Improvement of formation fluid separation efficiency

M Ya Khabibullin

Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation

E-mail: m-hab@mail.ru

Abstract. Producers and researchers pay attention to the improvement of high-quality and productive separation of liquid heterogeneous systems in the oil and gas industry. To perform these operations, various designs of sedimentation tanks, separators, hydrocyclones, etc. based on gravitational and centrifugal separation of inhomogeneous masses of various densities are used. A further noticeable increase in the diameter of the rotor, for example, up to 1500 mm, is associated with the search for new design forms of separators. This is due to serious design studies and restructuring of the production base.

1. Introduction

Producers and researchers pay attention to the improvement of high-quality and productive separation of liquid heterogeneous systems in the oil and gas industry. To perform these operations, various designs of sedimentation tanks, separators, hydrocyclones, etc. based on gravitational and centrifugal separation of inhomogeneous masses of various densities are used.

2. Results and discussion

In liquid separators, the separation surface is formed by a package of conical plates. Their performance is determined by the performance index determined by formula [1, 2]:

\[ \Sigma Q = \frac{2\omega^2 V}{g}, \]

where \(\omega\) – angular frequency of rotation of the separator rotor, \(\text{min}^{-1}\); \(V\) – volume limited by the working surface of the separation and its closing plane, \(\text{m}^3\); \(g\) – gravity acceleration, \(\text{m/s}^2\).

A natural way to increase \(\Sigma Q\) is to increase the size (diameter and height) and the number of plates. However, this leads to an unacceptable increase in the height of the rotor, worsening dynamic characteristics of the separators, and an uneven increase in the height of power supply of the package. It is known that modern relationships between the diameter and the height of rotors are dictated by many years of experience and supported by theoretical considerations regarding the optimal dynamic characteristics of separators. An increase in the number of plates is possible due to an increase in the height of the rotor, and a decrease in the gap between the plates for individual separated liquids. The volume limited to one plate of the separation packet in its constant form can be expressed as the product \(aR_t^2z\), where \(a\) is the proportionality coefficient; \(R_t\) is the largest radius of the plate.

\[ \Sigma Q = \frac{2aR_t^2z \omega^2}{g}, \]

where \(z\) – number of plates in one bag.
Given that the working linear speed of the rotor points farthest from the axis of rotation is \( v = \omega R \) (\( R \) – rotor radius), and conditionally assuming that the number of plates is proportional to \( R \), we have:

\[
\Sigma Q = \frac{2a_1 \omega^2 R^2}{g},
\]

where \( a_1 \) – a new coefficient of proportionality equal to the ratio of the total volume limited by all plates to \( R^4 \).

For further calculations, let us use the allowable value of the strength criterion of rapidly rotating nodes

\[
[Ne] = \frac{[\sigma]}{\rho},
\]

where \([\sigma]\) – allowable stress for the rotor material, MPa; \( \rho \) – density, kg/m\(^3\); \([\sigma]/\rho = \gamma \) – specific strength of the material.

Then

\[
\Sigma Q = 2\gamma a_1 R^2/[g[Ne]],
\]

The value \([Ne]\) for a rotating steel cylindrical rotor filled with water can be taken equal to 2 [3,4]. In this case, we have

\[
\Sigma Q = a_1 R^2/g,
\]

According to the last expression, performance of the separator at a given linear speed of the rotor can be increased by increasing the radius of the plate and the rotor.

From the expression for \([Ne]\) it follows that:

\[
\theta^2 = (\omega R)^2 = \gamma[Ne] = \text{const};
\]

\[
\omega = \frac{1}{R} \sqrt{\gamma/[Ne]},
\]

The specific strength of the material is the square of the peripheral fracture rate of a rotating thin ring made of the same material. Denoting the linear safe speed through \( \theta_d \) formula (7) at \([Ne] = 2\) can be written as

\[
\omega = 0.71 \frac{\theta_d}{R},
\]

At given values of density of its material and the liquid to be separated, the following relationships are given in [5] for a cylindrical rotor:

\[
s/R = f([Ne]),
\]

where \( S \) – rotor’s wall thickness.

Based on these dependencies, we built the dependence of ratio \( \theta_d/\theta \) on the relation \( sR \) (Figure 1).

3. Experiment

Let us use the example presented in [6]. It is required to design a rotor whose inner radius is 0.346 m, rotating with a frequency of 4500 rpm. Allowable stress \([\sigma] = 450 \text{ MPa} \). The linear velocity of the rotor surface at a radius of 0.316 m is 163 m/s, while the safe speed is \( \theta_d \leq 239.4 \text{ m/sec} \). The ratio \( \theta_d/\theta = 1.47 \).

This relation corresponds to the ratio \( s/R = 0.08 \); therefore, the wall thickness will be \( s = 27.7 \text{ mm} \).
As follows from Figure 1, the ratio $s / R = 0.175$ corresponds to a minimum of the ratio $\psi_d / \psi = 1.325$. Therefore, at the same value $\psi$ it is possible to increase the speed by $1.47 / 1.325 = 1.1$ times (i.e. by 10%), but the wall thickness will increase by $0.175 / 0.08 = 2.2$ times (the rotor mass will also increase accordingly). Figure 1 shows that a further increase in operating speed (when $1.325 \psi > \psi_d$) is excluded.

The reserve for increasing the rotor speed is possible by reducing the destructive speed. If you use the converted formula for the probability of non-destruction, taking the normal distribution of the strength of the material of the rotor, you can write [7]:

$$ P = 1 - \frac{1}{\sqrt{2\pi}} \int_0^{\infty} \exp \left(-\frac{x^2}{2}\right) dx, $$

(10)

where $b = \frac{K_{\psi}^2 - 1}{\sqrt{\psi_s^2 K_{\psi}^4 + \psi_s^2}}$; $P$ – rotor uptime; $K_{\psi}^4$ – speed margin; $\psi_s = 0.19$, the coefficient of variation of specific strength of the rotor for steel; $\psi_{si}$ – coefficient of variation of the square of rotor speed, which is taken equal to zero.

Calculating values of $b$ for different values of $K_{\psi}^4$, let us find the values of probability of non-destruction of the rotor by the standard method [8] (table).

| Parameters | Values |
|------------|--------|
| $K_{\psi}$ | 1.41   | 1.35 | 1.3 | 1.25 | 1.2 | 1.15 | 1.1 |
| $P$        | 0.9957 | -    | 0.9842 | - | 0.9463 | 0.8997 | 0.8186 |

Figure 2 shows the graph $P = f(K_{\psi})$. 

**Figure 1.** The dependence of the ratio $v_d/v$ of safe speed to the working speed on the ratio $S / R$ of the wall thickness to the radius of the rotor.
Figure 2. The dependence of probability of non-destruction of rotor \( P \) on the safety factor for speed \( K_u \)

The reserve of an increase in speed of the rotor is possible by reducing the value of destructive speed and decreasing its reliability.

Sufficient safety is ensured at a speed margin of 1.41, which corresponds to the twofold safety margin. In this case, only four out of 1000 rotors can be destroyed [9, 10]. However, if the margin of speed is reduced to 1.1, the probability of operational safety will decrease to 0.8186, i.e., an increase in permissible speed by 31% leads to a significant increase in probability of destruction, since almost 20% of rotors can be destroyed. Figure 3 shows the dependences of the rotor diameter on its rotation speed on the basis of equality (7) for two values \( P \) of the rotor failure-free operation. In Figure 3, dots denote parameters \( D = f (n) \) of modern separators. Most points are located near the bottom curve. The graph allows us to identify the border of the modern separator industry by values of the diameters of the rotors (shown by a dashed line).

Figure 3. The dependence of diameter \( D \) of the rotor on speed \( n \) of various separators (the dashed line delineates the border of modern separator construction): 1 - SA-160-06-117; 2 - MDA-300; 3 - SDS-901 K-01; 4 - MRPX-418; 5 - SB-80-36-076; 6 - SDS-530K-1; 7 - SB-60-36-076; 8 - SDS-531K-01 ; 9 - SAMR5036M; 10 - SOS-501K-3
4. Conclusion
To increase speed of the rotor, it is necessary to reduce the value of destructive speed and decrease its reliability. A further noticeable increase in the diameter of the rotor, for example, up to 1500 mm, is associated with the search for new design forms of separators. This is due to serious design studies and restructuring of the production base.

References
[1] Khabibullin M Ya and Suleimanov R I 2018 Selection of optimal design of a universal device for nonstationary pulse pumping of liquid in a reservoir pressure maintenance system Chemical and Petroleum Engineering 54(3-4) 225-232 DOI: 10.1007/s10556-018-0467-2
[2] Khabibullin M Ya, Suleimanov R I, Sidorkin D I and Arslanov I G 2017 Parameters of damping of vibrations of tubing string in the operation of bottomhole pulse devices Chemical and Petroleum Engineering 53(5-6) 378-384 DOI: 10.1007/s10556-017-0350-6.
[3] Polyakov V N, Chizhov A P, Kotenev Yu A and Mukhametshin V Sh 2019 Results of System Drilling Techniques and Completion of Oil and Gas Wells IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012119 1–7 DOI: 10.1088/1755-1315/378/1/012119
[4] Korn G A and Korn T M 1984 Mathematical Handbook for Scientists and Engineers: Definitions, Theorems, and Formulas for Reference and Review (Moscow: Nauka)
[5] Welsh E 1987 Borehole Coupling in Porous Media Ph. d. Thesis, Colorado School of Mines, Golden, Colo
[6] Barber A H, George C J, Stiles L H and Thompson B B 1983 Infill Drilling to Increase Reserves-Actual Experience in Nine Fields in Texas, Oklahoma and Illinois J. Pet. Tech 1530-1538
[7] Kuleshova L S, Kadyrov R R, Mukhametshin V V and Akhmetov R T 2019 Auxiliary equipment for downhole fittings of injection wells and water supply lines used to improve their performance in winter IOP Conference Series: Materials Science and Engineering (MEACS 2018 – International Conference on Mechanical Engineering, Automation and Control Systems) 560(1) 012071 1-6 DOI: 10.1088/1755-899X/560/1/012071
[8] Haoran Zh, Yongtu L and Xingyuan Zh 2017 Sensitivity analysis and optimal operation control for large-scale waterflooding pipeline network of oilfield Journal of petroleum science and engineering 154 38-48
[9] Sun W and Mun-Hong H 2017 Forecasting and uncertainty quantification for naturally fractured reservoirs using a new data-space inversion procedure European Assoc Geoscientists & Engineers Computational geosciences 15th Conference on the Mathematics of Oil Recovery (ECMOR) (Amsterdam, Netherlands) 21(5-6) 1443-1458
[10] Malyarenko A M, Bogdan V A, Kotenev Yu A, Mukhametshin V Sh, Umetbaev V G 2019 Wettability and formation conditions of reservoirs IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012040 1–6 DOI: 10.1088/1755-1315/378/1/012040