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Rotary Gas Separators in High GOR Wells, Field and Lab Tests Comparison

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Abstract

Monitoring and testing of subsurface equipment is crucial when stepping up artificial lift efficiency. Oil production using electrical submersible pumps (ESP) in RN-Purneftegas was initially complicated by a strong gas influence. The main method to increase ESP performance in wells with a high GOR is using rotary gas separators. Subsurface equipment adjustment for high GOR conditions, including gas separator calibration, is of primary importance, due to a strong influence of the ESP design on well performance.

To perform the corresponding calculations, appropriate data is necessary. Currently, there are many tools and measurement devices for oil production monitoring and controlling, however, it is impossible to use its data without a good understanding of all the parts of the ñreservoir-well-pumpò production chain. The artificial lift team formed under Rosneftôs New Technology System program conducted a wide range of field tests. The main goal of such tests was gathering information for parameter analysis and proper timing of ESPs with malfunctions in rotary gas separators. The collected information about real field performance was then used for validation of the accuracy of the lab data for gas separator performance, acquired by Russian State Oil&Gas University. It was concluded that the gas separator performance data obtained in laboratory if combined with correlation for natural separation prediction can be used for total separation efficiency estimation. The test results allowed us to estimate the potential for oil production increase at over 700 tons per day in Purneftegas.

Importance of separation efficiency for well performance

A number of geological and technical factors such as pump performance acquired in lab tests with a single phase fluid (typically water), or well operation history are used in ESP calibration. However, gas separator performance had not been adequately modeled during previous ESP sizing. The separator was treated as an intake module with constant separation efficiency in most cases.

Yet separation efficiency is a critical parameter for the performance of an injecting well. If we increase separation efficiency than ESP stages performs better, and we can attain a lower bottom-hole pressure. Figure 1 demonstrates the correlation of potential bottom-hole pressure and flow rate with different separation efficiencies for some of Rosneftôs oilfield.

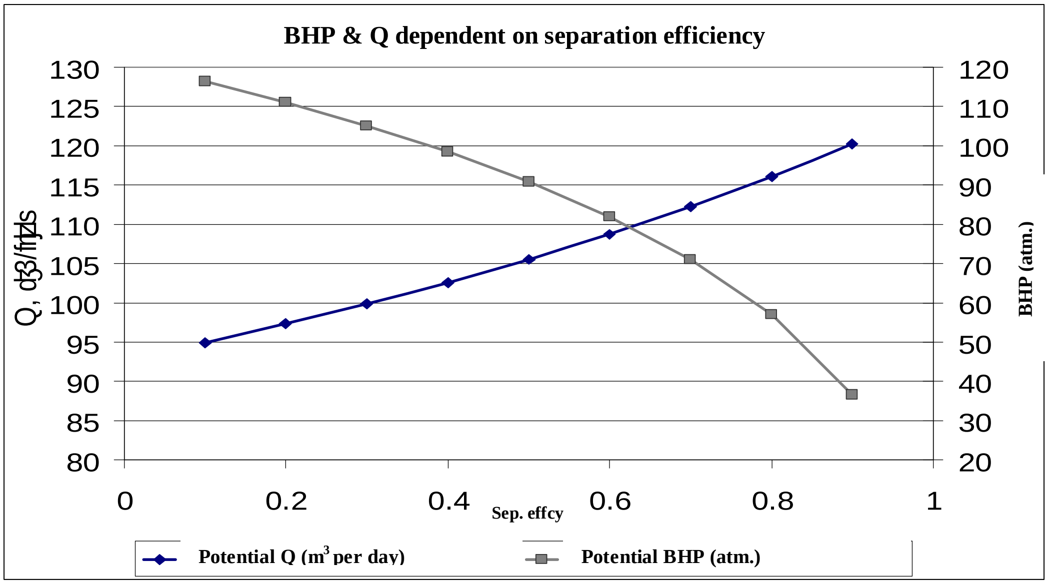

Figure 1. Bottom-hole pressure and well rate dependent on separation efficiency

Errors in separation efficiency estimation result in an inappropriate design of the equipment, dropping oil rates and equipment run life, and increasing electricity consumption. Figure 2 shows that different types of equipment must be calibrated in case of different separation efficiencies for the same flow rate. The head curve of ESP REDA D2400N is presented in the figure mentioned. The solid lines indicate the inflow performance reservoir curve, the vertical lift performance curve with Es=05, and the ESP head curve with 347 stages, allowing for the rate of 105 cubic meters per day. The dashed lines designate the IPR and VLP with the separation efficiency = 0.8. For the rate of 105 cubic meters per day, 408 ESP stages are required. This case required additional stages, because of a higher density of gas liquid mixture in the tubing necessitating additional energy to perform lift of 105 m^3 per day.

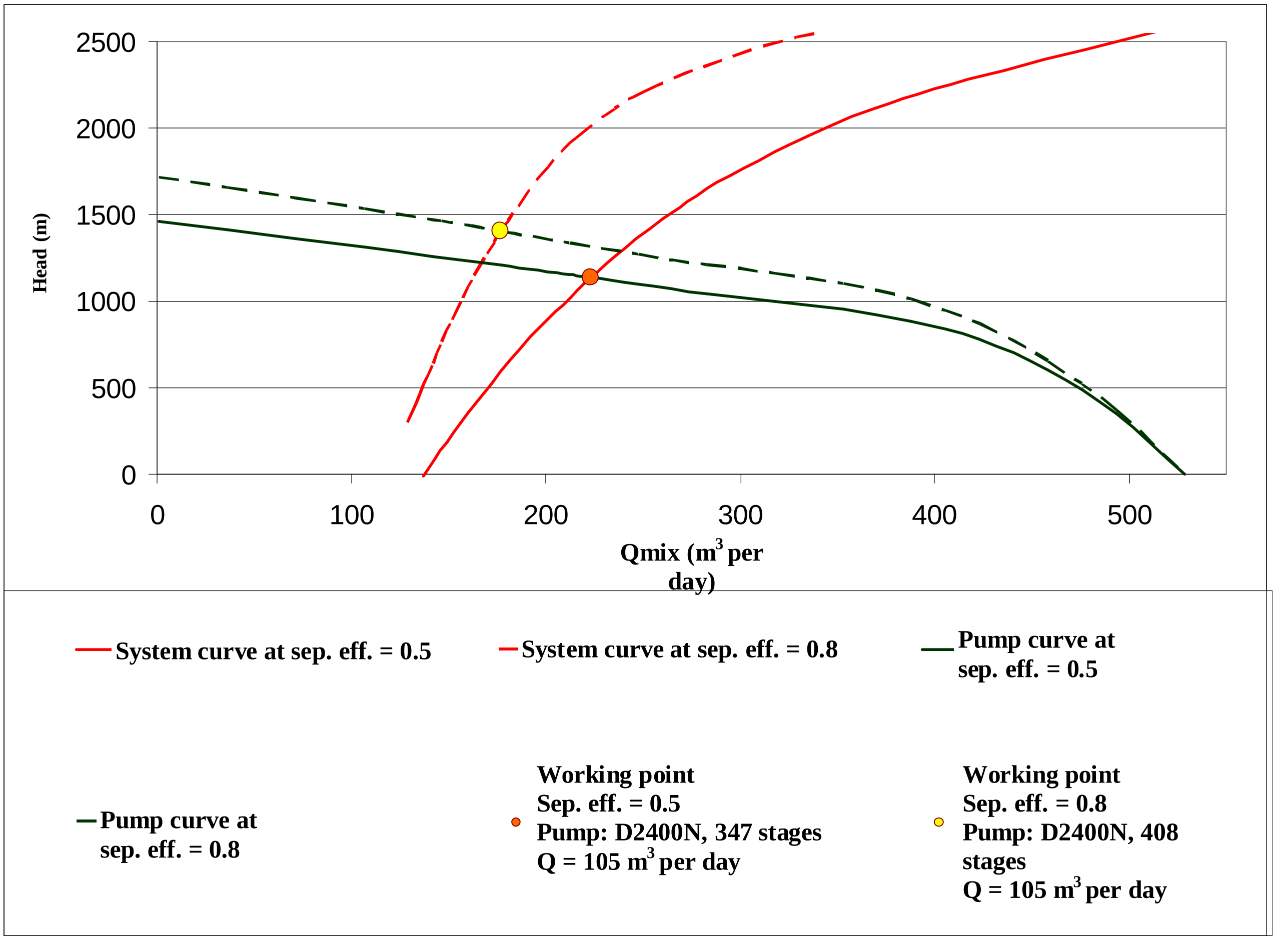

Figure 2. Results of ESP sizing for different separation efficiency values

Definition of separation efficiency

Let us consider gas movement at the section of pump with a rotary gas separator in the well. The gas flow is divided into two parts: one part goes into the pump intake, while the other part moves up into the annulus. This process is called **natural separation** of the gas. The gas that goes to the intake is separated by centrifugal forces from the gas-liquid mixture, and pushed out into the annulus by the inducer head. The separation process performed in the gas separator is called **artificial separation**. Thus, in order to determine separation efficiency, we have to estimate both natural separation efficiency and artificial separation efficiency.

Natural separation

The natural separation process has been investigated by many researchers in Russia (Lyapkov) [6] and the US (Alhanati, Serrano, Harun, Marquez, etc.) [8]. Many correlations and mechanistic models have been developed to describe and quantify this process. The most affecting factors are:

- Flow rate
- Flow regime
- Pump intake outer diameter
- Casing inner diameter

- Well deviation and pump eccentricity
- Fluid viscosity
- Fluid flow direction (in case of pump intake below perforation zone)

Currently, the software on the market allows using one of the oldest correlations ï the Alhanati correlation developed in the early 1980-ies. No field testing was performed. After correlation analysis, the Marquez mechanistic model seems to be the best option, since it describes the physics of natural separation better than other models (Figure 3).

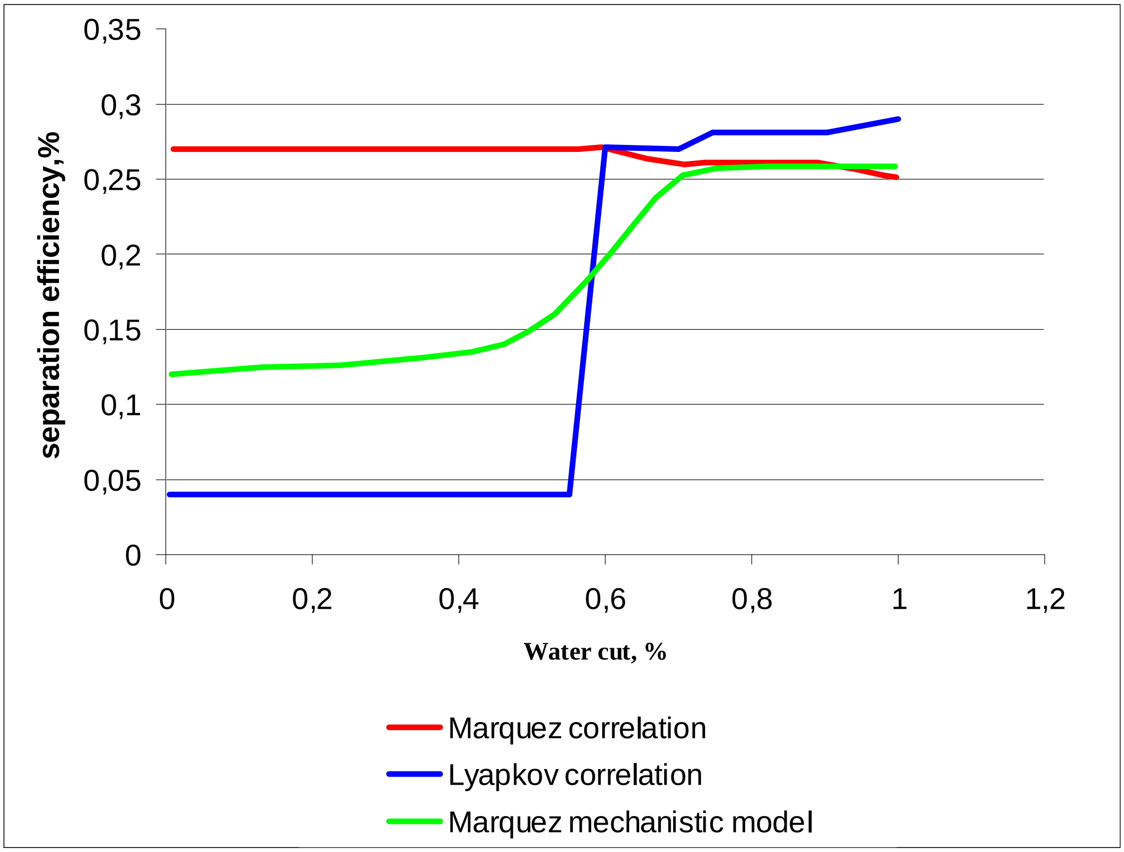

Figure 3. Comparison of the Marquez correlation, the Lyapkov correlation, and the Marquez mechanistic model for natural gas separation

Artificial separation

Artificial separation was investigated by Alhanati and Harun of Tulsa University in the late 1990-ies ï early 2000-ies. Three gas separators were tested and a mechanistic model was proposed. Similar research was carried out by some leading Western pump manufactures (Centrilift, REDA). It has been elicited that artificial separation efficiency is affected by the following parameters:

- inducer performance ï a component of a gas separator creating additional pressure inside the separator to remove extra gas into the annular space
- Gas-liquid rate in the separator
- Gas fraction at pump intake in situ
- Separator rotor frequency

The inducer performance depends on the construction type of the separator. The rest of the factors may be seen as external to the separator. It is therefore expedient in bench tests to vary the fluid rate, the gas rate, and the rotor frequency to obtain correlations between the separation efficiency and the mentioned parameters.

Only a few software packages afford setting an artificial separation efficiency by the bench test correlations. These programs are chiefly developed by equipment producers and only allow honoring the efficiency value for their separators. Thus, for example, Centriliftõs Autograph PC software allows calculating separation efficiency only for Centrilift separators; also REDAõs DesignPro may be used only to find efficiencies for REDA-manufactured gas separators. It should be noted that these programs use data obtained from the equipment manufacturersô bench tests, the testing conditions having never been published or open for collation. The software user never sees the correlations used, so no efficiency comparison of gas separators is possible with these data. It is therefore important to bench-test different separators using one bench facility under unchanging conditions.

Gas separator testing

To perform the testing, the facility owned by the Russian State Oil and Gas University named after I.M. Gubkin was used (see Fig. 4). The tests used the water-surfactant-air fine mixture made by the ejector [7]. The separators were run parallel with a 12-stage ECP 5-125. The facility was equipped with a frequency modulator capable of varying current frequency from 20 Hz to 90 Hz. During the experiments, data for separation efficiency with different gas fraction values at the intake, fluid rates and motor rotation frequency were obtained.

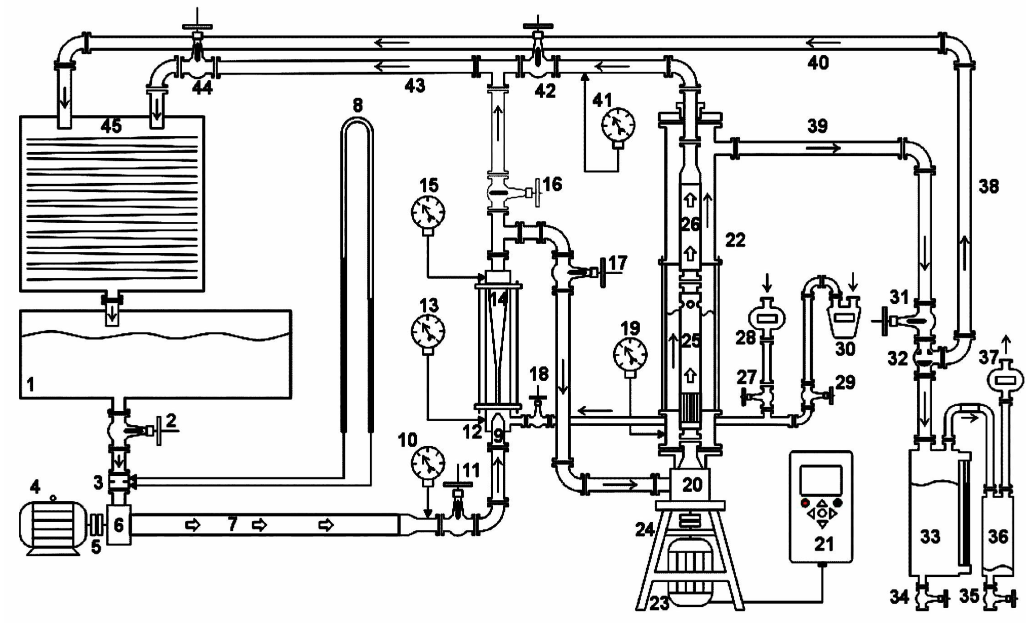

Figure 4. Gas separator bench-test facility

Testing results and correlation analysis

The testing resulted in determining the characteristics of 20 Russian- and American-made gas separators. After processing the test results, a number of regularities were induced:

1. The separation efficiency in the main working zone is linearly dependent on the rate and tends to become non-linear at minimum and maximum rate values (Fig. 5).

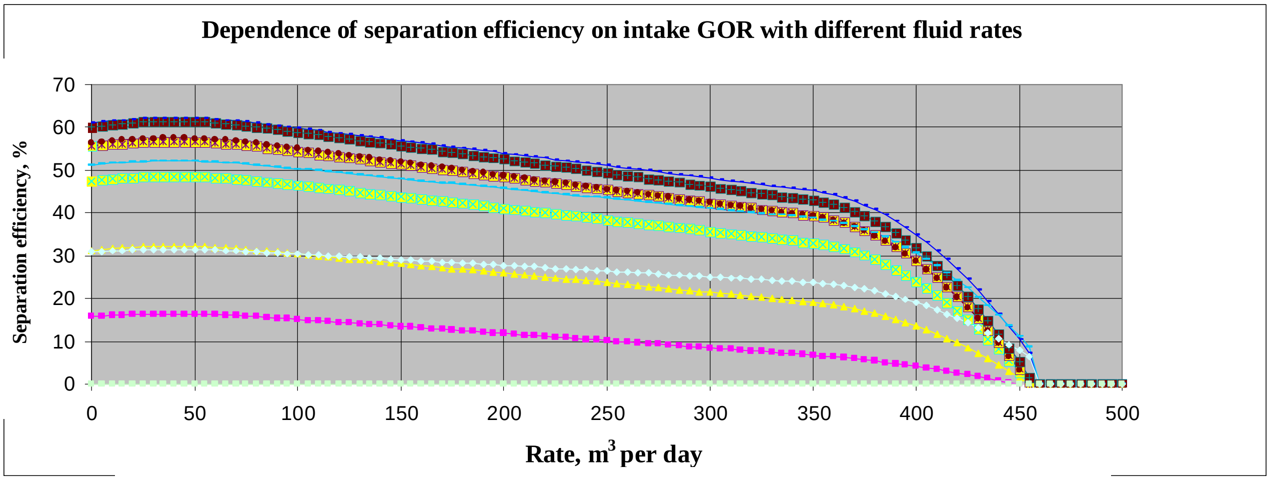

Figure 5

2. The dependence of separation efficiency on intake gas fraction is described by a convex function (Fig. 8).

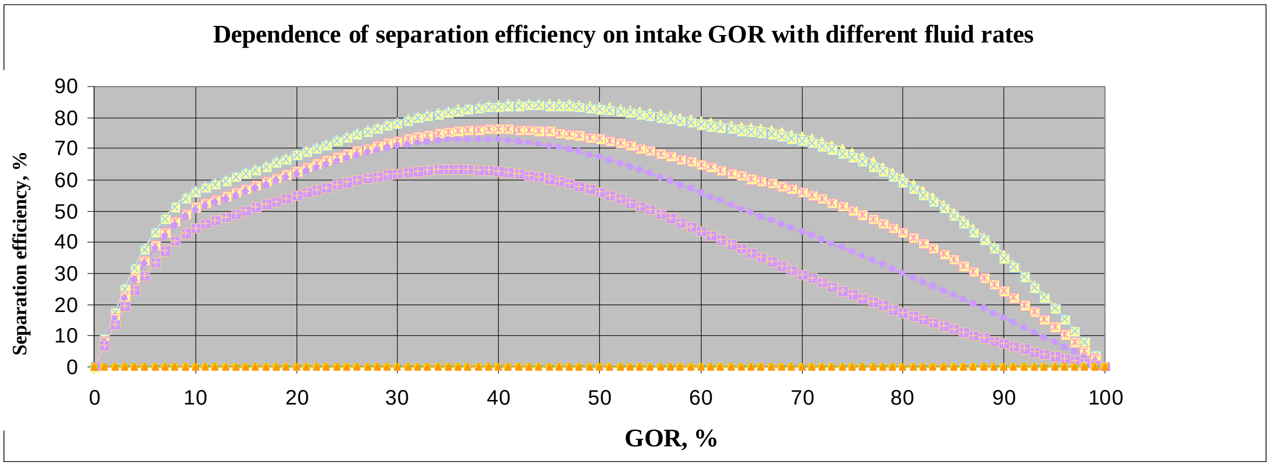

Figure 6

3. For the frequency, the correlation is close to linear (Fig. 6). Depending on separator configuration, the function can be either ascending or descending.

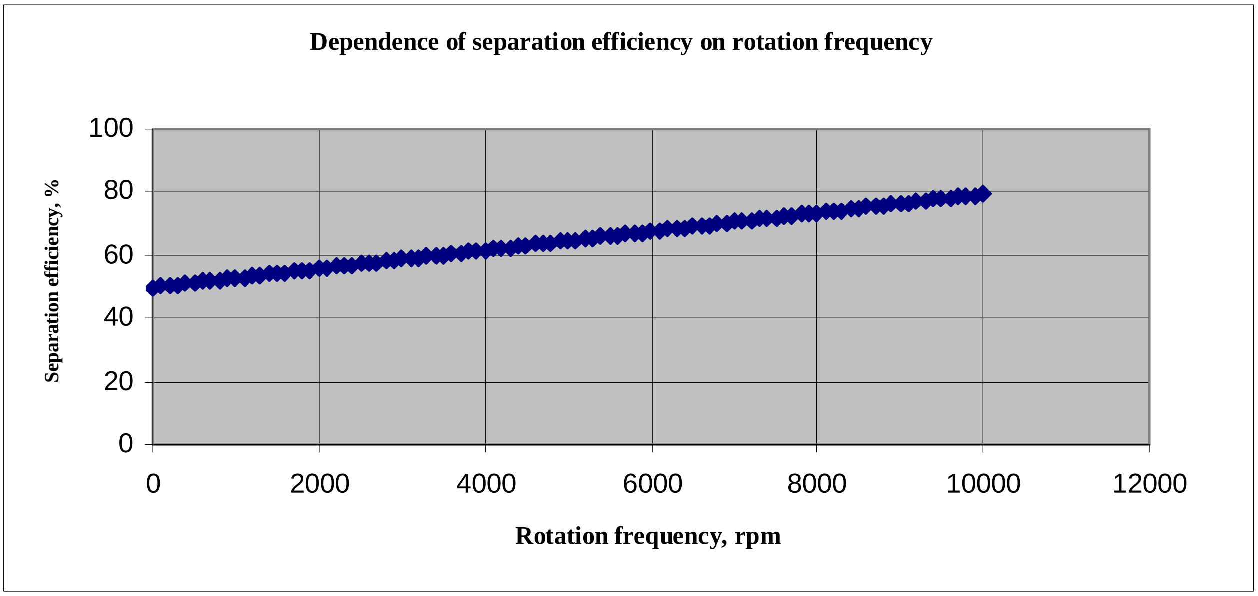

Figure 7

Deriving the correlation for artificial separation

In analyzing the obtained data, it was found that efficiency in all the separators changes depending upon the fluid rate, mixture gas fraction at the pump intake and the rotation frequency of the motor shaft by some correlations.

It was, however, observed that individual measurements can be grossly different from the immediate values. It was therefore decided to carry out a mathematical processing of the bench test results to obtain an alteration function of separation efficiency as dependent on intake gas fraction, fluid rate, and rotation frequency. The class of parametric functions was defined to that end, which describes the behavior of efficiency, followed by solving an optimization problem of finding parameter sets for each separator. The problem boiled down to finding a surface in a 4D space with the maximum deviation of the real values no higher than 5%, with the minimum number of parameters. To solve this problem, a genetic algorithm was applied which resulted in finding a 12-parameter function:

$$f(Q,\beta,F)=\theta_1\beta^4+\theta_2\beta^3+\theta_3\beta^2Q+\theta_4\beta^2+\theta_5\beta Q+\theta_6\beta F+\theta_7Q^2+\theta_8QF+\theta_9\beta$$
$$+\theta_{10}Q+\theta_{11}F+\theta_{12}$$

Formula 1

where

Q, β, F ï fluid rate, intake gas fraction, rotation frequency;

d$_{1é\ 12}$ ï function parameters.

As a result, each separator can be characterized by only 12 parameters (Figure 8).

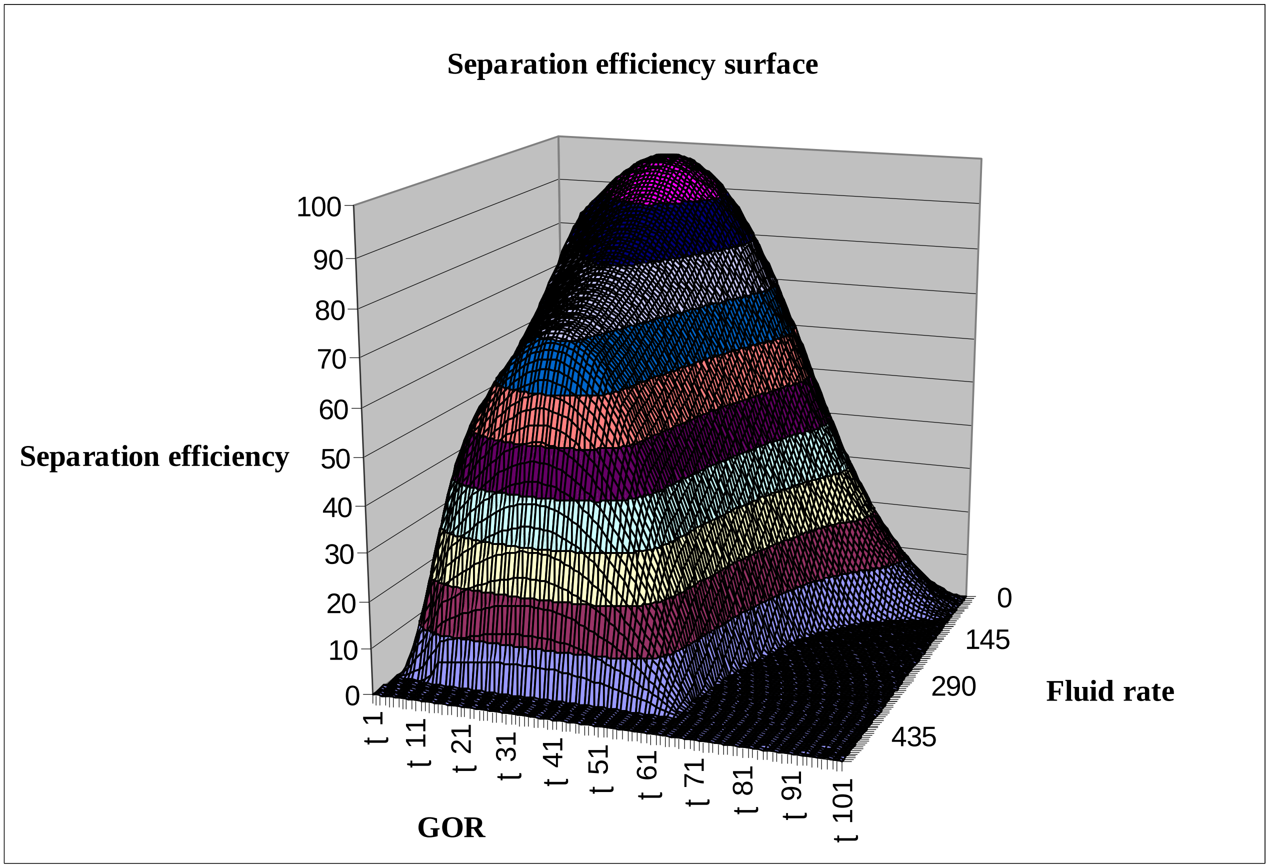

Figure 8. Separation efficiency surface at a given rotation frequency

Testing in wells

Field measurements of separation efficiency were performed under Rosneftôs New Technologies System on oil fields operated by Purneftegaz.

The total efficiency of gas separation for a well can be calculated through individual measurements of gas rate through the tubing and through the annular space. The efficiency will amount to

$$\eta_{total\_sep} = \frac{Q^{s.c.}_{tubing}}{Q^{s.c.}_{tubing} + Q^{s.c.}_{ca\sin g}}$$

Formula 2

where $Q^{s.c.}_{tubing}$ is the rate of gas flowing out of the separator and through the ECP, reduced to standard conditions (m^3 per day). This rate can be calculated using the tubing gas rate measured at the well head, considering that in the pumping conditions (given the pressure and temperature equal to those at the pump intake) part of the gas measured on the surface was dissolved in oil as a free phase.

$Q^{s.c.}_{ca\sin g}$ is the rate of the gas travelling through the annulus, reduced to standard conditions (m^3 per day). Given the total rate of the well, $Q^{s.c.}_{ca\sin g}$ can be defined as $Q^{s.c.}_{total} - Q^{s.c.}_{tubing}$ where $Q^{s.c.}_{ca\sin g}$ is the total gas rate through the tubing and the annulus measured on the surface and reduced to standard conditions. To measure the gas, fluid, and water cut rates Schlumbergerôs Vx mobile multiphase flow meter was used. These measurements were confirmed by Purneftegazôs standard measurement tools ï the Sputnik meter station and the mass meter unit ASMA-T.

The viability natural separation model was verified at wells equipped by ECPs with no separators. Different gas rates and percentages were produced at the intake by changing pump frequency by means of a frequency modulator.

Out of the models analyzed, the Marquez mechanistic correlation appeared to be the best fit (Fig. 9).

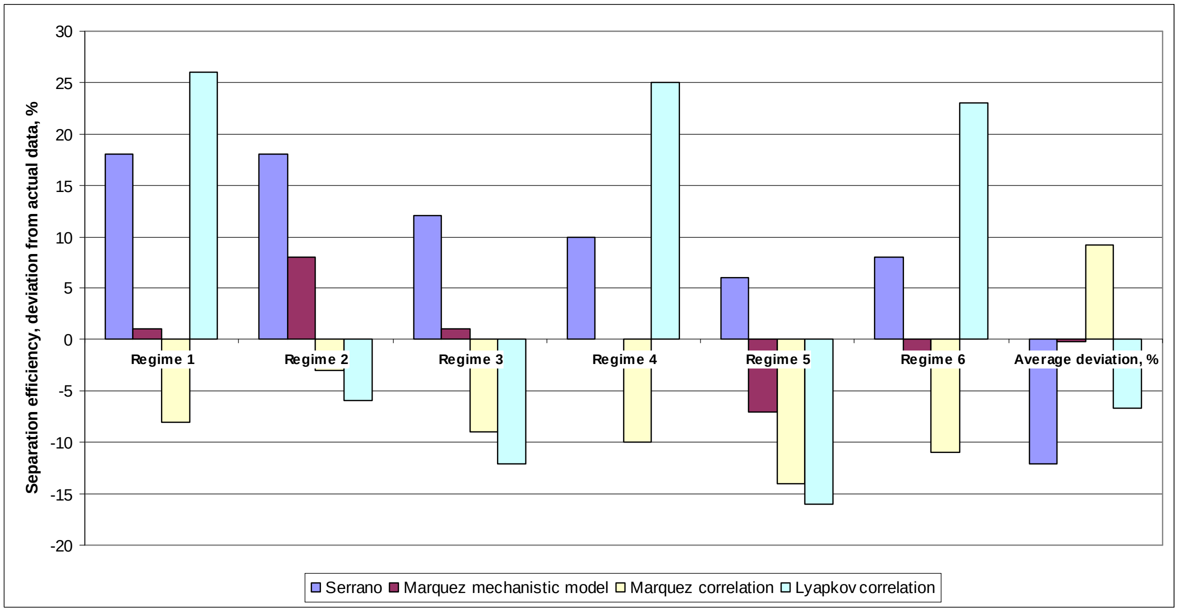

Figure 9. Comparsion of different natural separation models for various oil well regimes

Separation efficiency for wells having separators was calculated as follows:

- Natural separation was calculated using the Marquez model;
- Artificial separation was calculated using the separator correlation (Formula 1);
- The total efficiency was then found using the formula:

$$ȿ_{total\_sep} = ȿ_{natural\_sep} + ȿ_{artificial\_sep}(1 - ȿ_{natural\_sep})$$

Formula 3

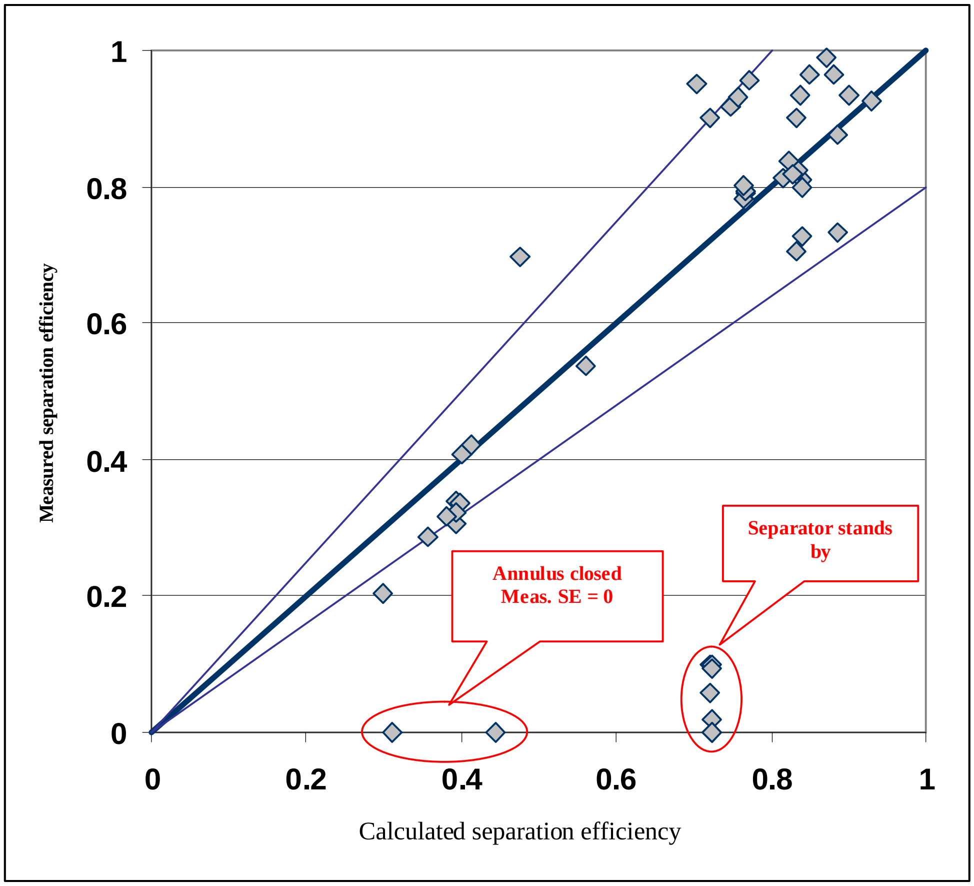

Figure 10. Comparison of measured and calculated efficiencies in separator-equipped wells

Figure 10 shows that in most cases the calculated separation efficiency with a degree of precision applicable to practical computations (20%) coincides with factual data (measurements). The individual points on the scheme correspond to well measurements [9]. One point corresponds to a measurement in one well. A detailed analysis of outlying deviations showed that some equipment or well problems had been present while measuring. The correlation of gas separation efficiency obtained from bench-test data, together with the mechanistic correlation to calculate natural separation, may be advised in practical calculations while selecting and analyzing ECPs equipped with a rotor gas separator.

Conclusions

The following has been concluded from the investigation results:

1. The efficiency of a rotary gas separator depends on the rate, the percent of gas in the intake flow, and the rotation frequency.
2. A 12-parameter correlation is found that describes the dependence of mechanical separation efficiency on the rate, the intake gas fraction, and the rotation frequency.
3. Using the total separation efficiency derived from natural and artificial separations is a good approximation to solve practical problems, for example while selecting and analyzing ESPs.

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