Laboratory experimental studies of the multiphase separator

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Abstract

In this paper we have characterized the vortex type separator for the four-phase mixture separation in traditional system of separation and redesign or improvement of the vortex type horizontal separator with gravity filter for minimizing the dimension and mass of the separator. There are also presented the experimental studies made on the basis of this equipment.

Keywords: *multiphase flow fluid, study of the multiphase separator, subsea separators, vortex type separator.*

A typical separator is a large pressure vessel designed to separate production fluids into their constituent components of oil, gas and water. The separator generally utilizes the force of gravity to separate oil-gas mixtures (due to different densities of the fluids). A hydrocyclone (desander and desilter) utilizes the centrifugal force and mass difference between solids and liquid densities for solids removal from fluid. Our main task is separating gas and sand from emulsion to significantly improve the reliability of the subsea equipment. For this purpose there is used a new type of a vortex four-phase mixture separator as well as a hydrocyclone for sand removal. A new type of separator enhances the separation efficiency by 99.9% due to the application of vortex forces in construction. The mass and dimensions of a new separator is 15 times less than that of a typical one.

The ideal system for separation and pumping should ensure separate pumping of multiphase medium components (fluid-gas-water-solid, usually sand) from oil well and the material should be transported to a 10-mile distance and more.

Laboratory experimental studies

The separator should be divided into all design elements to carry out detailed experimental studies. Figure 1 shows a diagram of pressure measurement points location in the separator. The scheme of pressure measuring enables to measure the pressure and pressure drop in all major cells of the separator depending on the separation efficiency.

The total pressure loss in the separator consists of pressure losses in its separate elements:

pressure loss when the gas-liquid mixture enters the separator;

pressure drop when the gas-liquid mixture passes through the separator and then between the separation package and the separator housing;

pressure loss during the gas passage through the separation package;

pressure drop at the confusor;

pressure loss at the pipe outlet.

Pressure losses in each element were determined by liquid indications of differential pressure gauges. The total pressure drop in the separator consists of the sum of pressure losses in each part of the separator.

To measure the pressure loss in the basic elements of the separator it was equipped with measuring tubes. Figure 1 presents the separator equipped with measuring tubes.

A laboratory experimental plant is able to determine the pressure loss in separator`s elements during the whole cycle of its operation, as well as pressure differences between the various elements of the separator. In addition, it allows sampling of gas-liquid mixture in each element of separator.

A laboratory experimental plant also allows us to create the actual operating conditions, under which the separation equipment is operated. It also helps to explore changes in technological and operational parameters of the separator`s main structural elements that affect the separation efficiency.

Pressure drop was measured by the differential pressure gauge in the separator cell. During laboratory experimental studies there were determined such parameters as gas flow (gas stream velocity at the inlet of the separator) and pressure drop in separator elements. During these experiments the limits of the rate of the gas flow change at the separator`s inlet were equal to the velocity of gas flow in real conditions.

The main parameter, which is measured during the experiments, is the difference of pressure in the cell of the separator because the pressure drop in the separator`s element mainly characterizes its efficiency.

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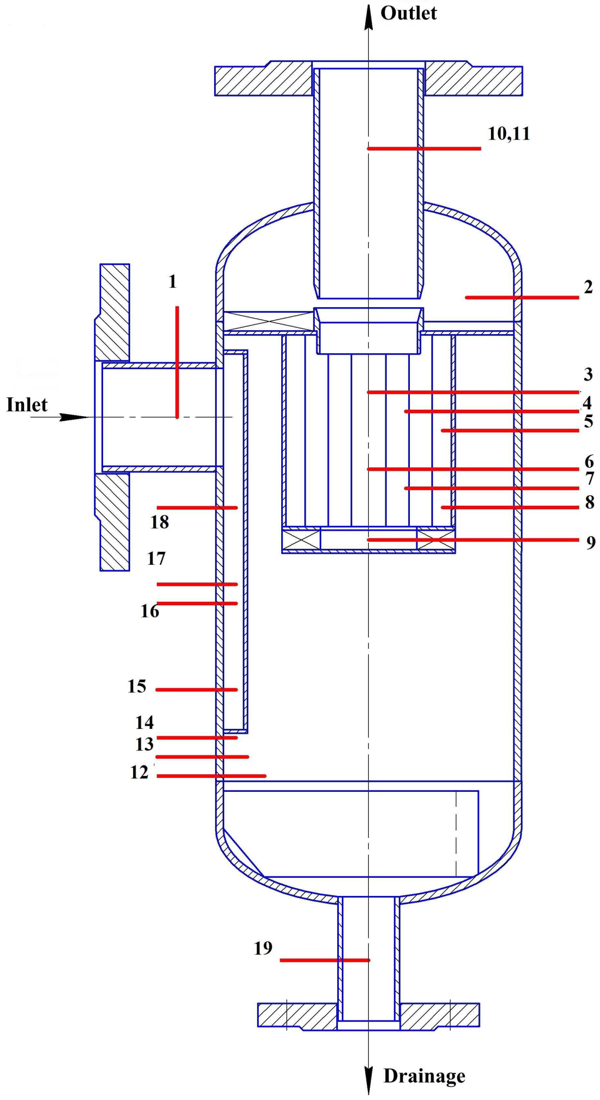

1 – inlet, 2 – chamber of accumulation, 3 – separation set, 4 – axial disk, 5 – disk, 6 – separation set, 7 – axial disk, 9 – radial plates, 10, 11 – gas outlet, 12 – pin, 13, 14, 15, 16, 17, 18 – drainage pipe

Figure 1 – Scheme of pressure measurement in the separator

Elaboration of rational design of the separator

When choosing a constructive solution, shortcomings of a typical separator as well as irregularities of its operation were taken into account.

Benefits of the chosen separator design are the following:

a typical aerodynamic scheme with the same centrifugal hydrodynamic situation around the active volume;

a fairly high separation efficiency;

its ability to operate under a wide range of workloads;

efficient operation during cork flow of fluid in the machine;

low hydraulic losses;

the ability to separate not only the moisture, but also impurities (sand);

elimination of the separator`s stop associated with its flushing from separated solids, i.e. continuity of its work;

the vertical design of the separator housing needs minor space (footprint), and this is important when designing systems on offshore oil and gas platforms or subsea systems or in a limited space;

separation of gas-liquid mixture in several stages;

improved structure of gas-liquid flow generated by the separation package to reduce specific metal of the separator more than tenfold relative to a jalousie separator and 15 times – relatively to gravity separators;

the analysis of the separator structure shows significant advantages of the offered separator design.

Fine particles and mechanical impurities going through the field of centrifugal forces are more effectively reflected than under the influence of the gravitational force. It is caused by the fact that centrifugal forces arising in typical centrifugal devices far exceed the force of gravity. For example, if the speed of the gas-liquid mixture is equal to 10 m/s in a gravitational separator, the acceleration of particles equals 9.81 m/s^2, while moving in the field of centrifugal forces, and a separator radius is 0.1 m, then the acceleration is equal to 1000 m/s^2, which is almost 100 times more.

The mentioned advantages of a new type of the gas separator and the centrifugal principle of its action were taken as a basis for the separating type of device with a centrifugal force.

Having examined the shortcomings of gravitational and centrifugal separators that exist today, we defined the following directions of their design to address the deep separation of the gas flow from the solids:

the housing should be a vertical separator. This design solution will provide a reliable drain of fluid using gravitational forces to separate drops of mixture. It eliminates a sedimentation zone that contributes to the accumulation of impurities;

the gas-liquid mixture must be placed in the upper part of the separator. This will prevent the backflow of gas and the separated liquid. This scheme will dramatically increase the load on the separator and improve the separation efficiency;

the device must operate over a wide range of loads both in gas and liquid phases, especially in a pulsed mode, which forms usual operating conditions of oil and gas separators;

due to the presence of liquid in the gas environment it's necessary to develop a separating device which captures liquid fractions;

there should be observed the simplicity of the separator design, manufacturing technology, low hydraulic resistance system, reliability.

These requirements are the basis for the separator design that is offered. A detailed description of the chosen separator design is shown above.

When the gas-liquid flow passes through the separator elements there is observed a gradual separation of phases at each structural element of the separator. Let's consider sequential motion of gas-liquid

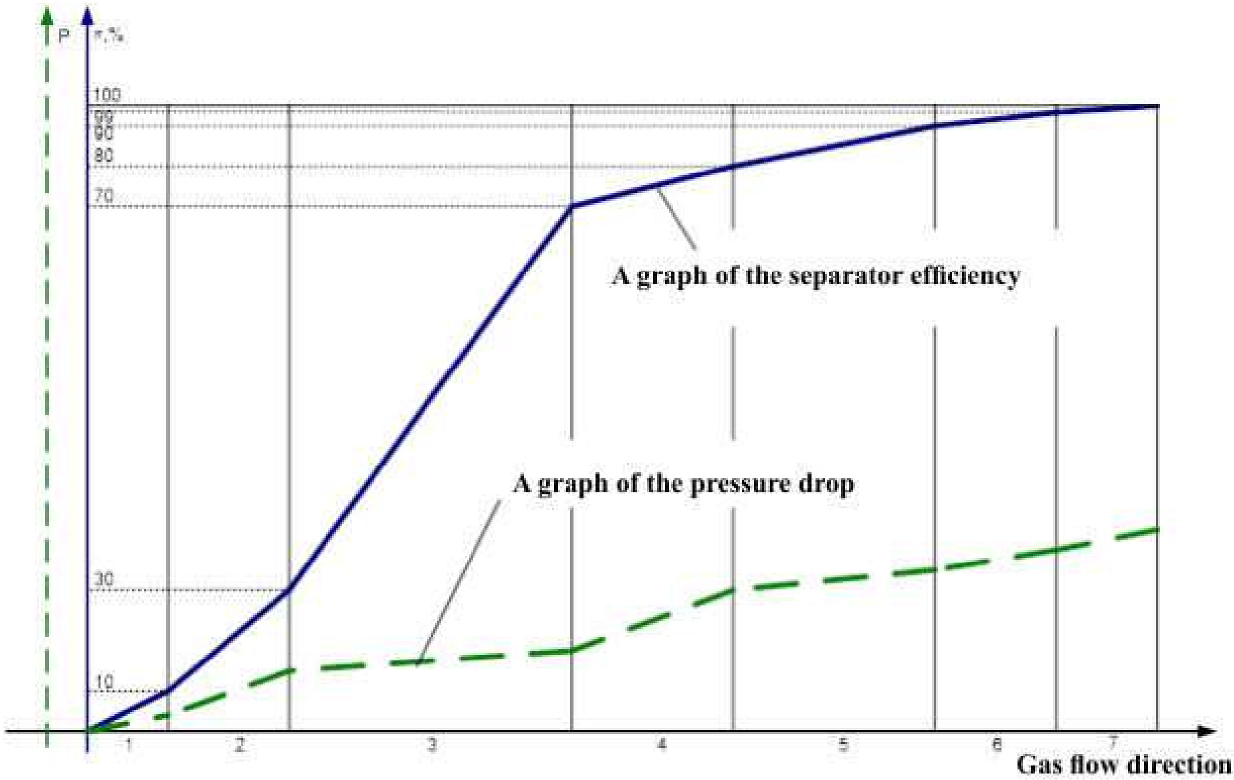

Figure 2 – The graph of liquids separation from the gas stream while passing through the separator elements

flow through separator elements and processes that affect the quality of phase separation occurring in each element.

Figure 2 shows a graph of fluid separation from the gas stream during the movement through the offered separator elements.

The offered separator can be conventionally divided into a set of separation stages, which include:

the inlet of the gas pipe;

the baffle;

the inner wall of the separator housing;

plates of the separation package;

the internal part of the separation package;

the confuser at the outlet of the separation package;

the outlet of the gas pipe.

As we can see from the graph in Figure 2 the main mass of water droplets and solids is separated into the deflector on the inner surface of the separator housing and the separation package. These design elements also create major pressure drops for the gas flow as it passes through the separator.

Let's consider separately the processes occurring at each stage of the separation process.

When the gas stream passes through the inner part of the gas pipe inlet there is observed the pre-separation of liquid and gas in the form of a ring.

The movement of fluid in the form of a ring is conditioned by the fact that the gas-liquid mixture moves at a speed that allows us to maintain a steady fluid motion with gas flow without forming liquid plugs, and the liquid with a certain density and viscosity is coagulated and moves in this direction in a pipeline. The separated liquid enters the separator with the gas flow.

Partially separated gas-liquid flow enters the deflector, where the rectangular gas-liquid jet is formed from the circular shape due to changes, providing the rotational component of motion. This is the next phase of separation. Then the separated liquid moves to the bottom of a deflector and to the bottom of the separator housing.

Gas-liquid mixture leaves the deflector and then hits the inside of the separator housing, where the primary phase of separation is implemented by centrifugal forces. The separated liquid and mechanical impurities continue their rotational movement in the form of the falling spiral and enter the trap pockets where they are sent to the bottom of the separator. The interior of the separator housing is a major element in separation, and the pressure drop is minimal in this part.

The gas stream, which contains a small amount of moisture drops after it was separated from the main mass of liquid, gets into cracks of the separation package. A moisture drip is reflected from gas-liquid flow due to inertial forces when it passes the cracks of the separation package. The droplets, suspended in the gas stream due to the effect of inertia forces, change the direction of the gas-liquid flow, hit the plate of the separation package, where they trickle down and get to the bottom of the separator.

Then the gas-liquid flow enters the inner cavity of separation package, where the liquid and solids are separated by centrifugal forces. After this the separated liquid flows into the bottom of the separator.

Gas enters the outlet of the separation package, where it runs through the outlet confuser. Here the fluid is separated during its upward movement at the plates of the separation package (this is the secondary removal from the device).

The purified gas enters the outlet pipe of the separator. This results in condensation of the dissolved moisture, which is in the vapor state, in the gas. Therefore, the gas gets to the next degree of separation and there is observed a certain number of moisture drops in the input gas stream.

Computer simulation of structural elements for choosing a separator

In order to optimize the design of the separator and its original structural elements, which improve the technical performance of the gas vortex separator (the inertial type), there were carried out computer simulations of separator`s real operating conditions.

The main technical characteristics of the gas separator subjected to optimization are the following:

pressure drop in the separator;

the capacity of the offered structure;

removal of its constituent elements or vice versa to improve the separator`s hydrodynamics.

To perform computer simulations of the separator construction there was built its 3D model (Fig. 3) on the basis of SolidWorks software. Computer simulations were carried out with the use of information technologies of CosmosFloWorks.

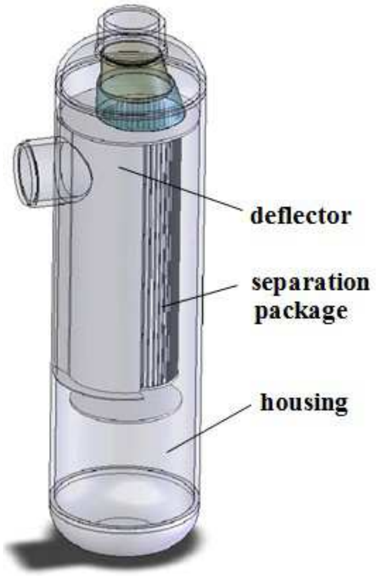

Figure 3 – The estimated 3D model of the separator

The structure of the estimated model includes all the basic design elements that are components of the separator basic design. In this chapter, computer studies are made based on the separator with the diameter of 273 mm and inlet and outlet pipes with the diameter of 100 mm (Table 1). To make calculations the separator is designed as a construction that includes a holding tank

Table 1 – The dependence of the separator`s dimensions on its operating pressure and capacity

Dimensions of separator		Pressure, MPa												
D, mm	H, mm	0.03	0.25	0.6	0.8	1.0	1.6	2.5	4.0	6.4	8.8	10.0	16.0	30.0
70	175	1.5	4	8	10	12	19	29	47	74	102	116	185	345
100	250	3	8	16	21	25	40	61	96	153	210	238	379	710
150	300	6	18	37	45	58	90	135	215	340	470	535	850	1590
200	430	12	30	65	85	100	150	240	380	610	835	940	1500	2800
265	500	20	55	100	140	160	270	410	650	1030	1300	1600	2550	4780
300	700	27	74	148	190	233	360	550	869	1378	1886	2141	3413	6380
350	750	38	100	200	270	315	515	790	1250	1980	2560	3080	4910	9150
450	1200	64	170	280	440	545	840	1290	2040	3230	4240	5020	8000	14900
500	1400	80	220	345	570	645	1070	1650	2600	4100	5235	6400	10200	19100
600	1500	110	290	590	760	930	1440	2200	3475	5510	7545	8560	13650	25515
700	1800	140	400	800	1030	1265	1950	2990	4700	7450	10240	11600	18500	34600
800	2000	195	525	1055	1355	1655	2560	3915	6175	9795	13410	15220	24265	45365
1000	2600	300	820	1645	2100	2590	3990	6100	9600	15200	20950	23700	37800	70700
1200	2900	440	1180	2370	3050	3730	5760	8800	13600	22000	30180	34200	54500	102000
1400	3400	590	1600	3230	4140	5075	7820	11950	18850	29900	41050	46450	74050	138450
1600	3600	780	2100	4220	5400	6630	10200	15600	24600	39000	53650	60600	96600	180600
		Flow rate of gas Q, Nm³/min												

as this design is the most complicated. Simulations were performed for the modes close to real operation modes of the separator (the gas flow rate is 3 m^3/s, the pressure is 1 MPa). However, the presence of a liquid phase in the gas flow is not taken into account during the simulation due to limitations of the software. That is why there are modeled motion modes of the pure gas. The laboratory and practical researches of the separator model show that the assumptions about the absence of a liquid phase in the gas stream do not significantly affect the basic elements of the separator aerodynamic performance.

Since the presence of a liquid phase in the gas flow is not taken into account, the drain pipe of liquid storage tanks is closed.

Modeling of the separator is based on the study of individual elements of the separator design, the quality of its operation and aerodynamics, movement of gas inside the device.

Figure 4 shows simulation results of the separator without a deflector. As we can seen from the Figure, the gas stream entering the separator passes straight through the separation package, almost not twisting. This stream is split into two components. One component of which tries to get into the holding tank of the separator, then gets to the bottom of the separation package, almost without rotational motion, and moves to the outlet pipe of the separator. The second component of the stream falls into the inner part of the separation package twisting and then goes through the outlet of the gas pipe.

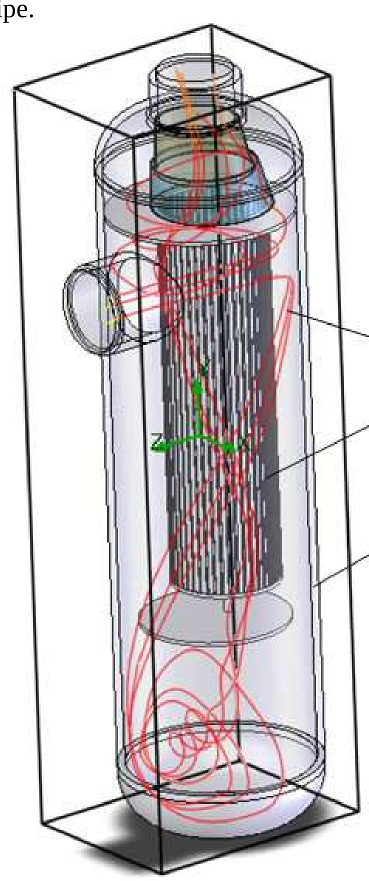

Figure 4 – The gas trajectory inside the separator without the deflector

These simulations confirmed the previous assumption that the deflector creates the necessary rotational movement of the gas flow in the inner part of separator. Thus the displacement of tangential entry of gas into the apparatus gives the desired effect. So we can conclude that the deflector is necessary for creating swirling flow of gas and ensuring the given speed in the separator housing.

As can be seen from the illustrations (Fig. 5), the gas flow enters the separation package, twisting around it, and tries to get into the separator`s holding tank.

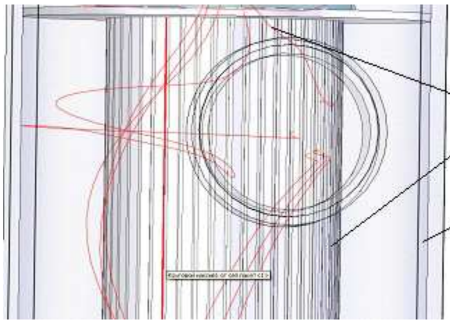

Figure 5 – Trajectory of the gas flow splitting in the separator without the deflector

This phenomenon is rather negative because the fluid in batch capacity should be the fluid at rest. The fluid will be removed by gas flows from the storage tanks only under these conditions. This confirms the need to evacuate the liquid by sand from lower part of the separator through the drain pipe.

Figures 6 and 7 show a computer simulation of the separator with a deflector.

However, it is clear from the illustrations that the color contours along the length are the same. This means that there is no significant pressure drop and the pressure is equal to 1 MPa across the cavity of the device.

Carrying out computer simulations of separator`s basic structural elements indicated their optimal design and their need for the design. These assumptions are confirmed by laboratory and practical researches of separator models. We have found that inner guide elements of the separator are made to prevent their wear in abrasive environments. Mechanical impurities and sand are not prejudicial in the gas-water stream and do not wear out separation design elements of the separator by the optimal placement, uniform distribution and direction of abrasive solids flow. They practically do not interact with internal guiding elements in the separation zone. This gas stream is purified from moisture and impurities in several stages. The improved characteristics allow most effective separation of liquefied moisture and impurities from the gas stream even in the modes other than those recommended. This means that the separating efficiency of the separator equals 99.9 % in performance from 10 to 130 % of the nominal value. The working pressure of the separation process has virtually no effect on the efficiency of the separator and is subject to change in a wide range of operation [5–7].

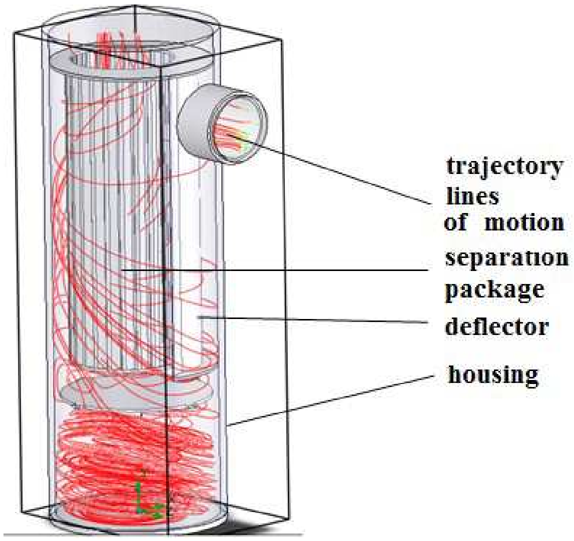

Figure 6 – Trajectory of the gas flow in the separator with the deflector

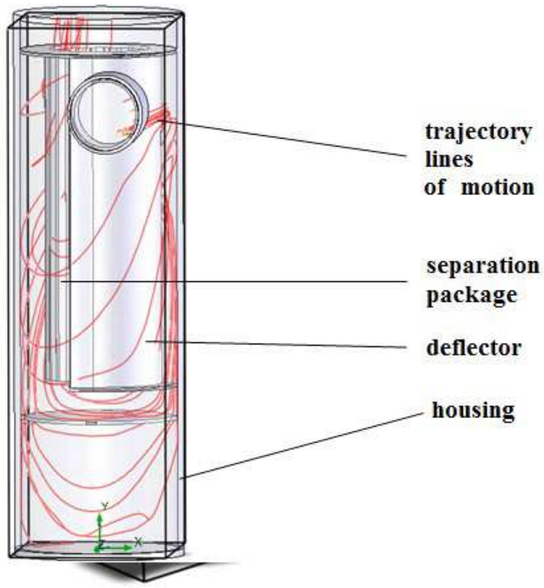

Figure 7 – Trajectory of the gas stream in the separator with the deflector

Conclusions

1. The structural elements of the separator are chosen. There has been illustrated the impact of each of the internal elements of the separator on the value of its effectiveness coefficient. It is shown that majority of moisture and solids droplets are separated in the deflector on the inner surface of the separator housing and in the separation package.

2. The dependence of thermodynamic parameters (pressure and density) of separated gas-liquid mixture on the radius of the layers rotation has been theoretically investigated. The analytical dependence of the separator efficiency on the gas flow and pressure in the separator, its geometric parameters and others characteristics have been determined.

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Лабораторні експериментальні дослідження багатофазних сепараторів

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Описано новий тип вихрового сепаратора для чотирифазної суміші. Наведено результати експериментальних досліджень.

Ключові слова: *багатофазний пластовий флюїд, вихровий сепаратор, дослідження багатофазного сепаратора, підводні сепаратори*