

Estimation of Input Pump Pressure in Conditions of Low Foaming Gas-Content Oil Pumping

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Abstract

Objectives: The core intention is to estimate input of submersible electric pump pressure in producing wells with using correlation during pumping gas-liquid mixture under oil low foaming conditions. **Methods/Statistical Analysis:** Known methods for calculating input pressure pump of high gas-content oil in well annulus are low-information and have poor accuracy. Based on the comparison and generalization of the data of comprehensive wellhead and deep well studies, we developed correlation dependencies for determining the density of a gas-liquid mixture taking into account the specific features of oil foaming in wells of the Upper Kama fields. **Findings:** Research results proved the influence of the content of high molecular compounds (resins and asphaltenes) determining the oil viscosity as well as gas-content on foaminess; wherein oil foaming properties decrease with increasing gas content. We developed equations for estimation relative density liquid mixture into the well annulus from pump submersion under dynamic level and oil foaming for mentioned above fields are obtained for the first time. These equations are based on the analysis of deep and estuarine well testing. It is shown that the oil gas-content affects the density of low foaming oil more than foaminess. According to the result to representativeness estimation of the obtained equations noted as accuracy sufficient for practical results to determine the density of the mixture in annulus and the input pump pressure. **Application/Improvements:** The basic field of application for the proposed approach is associated with exploitation of oil production wells. The results can be used for optimization of pump working in wells.

Keywords: Foaminess, Gas, Input Pump Pressure, Oil, Well Production

1. Introduction

One of the main parameters of the choice of pumping equipment and its mode in the well is the input pump pressure, details of which can be obtained by deep instruments as well as during estuarine research.¹⁻³

Currently, a significant amount of Russian oil fields are operated wells using ESP, fewer than half of them have a deep borehole instruments for measuring pressure and temperature. As a result there is no reliable information about the thermodynamic conditions of the pumps of the basic fund of wells. This information is necessary to analyze and optimize the performance of their operation. Thus sufficient volume of information about mechanized fund wells may be obtained by the wide use of estuarine research.

For determining the input pressure pump at the

wellhead measurements are very important reliability and accuracy of the input data used correlation and techniques of calculation. Currently there are several approaches to the calculation of the input pump pressure: hydrostatic formula, empirical methods algorithms based on RD 39-0147035-212-87 and correlation Hassan – Kabir.⁴⁻⁸ Selection of a particular approach depends on many parameters and must be confirmed by a certain number of deep researches.

Article's authors propose an approach based on the creation of empirical correlations for determining the density of Gas-Liquid Mixture (GLM) in the annulus by comparison and analysis of deep and estuarine measurements. This approach reduces the error in determining the input pump pressure with use the dynamic level in foam formation conditions in the annulus.

2. Research Bubbling Processes in the Annulus of Oil Wells

It is known that during operation by ESP wells part of the evolved gas is separated in the annulus which is a lift running on liquid supply zero-mode. This process is called bubbling. The free state gas may be regarded schematically as a ball under the action of a certain external pressure and the system in which gas bubbles (balls) is freely distributed relates to an emulsion of gas in liquid.

At the level of the input pump when a pressure below the saturation pressure GLM is a weakly concentrated emulsion. The pressure is significantly below the saturation pressure in the dynamic level. In this case such system in which the fluid is in contact with the gas phase over a larger area is in an unstable state and can form highly concentrated emulsions called foams. The main factor characterizing the foaming properties of liquids and foam stability over time is frothiness - the tendency of liquid to foam, which is quantified by the highest (critical) diameter wire ring d_{cr} excavated from the test fluid in the gas medium on which a liquid membrane may be at safe one second.⁹ When d_{cr} increases the foaming properties of the liquid is enhanced. According to research of VNIISPTneft Russian oil deposits frothiness varies widely from 9 to 105 mm. Oil for which d_{cr} ranges from 10 to 30 mm are not prone to foaming and oil d_{cr} more than 30 mm are systems foaming the stronger than d_{cr} higher. The oil being dispersed complex multicomponent systems containing heteroatom compounds in varying degrees involve foaming surfactants and differ in their foaming properties.

The foam properties and foam stability are important factors in preventing the coalescence of gas bubbles in a large cavity in GLM as well as in the annulus when pressure decreases. Reliability of the determination of the dynamic level when input pump pressure estimation may depend from manifestations of foaming properties.

They found that bubble stability in low foaming liquid is zero.¹⁰ During approaching the bubble fluid is expelled from the border films, coalescence occurs. Therefore, due to the coalescence of the gas bubbles their velocity relative ascent increases in the annulus of wells producing oil with low foaming properties, while the true gas concentration decreases, which leads to an increase in density in the annulus GLM.¹¹⁻¹³

3. Laboratory Studies of the Effect of Physical and Chemical Properties of Oils on their Foaming Properties

To study the role of the foaming properties of GLM in the process of determining the input pump pressure conducted laboratory studies. As mentioned earlier the presence of oil in macromolecular heteroatomic compounds causes manifestation foaming properties. According to studies by various authors as a result of ozonation oil changes occur elemental and functional composition of its components, creating favorable conditions for the conversion of oil components in macromolecular substances (number of asphaltene-resin components increases).^{14,15} According to the research there is a direct relationship between the amount absorbed by ozone and asphaltene-resin substances (ARS), which lead to increased foaming properties of the oil.¹⁶

Table 1 summarizes the data obtained in the study of oil from well #216 Unvinsky field (layer Bb) after ozonation with different concentrations of O_3 at 20°C.

Value of oil foaming was measured using an instrument consisting of a semi-automatic drive K11 tensiometer (Switzerland) and a set of rings of different diameters. Diagram of the device for determining d_{cr} shown in Figure 1. With movable mechanism 4 immersed stationary ring 2 suspended on a support 1 in a glass with studied oil 3. Each oil sample was immersed rings of different diameter and the maximum diameter was determined on which a film of oil can exist at least one second.

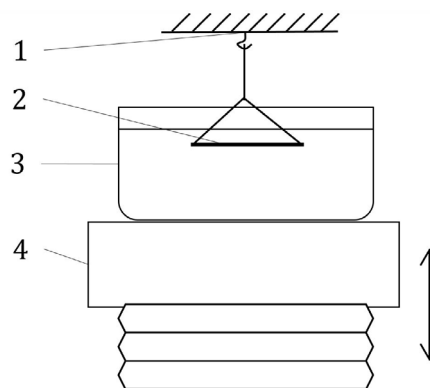


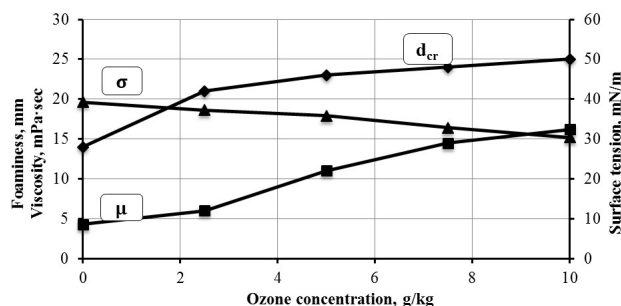
Figure 1. Schematic of the device to determine the foaming oil: 1 - support for hanging rings; 2 - ring; 3 - glass studied oil; 4 - semi-drive.

Table 1. Physical and chemical characteristics of oil samples Unvinsky

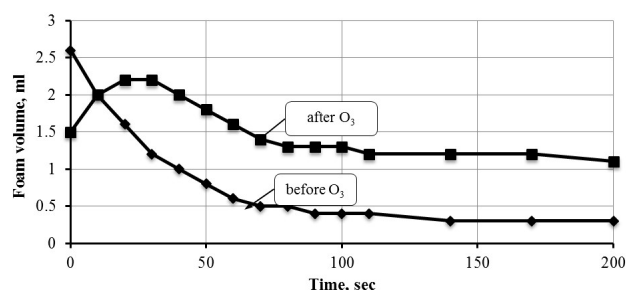
No.	Ozone concentration in the oil g / kg	Foaminess d_{cr} mm	Dynamic viscosity μ , mPa·sec	Surface tension σ , mN/m
1	0	13	4,3	39,22
2	2,5	21	6,0	37,25
3	5,0	23	11,0	35,82
4	7,5	24	14,5	32,86
5	10,0	25	16,2	30,45

The dynamic viscosity was measured in a rotary viscometer Rheotest RN 4.1 (Germany), surface tension - by plate on K11 tensiometer.

Oil viscosity increases with the increase in the amount of absorbed ozone and surface tension decreases indicating the formation of high-molecular compounds – ARS. Appearance of ARS causes the increase of the foaming properties of oil (Figure 2).

**Figure 2.** Dependences of foaming, dynamic viscosity and surface tension of the oil from the amount of absorbed ozone.

For improvement of the estimate reliability of P_{input} it is important to take into account the stability of the foam and its ability to merge gas bubbles in large formations in the annulus. Foam stability before and after ozonation oil (oil with different foaming properties) assessed by the kinetics of fracture foam column Unvinsky oilfield (well #216). One of the oil samples treated with ozone in an amount up to 10 g on 1 kg of oil. Foam column created by shaking the oil sample volume of 16 ml in a measuring cylinder with a glass lid with measuring the rate of change in time foam column. Results of the study are shown in Figure 3.

**Figure 3.** Kinetics of changes foam column Unvinsky oil before and after ozonation (5 g O₃ 1 kg of oil).

Experimental results show that the formation of foam in the ozonated oil occurs for some time after shaking while foam non-ozonated oil begins to break down immediately after its creation.

Oil after the action O₃ according to results as shown in Figure 5 has increased foaming properties that provide little foam stability over time, due to the creation of a number of adsorbed on the surface of the bubble blowing surfactants which leads to a very slight increase in the stability of the interface «gas – liquid».¹⁷

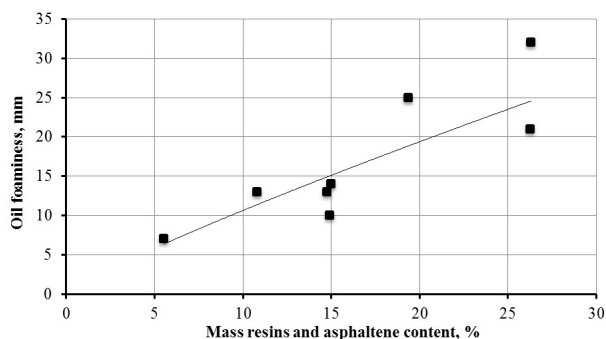
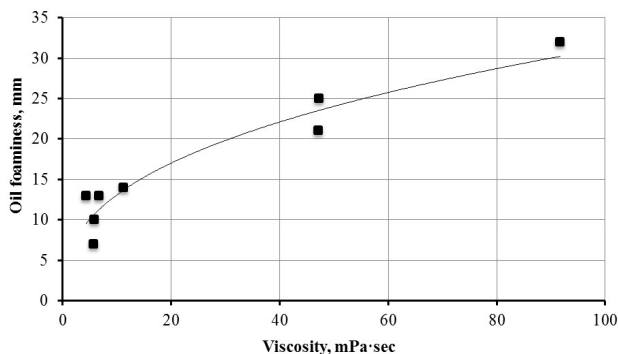
Thus, treatment crude oil with low foaming properties for ozone up to 10 g/kg increases their foaminess and improves resistance to foam fracture, however such oil is not transferred to another category according to foaming.

Laboratory experiments with oil of Sibirsky, Shershnevsky, Unvinsky, Magovsky, Ozerny, Jurchuisky and high-viscosity oil of Shagirtsko-Gozhansky and Nozhovsky oilfields are conducted to investigate the foaming, dynamic viscosity μ and σ the surface tension of oil. The results are shown in Table 2.

Table 2. Physical and chemical properties of oils

No.	Oilfield (deposit)	d_{cr} , mm	μ , mPa·sec	σ , mN/m	Oil content (mass), %			P_{sat} , MPa	G_o , m ³ /t
					paraffin	wax	asphaltene		
1	Sibirsky (carbon)	10	5,8	28,7	3,17	12,74	2,17	17,25	106,4
2	Shershnevsky (terrigen)	14	11,2	39,22	5,59	13,63	1,35	11,9	53,7
3	Unvinsky (terrigen)	13	4,3	31,22	3,84	9,85	0,94	14,22	101,6
4	Magovsky (carbon)	7	2,0	43,3	2,79	5,07	0,45	20	225
5	Nozhovsky (terrigen)	25	47,3	22,32	3,02	15	4,36	9,45	12,3
6	Ozerny (carbon)	13	6,76	-	2,71	12,58	2,17	13,58	53,8
7	Jurchuksky (carbon)	21	47,16	-	3,88	18,95	7,3	12,42	52,8
8	Shagirtsko-Gozhansky (terrigen)	32	91,7	-	4,34	22,86	3,43	4,06	12,12

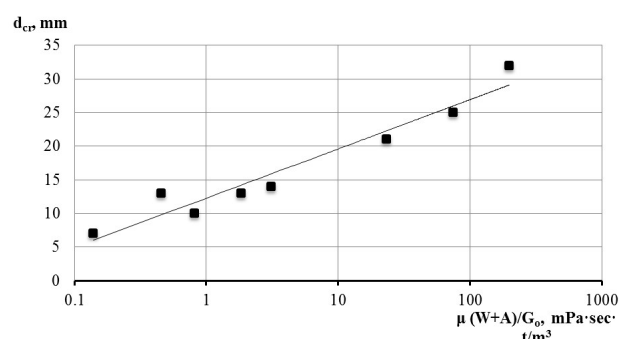
Thus, the amount of foaming depends on the content of high molecular compounds (resins and asphaltenes) determining the viscosity of oil. Figures 4 and 5 show the dependence of the mass d_{cr} ARS-content and viscosity of the reservoir oil.


Figure 4. The dependence of the foaming mass content of resins and asphaltenes in the oil.

Figure 5. The dependence of the viscosity of the foaming reservoir oil.

Obtained dependences $d_{cr}=f(R+A)$ and $d_{cr}=f(\mu)$ reflect the basic laws foaming. Assuming that the amount of dissolved gas in oil affects its foaminess, generalization assessment was conducted in the form of foaming

$$d_{cr}=f(\mu(R+A)/G_o).$$

As presented in Figure 6, the dependence has the best convergence results and confirms the influence of gas content of reservoir oil on its foaming properties.


Figure 6. The dependence of the viscosity and foaming gas content from the reservoir oil viscosity, gas content, resin and asphaltene content.

4. Development Gas-Liquid Mixture Density Dependences from Immersion Pump and Oil Foaming

The analysis of the craft data about the work of 11 wells Shershnevsky, 13 - Sibirsky, 11 - Magovsky, 16 - Unvinsky and 8 wells Nozhovsky fields to investigate the density of GLM in the annulus of wells producing low foaming carbonated oil. All wells are equipped with instrumentation to measure temperature and pressure at the input pump. These wells evenly distributed over an area of fields that will use the results of research on well not included in the sample.¹⁸ The sample covers the full range of indicators of technological modes of wells,

characteristic for the specified operating conditions considered deposits.

Measurements of the gas pressure at the wellhead and fluid level in the annulus, and the corresponding results of recording time using the stand-alone devices SKAT-28K and telemetry systems of pressure and temperature in wells at the suspension pumps are used for the analysis of 523 wells modes.

For the analysis of each of the modes used the integral form of the pressure gradient in the area of the bubble layer:

$$P_{\text{input}} = P_{\text{ann}} + \Delta P_g + P_{\text{glm}} = P_{\text{ann}} + \Delta P_g + \rho_{\text{glm}} g H_{\text{sub}} \quad (1)$$

P_{ann} – annulus pressure; ΔP_g – column pressure gas in the annular space; H_{sub} – submersion under the dynamic level; ρ_{glm} – GLM average density in the annulus:

$$\rho_{\text{glm}} = \rho_{\text{liq}} (1 - \phi) + \rho_g \phi \quad (2)$$

ρ_{liq} and ρ_g – average densities of liquid and gas in the free space, ϕ – gas content.

Considering the relationship between the density of GLM and immersion pump under dynamic fluid level in the annulus and passing to the relative density, the results of well testing data are presented as $\rho_{\text{glm}}/\rho_{\text{res oil}} = f(H_{\text{sub}})$ (where $\rho_{\text{res oil}}$ – reservoir oil density). Results are shown in Figure 7.

Thus, there is a tendency of the relative density of GLM in the annulus for oil with lower d_{cr} which is inconsistent with the above representations when the analysis of the obtained relationships (Figure 1) for low-viscosity oils low foaming deposits Upper Kama region with different values of d_{cr} (7 ... 14 mm). It means that there is a factor affecting the density of the low foaming in the carbonated oil more than the amount of its foaming. The dependence $\rho_{\text{glm}}/\rho_{\text{res oil}} = f(H_{\text{sub}})$ was higher than for oil Upper Kama region at studying the oil properties of Nozhovsky field

characterized smaller value of gas content (12,3 m³/t) and foaminess $d_{\text{cr}} = 24$ mm. It confirms that the greatest influence on the disposition of low foaming carbonated oil density in the annulus has its gas content.

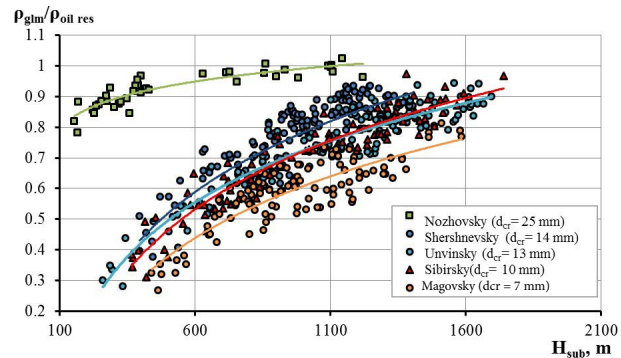


Figure 7. The dependence of the relative density of GLM from the depth of the pump under the dynamic level.

Referring to Figure 1 results of field studies determination are approximated by functions given in Table 3.

Obtained dependences are considered as the statistical relationship between random variables having a joint normal distribution. Estimation of the correlation between random variables is given by calculating the correlation coefficients. The values of correlation coefficients amounted to no less than 0,74.

The obtained results quantitatively determine the decrease intensity of the low-viscosity low-foaming carbonated oil density at reduction of immersion pumps under dynamic fluid level.

To assess the quality of the obtained equations test sample are organized. It consists in 4 wells (50 modes) Magovsky field equipped with downhole instrument for getting the actual input pump pressure data. Deviation of results the calculated values $\rho_{\text{glm}}/\rho_{\text{res oil}}$ and actual data were insignificant (Figure 8). The linear correlation coefficient of 0,91.

Table 3. The equations for determining $\rho_{\text{glm}}/\rho_{\text{res oil}}$ oil in the annulus

Oil field	Change interval H_{sub} , m	Type equations $\rho_{\text{glm}}/\rho_{\text{res oil}} = f(H_{\text{sub}})$	Determination factor	$\sigma \rho_{\text{glm}}$, kg/m ³	σP_{input} , MPa
Shershnevsky	400 ... 1400	$0,380 \cdot \ln(H_{\text{sub}}) - 1,845$	0,74	±50	±0,10
Unvinsky	250 ... 1700	$0,370 \cdot \ln(H_{\text{sub}}) - 1,838$	0,87	±15	±0,08
Sibirsky	350 ... 1700	$0,330 \cdot \ln(H_{\text{sub}}) - 1,554$	0,90	±10	±0,10
Magovsky	400 ... 1700	$0,331 \cdot \ln(H_{\text{sub}}) - 1,681$	0,74	±54	±0,13

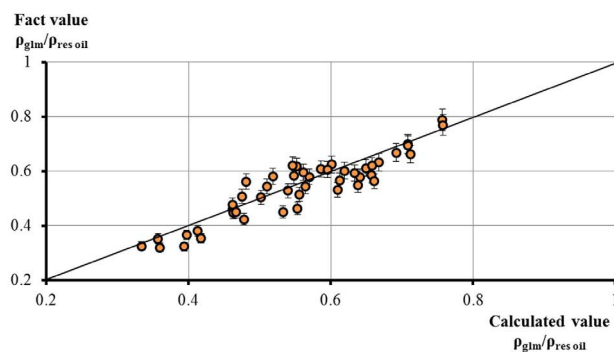


Figure 8. Dependence of the actual values $\rho_{glm}/\rho_{res oil}$ from the calculated.

Analysis of the results showed that the standard deviations of the calculated values ρ_{glm} and P_{input} from actual data found during the analysis of data craft depth studies are minor.

5. Conclusion

- The value of foaminess depends on the content high molecular compounds (resins and asphaltenes) determining the oil viscosity as well as gas-content wherein oil foaming properties decreases with increasing gas content.
- During ozone treatment low foaming oil up to 10 g/kg the foaminess increases, the resistance to fracture foam improves, but such oil is not transferred into a different category on the foaminess.
- Gas content of the reservoir oil affects the density of low foaming oil to a greater than its foaminess.
- Approximation formulas shown in Table 3 have simplicity and satisfactory accuracy of calculation results of the input pump pressure. The obtained dependences can be used to determine the input pump pressure in wells in which the use of special deep instrumentation and difficult or economically viable.

6. References

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