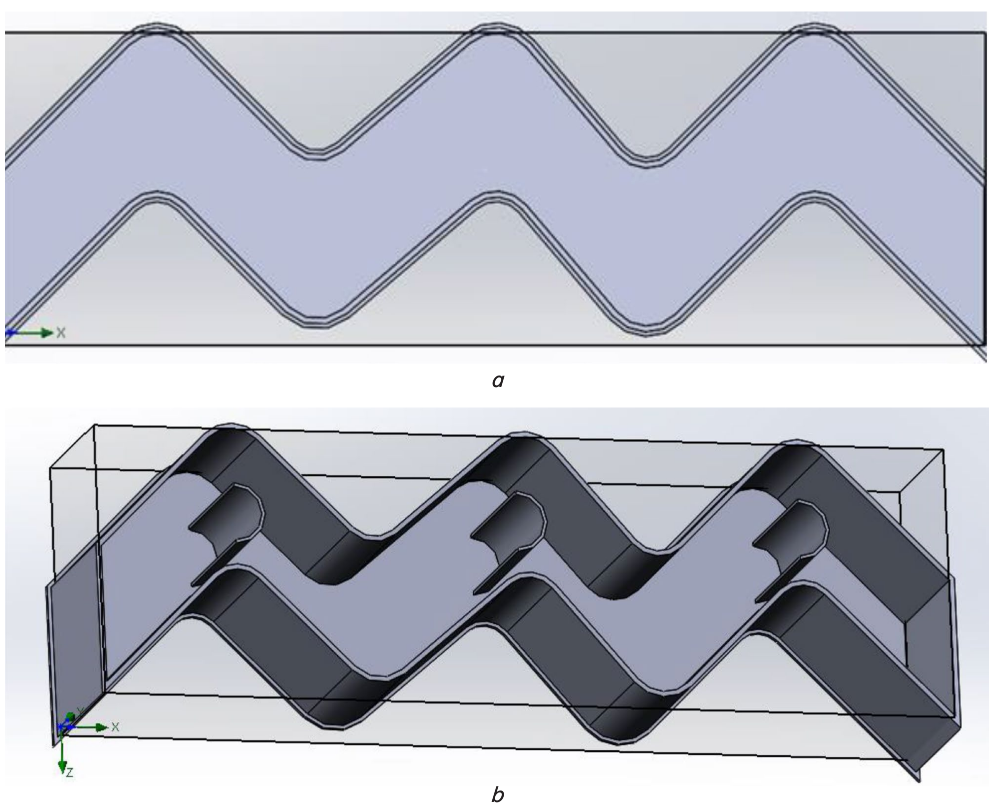
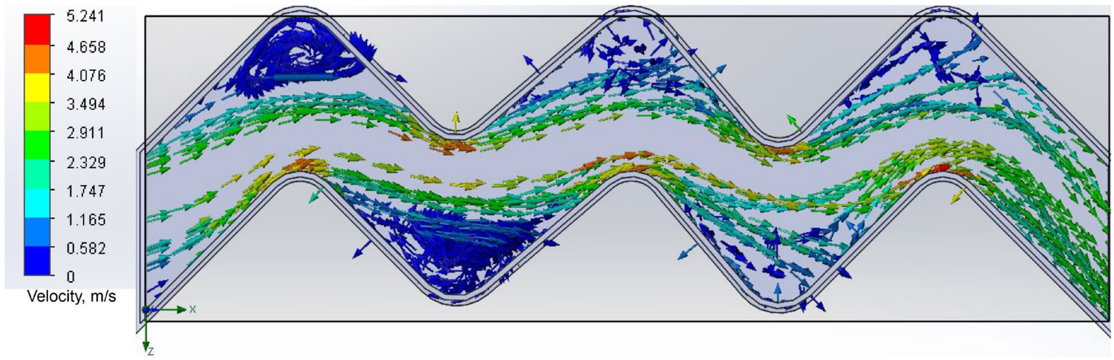
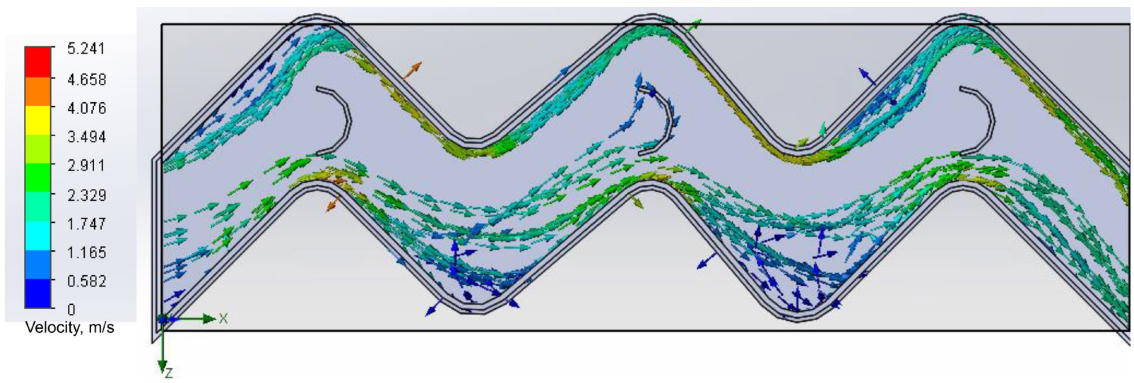


Fig. 5. Separated rounded corrugations of the louvered package:
a – without c-shaped elements; *b* – with c-shaped elements



a



b

Fig. 6. Distribution of gas velocity through corrugated elements:
a — without c-shaped elements; *b* — with c-shaped elements

5. 4. Results of simulating associated formation water purification in Aspen HYSYS

We simulated the formation water purification process with preliminary settling in the AspenHYSYS software package. The results are shown in Fig. 7.

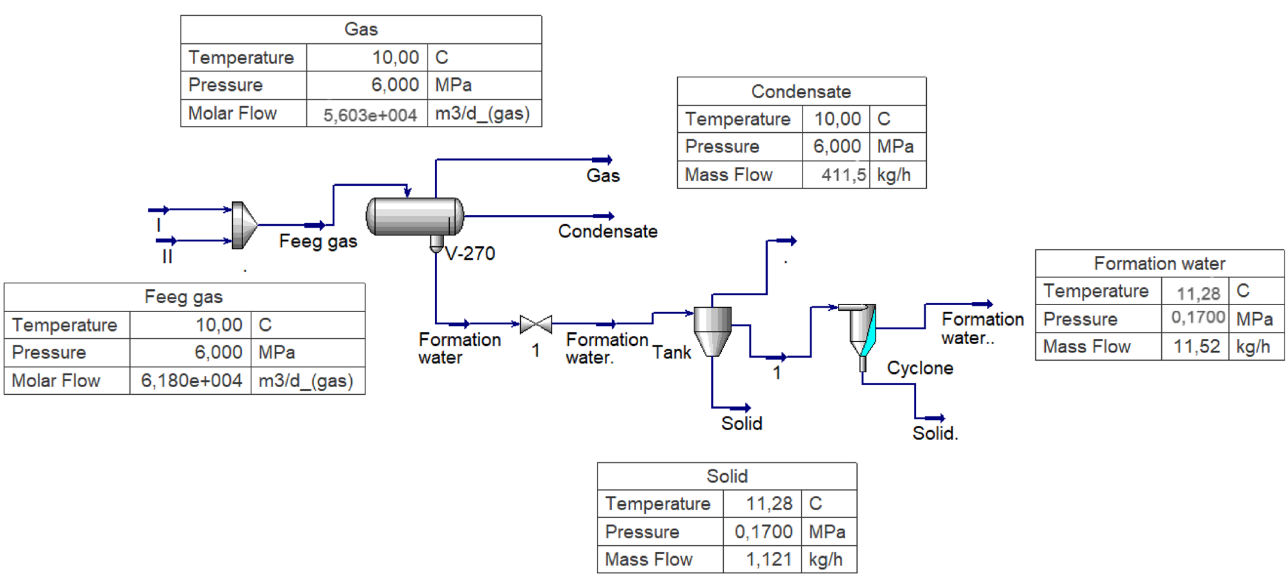
The content of mechanical impurities in the formation water after treatment is 4.15 mg/dm^3, which exceeds the permissible level of 3 mg/dm^3, so it is necessary to either improve the technological scheme or improve the design of the cyclone separator.

5. 5. Results of CFD simulation of fluid flow in the cyclone separator

To increase efficiency, simulation of flows in the cyclone separator with various design solutions was performed.

The results of flow modeling are shown in Fig. 8–10.

For a cyclone separator of the classical form, the maximum velocities are concentrated in the axial and peripheral zones, and an intense swirling flow is formed in the conical zone (Fig. 8).



Gas		
Temperature	10,00	C
Pressure	6,000	MPa
Molar Flow	5,603e+004	m3/d_(gas)

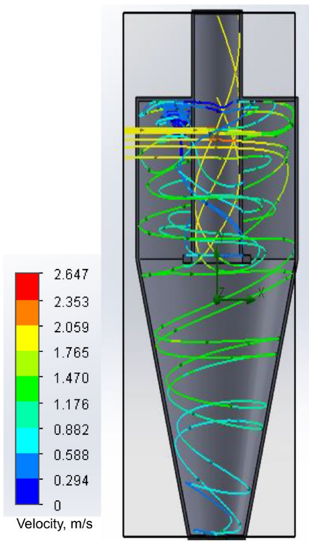
Condensate		
Temperature	10,00	C
Pressure	6,000	MPa
Mass Flow	411,5	kg/h

Feeg gas		
Temperature	10,00	C
Pressure	6,000	MPa
Molar Flow	6,180e+004	m3/d_(gas)

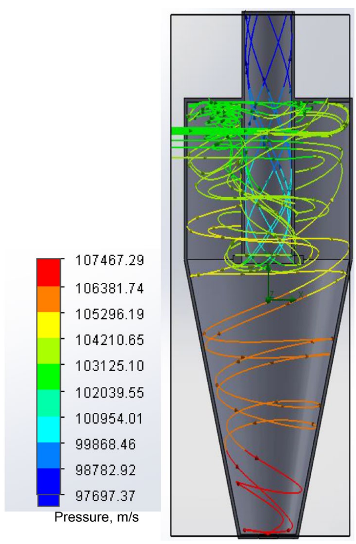
Formation water		
Temperature	11,28	C
Pressure	0,1700	MPa
Mass Flow	11,52	kg/h

Solid		
Temperature	11,28	C
Pressure	0,1700	MPa
Mass Flow	1,121	kg/h

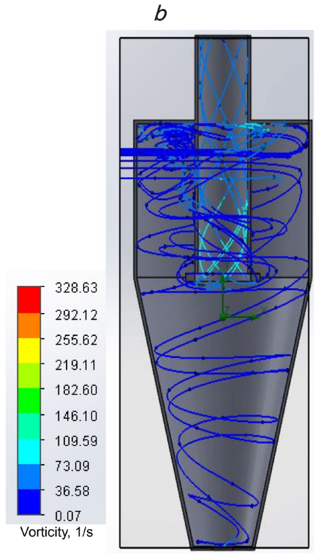
Fig. 7. Calculation results for associated formation water purification



a



b



c

Fig. 8. Diagrams of the distribution of fluid parameters along the flow path during cyclone operation (classical form): *a* – diagram of the distribution of fluid velocity along the flow path; *b* – diagram of the distribution of pressure along the flow path; *c* – diagram of the distribution of fluid turbulence along the flow path

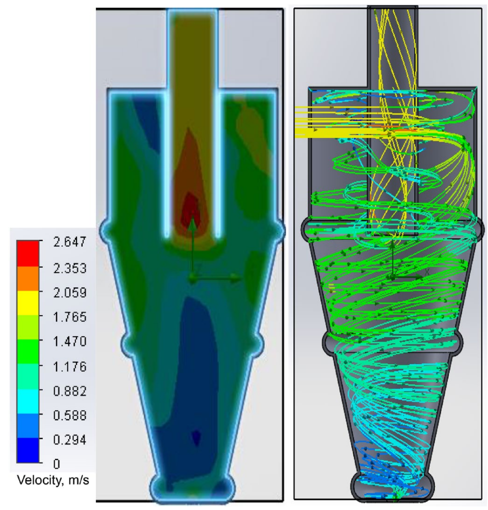


Fig. 9. Diagram of fluid velocity distribution along the flow path during cyclone operation (with internal groove)

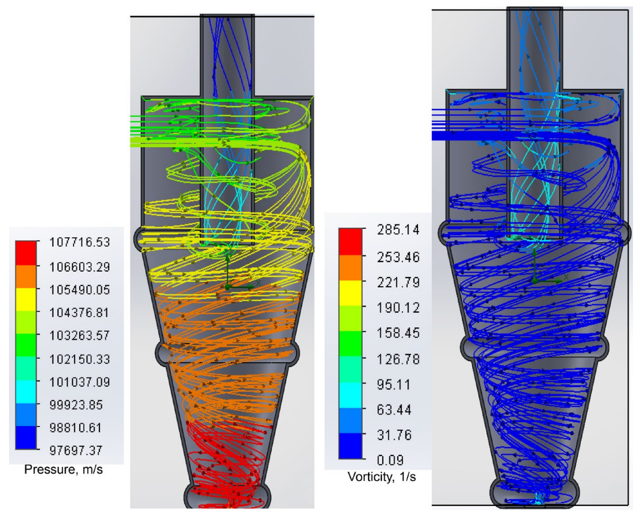


Fig. 10. Diagrams of the distribution of fluid parameters along the flow path during the operation of the cyclone (with an internal groove): *a* – diagram of the pressure distribution along the flow path; *b* – diagram of the distribution of fluid turbulence along the flow path

When modeling a cyclone with an internal groove, it is seen that such geometry changes the flow structure, contributes to the redistribution of velocities and increased turbulence in individual local zones, which in turn has a positive effect on the separation of mechanical impurities (Fig. 9, 10).

6. Discussion of results related to the study of processes in a three-phase separator and a hydrocyclone separator

Analysis of the results in Tables 2, 3 reveals that the use of louvered packages reduces the removal of light and heavy hydrocarbon fractions into the gas stream. The total removal of hydrocarbon fractions into the gas stream decreases from 0.20206 kg/h to 0.03076 kg/h. This can be explained by the effect of the settling of condensate drops on the surfaces of the louvered package, which confirms the effectiveness of the use of louvered packages.

Also, the use of louvered packages affects the gas flow, in particular, the flow structure. From Fig. 5, 7 it is seen that the use of c-shaped elements leads to a decrease in the flow velocity in the central part of the louvered space.

Installing additional louver packages leads to an increase in the total hydraulic resistance of the separator, which, according to the results of our calculation using formulas (1) to (4), is 0.037 MPa, which does not exceed the permissible limit for this type of separators – 0.05 MPa.

The effectiveness of the existing system for purification of associated formation water was assessed by the content of mechanical impurities – 4.15 mg/dm^3 (Fig. 7), which exceeds the permissible value. This shows that the traditional scheme for purification of associated formation water needs improvement. This is especially necessary when the flow contains finely dispersed impurities and the associated formation water is then used in the reservoir pressure maintenance system of the field.

CFD simulation of a cyclone separator of an improved design showed that changing the internal geometry affects the distribution of velocities, pressure, and flow turbulence (Fig. 8–10). The modeling established that additional turbulent flows are generated, which will contribute to the purification of the cyclone by reducing the "dead" or slow-moving zones of fluid movement. This is the advantage of the improved design solution compared to the conventional cyclone separator scheme.

There are limitations to this study in that the results are adequate within the framework of the adopted simplifications, calculation models, and boundary conditions. Also, the results of complex modeling assess the regularities of flow movement and give a relative assessment of the effectiveness of the proposed design solutions since they do not take into account the influence of all real operational factors.

Our study also has certain shortcomings. The study is based on modeling and requires further experimental verification either under field conditions or in laboratory setting. Further research should be directed to experimental testing of the proposed designs and optimization of their geometric parameters for actual industrial conditions.

7. Conclusions

1. We have proven that the installation of louvered packages in a three-phase oil and gas separator significantly reduces the removal of the liquid fraction of hydrocarbons into the gas stream. For the light fraction, the removal decreases from 0.20206 to 0.03076 kg/h, and for the heavy fraction – to 3.23953 · 10^{-6} kg/h, which indicates an increase in the quality of gas separation and additional condensate production of about 1500 kg/year.

2. Our calculations have established that the required area of louvered elements is 0.2546 m^2, and the total hydraulic losses are 0.037 MPa. This means that the separation efficiency could be increased without a noticeable increase in flow resistance.

3. CFD simulation showed that the improved design of the louver package with C-shaped elements provides a more uniform gas movement and creates zones with reduced speeds, in which liquid droplets settle better. Unlike the basic design, such a solution improves separation without a significant increase in pressure losses.

4. For the associated formation water purification system, it was found that after pre-treatment the content of mechanical impurities was 4.15 mg/dm^3, which exceeds the permissible value of 3 mg/dm^3. This confirms that the existing purification scheme needs improvement.

5. During the modeling of cyclone separators, it was proven that a change in the internal geometry affects the change in velocities, pressure, and flow turbulence. An increase in the flow turbulence intensity by an average of 27 s^{-1} causes a decrease in the number of slow-moving zones in the cyclone separator. This creates better conditions for the separation of oil inclusions and mechanical impurities from the aqueous phase and confirms the feasibility of further improving cyclone separators.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

In this work, the authors used GPT-5.2 for grammatical, linguistic, and stylistic correction. The authors manually checked and edited the material and confirm that artificial intelligence tools were only auxiliary and were not used for hypothesis generation and formulation, methodology, analysis of results, or formulation of conclusions.

Authors' contributions

Tetiana Nesterenko: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Project administration; **Ivan Nazarenko**: Methodology, Validation, Supervision; **Mykola Nesterenko**: Methodology, Formal analysis; **Oleksandr Shevchenko**: Writing – original draft; **Andrii Khyzhniak**: Writing – original draft; **Iryna Bernyk**: Formal analysis, Visualization; **Artur Onyshchenko**: Writing – original draft, Visualization; **Roman Moshkivskyi**: Writing – original draft, Visualization.

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