Development of vertical and horizontal vortex type separator for subsea application

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Abstract

The paper offers 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, collecting sand in a separate tank, enhancing mechanical properties of a multiphase twin-screw pump material by decreasing the hydro-abrasive wear. The mathematical model for the proposed construction of the separator is also elaborated.

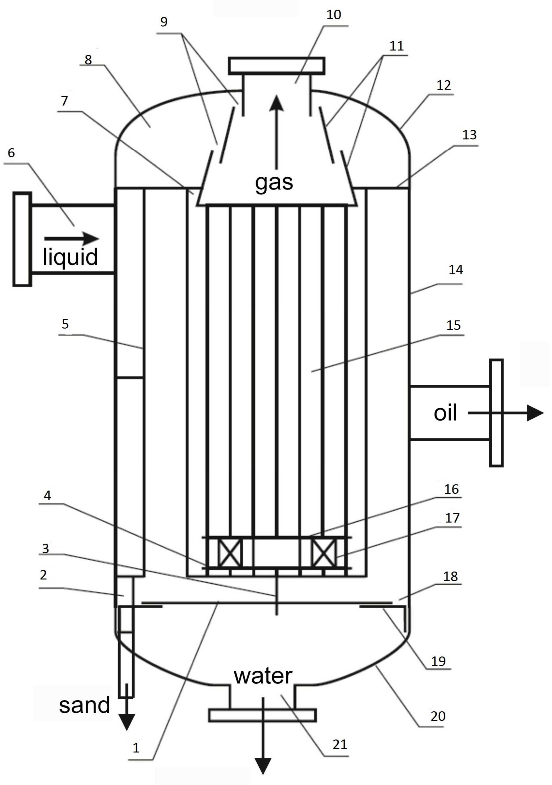
Keywords: *mathematical model, multiphase mixture, subsea separator.*

Traditional separator is a large pressure vessel designed to separate production fluids into their constituent components of oil, gas and water. Generally the separator utilizes the force of gravity to separate oil-gas mixtures (due to different densities of the fluids). Hydrocyclone (desander or desilter) utilizes centrifuge force and mass difference between the density of solid and liquid for solid's removal from fluid [1–3]. Our main task is to separate water, gas and sand from oil to raise the reliability of the subsea boosting twin screw pump considerably. For this purpose a new type of vortex four-phase mixture separator is used as well as a hydrocyclone for sand removal. A new type of separator enhance the efficiency of separation to 99.9 % due to application of vortex forces in construction. The mass and dimensions of a new separator is 15 times less than the usual one [4].

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

We have studied two variants of a vortex type separator in this paper. Vertical one has both its advantages and disadvantages. This type of a vortex type separator helps to lift four phases of fluids from the seabed, which makes all the products to be separated (Fig. 1).

This technology consists of a vertical separator with the inlet near the top with vortex separate plates and compartments in which gas is separated from oil, water, and sand. Then water goes to the very bottom, where it is evacuated by the pump to the liquid-water phase, and the gas-phase gets upwards out of the center of the separator positioned at the top.



1– conditional bottom, 2 – drainage pipe, 3 – pin, 4 – disk, 5 – deflector, 6– inlet, 7 – catching space, 8 – chamber of accumulation, 9 – clearances ring, 10 – gas outlet, 11 – conical directional confusor, 12 – cover, 13 – horizontal divertor, 14 – cylindrical housing, 15 – separation set, 16 – axial disk, 17– radial plates, 18 – circular clearance, 19 – L-form plates, 20 – bottom, 21– emulsion outlet

Figure 1 – Vertical vortex type four-phase mixture separator

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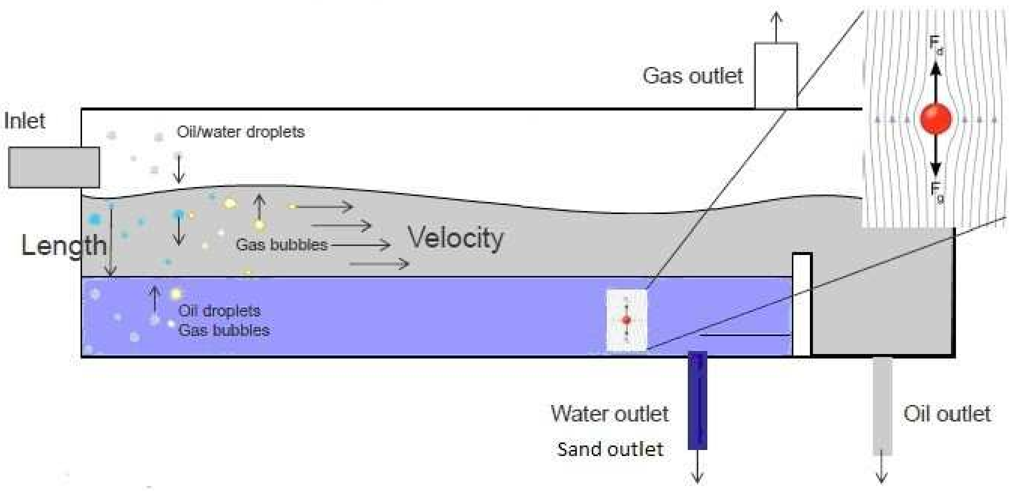

Figure 2 – Scheme of multiphase separation in a horizontal vortex-type separator

Due to its helix motion and low density gas gathers in the center and flows out of the gas outlet near the top of the separator in the opposite side of the inlet. Oil is directed to the wall and flows into an outlet pipeline.

As can be understood from the previous explanation the separator has four outlet compartments: an outer cylindrical compartment where gas is separated; the compartment where oil is collected on the periphery and separated from the gas, water, and sand; the compartment, where the liquid phase encounters initially; and the inner cylindrical compartment where the water gets pumped out.

Separation occurs in both the tangential and inclined inlets as well as within the separator itself. Heavy liquid is directed to the wall due to centrifugal forces while light gas gets directed to the center and flows out from the top gas outlet. Liquid is separated in a circular motion as it falls until the liquid level is reached. Some gas is carried to the liquid outlet and then it is pumped with the liquid while the liquid carryover takes place at the gas outlet. In this case there may form emulsions but we can avoid them and improve separation of sand from water by regulating the velocity of the output stream from the well. This is important due to the fact that water has to undergo re-injection after its separation for maintaining reservoir pressure in the well. That is why water must be less aggressive for the equipment.

Another variant of a vortex type separator is a horizontal vortex type separator (Fig. 2). We add a gravity filter for improving the process of separation. The advantage of this type of separator is that the gravitational forces are in conjunction with centrifugal forces. This kind of water can be easily re-injencted in the well. In this case we have to construct a body of this type of separator for obtaining an easy access to the gravity filter because it can quickly deteriorate and fix this element due to the sand abrasion. During the process of subsea separation it is difficult to perform these actions. The sand handling part would be carried out by a sand jetting arrangement in the separator.

During analysis of the mechanism of separation and its performance it is observed that the stream of a four-phase gas-liquid-solid mixture comes from the inlet pipe to the separator.

Drops of liquid phase (water and oil) are formed in the flow from the source of admission (reservoir) and to the entrance of the separator. For evaluation the efficiency of the separator it is necessary to know the volumetric content of the liquid phase ω, the average radius R_c of the soil and its distribution in size $n(R)$. The pressure and temperature are continuously changing during the development of deposits and gas movement from the reservoir to the separator. As a result, the thermodynamic equilibrium of the whole four-phase multi-component system is disturbed and the process of mass transfer (condensation and evaporation) occurs between the phases.

Sand and hydrates lead to the formation of small solids, whose size varies due to hydrates growth in supersaturation conditions and coagulation as well as grinding in the multiphase stream. As a result, equilibrium distribution of solids in size, characterized by the parameters ω, R_c and σ_1, where σ_1^2 is the variance distribution, takes place in the inlet pipe before the separator.

If there is no any device of prior condensation before the separator, the gas flow with established distribution $n(R)$ enters the separator, in which the phase separation occurs. In this case, the basic mechanism of the solids formation in a turbulent multiphase stream is pounding and coagulation processes occur. Both processes occur simultaneously. As a result, there is formed a size distribution. Based on experimental data it has the form of the following lognormal distribution:

$$n(R) = \frac{n_* R_1}{\sigma_1 R} \exp\left\{ -\frac{\ln^2 (R / R_1)}{2\sigma_1^2} \right\}, \qquad (1)$$

where R is a radius of the droplet,

$$n_* = 3\omega \exp\left(-5\sigma_1^2/2\right) / 4\pi\sqrt{2\pi} R_c^4,$$

$$R_1 = R_c \exp\left\{-\sigma_1^2/2\right\}.$$

Calculation of the variance distribution showed that the separator's characteristic σ_1 is from 0.4 to 0.5 over a wide speed range.

To determine the average radius R_c of solids it's necessary to consider the mechanism of coagulation and crushing. It is known that the solid in a multiphase stream is crushed when its radius exceeds a certain critical value.

The probability of solids crushing with radius smaller than the critical value is very small and therefore they can only coagulate until their size reaches a critical value again. Therefore, it's necessary to take a critical radius as a medium radius, which has been determined experimentally in a turbulent multiphase stream. Analysis of experimental results has led to the following empirical formula:

$$R_{cr} = 0.12 d We^{-3/7} \left(\rho / \rho_1\right)^{4/7} , \qquad (2)$$

where ρ is the density of the gas phase; ρ_1 is the density of the liquid phase; $We = \frac{\rho \Delta u^2 d}{\sigma}$ is the Weber number; Δu is the difference of the multiphase velocity in a pipe at its inlet and outlet; d is the diameter of a pipe; σ is the surface tension of the liquid phase.

The main parameter that characterizes the degree of separation of liquid from the gas separator is the efficiency factor equal to the ratio of the volume of the liquid phase Q_{dep}, deposited in the separator, to the volume of the liquid phase Q_{lp}, contained in the gas stream at the separator inlet:

$$\eta = \frac{Q_{dep}}{Q_{lp}} .$$

Thus the assessed efficiency factor η depends on the design of the separator, thermobaric conditions, flowsheet parameters, composition and physico-chemical properties of gas-liquid-solid flow.

As the separation of gas and liquid-solids phase mixture is very fast in the inertial separators, construction of which is studied, so it is assumed that the change in the separator thermobaric conditions does not have time to significantly affect the initial distribution of solids, which is the input stream gas-liquid-solid mixture. Based on this assumption the separator efficiency ratio is calculated according to the following formula:

$$\eta = 1 - \frac{\omega_1}{\omega_0} , \qquad (3)$$

where ω_1 is a volumetric liquid content in the flow inlet separator, equal to:

$$\omega_0 = \int_0^{\infty} V n_0 \left(R\right) dR , \qquad (4)$$

where ω_0 is a volumetric liquid content in the stream at the outlet of the separator, equal to:

$$\omega_1 = \int_0^{R_m} V n_0 \left(R\right) dR , \qquad (5)$$

where $V = \frac{4}{3} \pi R^3$ is the volume of solid; $n_0(R)$ is the initial distribution of solids at the inlet; R_m is a minimum radius of solids in the separator.

When we substitute (4) and (5) into (3) we obtain the following result

$$\eta = 1 - \frac{4\pi}{3\omega_0} \int_0^{R_m} R^3 n_0 \left(R\right) dR . \qquad (6)$$

If a lognormal distribution, provided in (1), is taken as the initial distribution, we receive the final expression for determining the efficiency of the separator

$$\eta = 1 - \frac{\exp\left(-3\sigma_1^2\right)}{\sqrt{2\pi}\sigma_1} \int_0^{Z_m} z^2 \exp\left\{ -\frac{\ln^2\left(z / z_1\right)}{2\sigma_1^2} \right\} dz , \qquad (7)$$

where $Z_m = R_m / R_c$; $z_1 = R_1 / R_c = \exp\left(-\sigma_1^2 / 2\right)$.

As follows from the expression (7) the efficiency of the separator is determined by the upper limit of the integral Z_m, and thus by the limit of a minimum radius of solids R_m, deposited in the separator. Therefore, it is necessary to explore the process of solids separation in the separator, shown in Fig. 3. The separator consists of two coaxial cylinders with the equal height, outer radius r_2, inner radius r_1, and it has jalousie type holes. The pipe, through which a gaseous mixture is fed into the space between the cylinders by the inlet pipe with the diameter d, is adjacent to the inner surface of the outer cylinder.

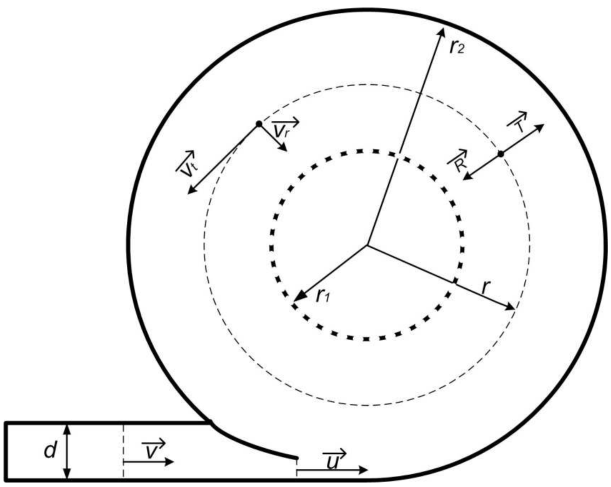

Figure 3 – Scheme of inertial vortex type separator

The main factors that determine the efficiency of the separator are the centrifugal force T, which is directed from the axis to the periphery, and the resistance force R, oppositely directed to T. To simplify the calculation model there are neglected the vertical forces, acting on the motion of solids, and it is assumed that the solid moves in a plane perpendicular to the axis of the separator. This assumption somewhat simplifies the true picture of the solids traffic, but considering that the centrifugal force is of the major importance, it is quite justified.

In case of similar conditions (the diameter of solid, its density, viscosity and the density of the medium) the resistance force of the medium depends on the radial velocity component υ_r, and centrifugal force T – from centrifugal acceleration a, which, in its turn, is directly proportional to the square of the tangential velocity υ_t:

$$a = \frac{\upsilon_t^2}{r}.$$

Centrifugal force in the multiphase stream can be found by the formula:

$$T = \frac{4\pi R^3 (\rho_1 - \rho)\upsilon_t^2}{3r}, \quad (8)$$

where r is the radius of the solids trajectory; υ_t is the tangential velocity at this radius; R the radius of the solid; ρ_1 is the density of the liquid phase; ρ is the density of the medium.

Conclusion

These two variants of separators have both advantages and disadvantages, but the laboratory testing can accurately show which option will have better performance and quality separation. It is a mathematical theory and it needs to be proved in case of the multiphase mixture.

References

[1] Zuniga, SO & Gudmundsson, JS 2013, 'Separation technologies in oil and gas production'; *Institutt for petroleumsteknologi og anvendt geofysik*k; Innlevert: juni 2013.

[2] Prescott, CN 2012, 'Subsea Separation and Processing of Oil, Gas & Produced Water Past, Present and Future: Why We Need It Now', *Fluor Offshore Solutions*, USA [13 January 2012].

[3] Acker, RM 1978, *Liquid – Gas Separator Apparatus*, US Patent 4231767, Int. cl. B01D 19/00; Available from [4 November 1980].

[4] Yuriev, EV 2010, 'Computer investigations of optimal design separator', *Scientific Bulletin of Ivano-Frankivsk National Technical University of Oil and Gas*, no 2(24), pp. 90–93. (in Ukrainian).

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Розроблення вертикального і горизонтального сепаратора вихрового типу для підводного застосування

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У даній статті запропоновано вдосконалену конструкцію сепаратора вихрового типу для розділення чотирифазної суміші в традиційній системі і оптимізований дизайн горизонтального вихрового сепаратора з гравітаційним фільтром для зменшення маси самого пристрою, відсіювання сепарованого піску в спеціальну ємність для захисту від абразивної дії на матеріал двогвинтового багатофазного насоса. Наведено математичну модель сепаратора.

Ключові слова: *багатофазна суміш, математична модель, підводний сепаратор.*