Improvement of the technical and economic indicators of oil production

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Abstract. To understand the stated theory and technical specifications, a specific problem of optimizing experimental studies of the gas-lift process has been solved: the process of measuring the parameters of a gas-lift well necessary for solving and plotting the dependence of the well flow rate on the flow rate of injected gas is given. The measurements consisted of three main components (stages of types of measurements). It is indicated that all components are interconnected, therefore, an error in readings at any one stage leads to a violation of the relationship curve between the well flow rate (lifter supply) and the flow rate (volume) of injected gas. The reliability of the instrument's readings can be increased by duplicating each measurement step by step. As a result of the research, a method was indicated to improve the technical and economic indicators of the gas-lift method of oil production.

1 Introduction

One of the important directions of technical progress in the oil industry is the improvement of the technical and economic indicators of the gas-lift method of oil production, which has become widespread both in our country and abroad, due to several its advantages over other mechanized methods of well operation.

The purpose of the study of gas-lift wells is to determine the parameters of the reservoir, formation fluids and bottomhole zone to assess the allowable bottomhole pressures and rational distribution of working agent resources between wells according to the criterion of maximizing the total oil production or other accepted optimality criterion [2]. Gas-lift wells are currently being explored by tracking levels or pressures and test pumping [4-7]. In all cases, it is necessary to conduct a complete study of the well and, on their basis, establish the flow rate, select equipment and its mode of operation so that the given flow rate is obtained with the greatest efficiency [8-14].

Along with a full study of the characteristics of the reservoir, it is necessary to study the operation of the elevator for optimization to clarify the amount of gas that should be injected into the well to obtain a given flow rate [1, 3]. This method, in comparison with the previous one, has the advantage that, in addition to determining the type of the inflow

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equation, it allows specifying the amount of injected gas to obtain a given flow rate. These circumstances determine the relevance of the work carried out in this project.

2 Principles of operation and basic designs of gas lift wells

A gas-lift well is a well in which the gas missing for the necessary degassing of the liquid is supplied from the surface through a special channel (Figure 1). Through the pipe string 1, gas from the surface is supplied to the shoe 2, where it mixes with the liquid, forming a GSL, which rises to the surface through the lifting pipes 3. The injected gas is added to the gas released from the reservoir fluid. As a result of the mixing of gas with liquid, GLS is formed of such a density at which the available pressure at the bottom of the well is sufficient to lift the liquid to the surface. The point of gas entry into the lifting pipes (shoe) is submerged under the liquid level by the value h; the gas pressure P_1 at the point of its entry into the pipes is proportional to the immersion h and is related to it by the obvious relationship $P_1 = h\rho g$. The pressure of the injected gas, measured at the wellhead, is called the working pressure P_p. It is practically equal to the pressure at the shoe P_1 and differs from it only by the value of the hydrostatic pressure of the gas column ΔP_1 and the pressure loss due to gas friction in the pipe ΔP_2, and ΔP_1 increases the pressure below P_1, and ΔP_2 decreases. Thus,

$$P_1=P_P+\Delta P_1-\Delta P_2.$$

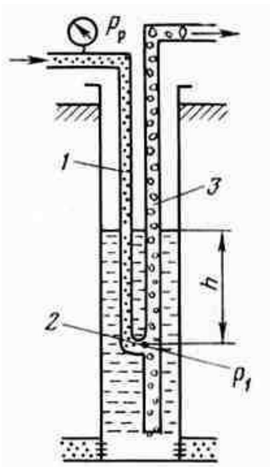

Fig. 1. Schematic diagram of a gas lift.

In real wells, ΔP_1 is a few percent of P_1, and ΔP_2 is even less. Therefore, the working pressure Pp and the pressure at the shoe P_1 differ little from each other. Thus, it is quite simple to determine the pressure at the bottom of a working gas-lift well by its working pressure at the wellhead [15]. This simplifies the procedure for examining a gas-lift well, adjusting its operation and establishing the optimal mode. A well into which gas is pumped in order to use its energy to lift liquid is called a gas-lift well, when air is injected for the same purpose, an air-lift well.

The use of air contributes to the formation of a very stable emulsion in the tubing, the decomposition of which requires its special treatment with surfactants, heating, and long-term settling. The gas-air mixture released during separation on the surface is dangerous in terms of fire since it forms an explosive mixture at certain ratios [16]. This creates the need to release the spent gas-air mixture after separation into the atmosphere.

The use of hydrocarbon gas, although it contributes to the formation of an emulsion, but such an emulsion is unstable and is often destroyed (stratified) by simple sludge without the use of expensive processing to obtain clean conditioned oil. This is due to the absence of oxygen or its low content in the hydrocarbon gas used and the chemical relationship of gas and oil, which have a common hydrocarbon base. Oxygen contained in the air contributes to oxidative processes and the formation of stable shells on water globules, which prevent water from merging, enlargement of globules and their subsequent settling during sedimentation. Due to its relative explosion safety, the exhaust gas after separation is collected in a gas collection system and disposed of [17]. Moreover, the separated gas of a gas-lift well, when it is vigorously mixed with oil while moving along the tubing, is enriched with gasoline fractions.

As for oil, it stabilizes, which reduces its evaporation during transportation and storage. The gas processed (dried) at gas-gasoline plants is again used for the operation of gas-lift wells after its preliminary compression to the required pressure at the compressor stations of the field.

Thus, the gas lift allows to improve the use of gas and operate the field more rationally in comparison with the air lift. The only advantage of an airlift is the unlimited source of air as a working agent for a gas-liquid lift. Real gas lift wells are not equipped according to the scheme shown in Figure 2, since it is practically impossible to lower two parallel rows of pipes into the well, rigidly connected at the bottom with a shoe. This diagram is shown only to explain the principle of operation of the gas lift. However, its use is quite possible and, in some cases, expedient for pumping large volumes of liquid, for example, from mines or other containers with a wide flow area.

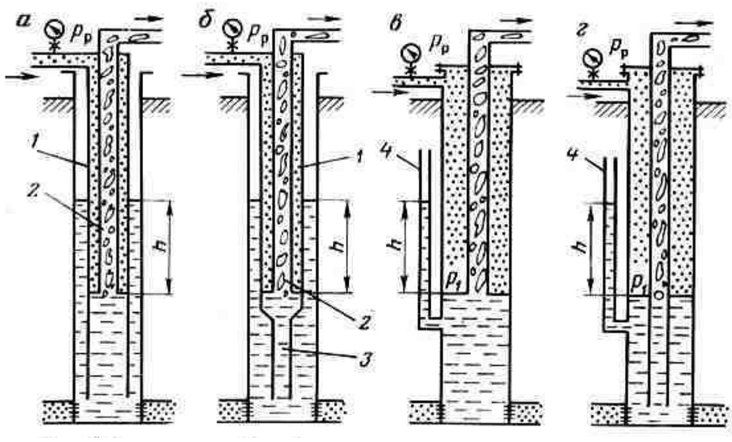

Fig 2. Structural diagram of gas lifts: a - two-row lift; b - one and a half row lift; c - single-row lift; g - single-row lift with a working hole.

For the operation of gas-lift wells, hydrocarbon gas is used, compressed to a pressure of 4-10 MPa. Sources of compressed gas are usually either special compressor stations or compressor gas processing plants that develop the necessary pressure and provide the necessary supply.

Such a gas lift operation system is called compressor gas lift. Systems in which natural gas from purely gas or gas condensate fields is used for gas lift are called non-compressor gas lift. In uncompressed gas lift, natural gas is transported to the location of gas lift wells and usually undergoes preliminary treatment in special installations, which consists in separating condensate and moisture, and sometimes in heating this gas before distribution to wells. Excess pressure is usually reduced by throttling the gas through one or more stages of fittings. There is a system of gas lift operation, which is called downhole gas lift. In these systems, the source of compressed gas is gas from gas-bearing formations above or below the oil-saturated formation. Both layers are opened by a common filter.

3 Mathematical model of the optimal distribution of the working agent

In practice, most often they are limited to research for the construction of so-called control curves, i.e., dependences of the well flow rate Q(V) and the specific flow rate of the injected gas R(V), on the flow rate of the injected gas Q(V)= f(V) and R(V)= f1(V). To build these curves in field conditions, the number of investigated modes of operation of the lift must be at least six.

The dependence of the well flow rate on the injected gas flow rate is proposed as a parabolic function. The proposed form of the approximating function of the gas lift well survey data, which makes it possible to increase the accuracy of the approximation, was obtained by introducing an additional nonlinearity in the form of a logarithm into the original parabolic function, i.e.:

$$Q(V) = \beta_0 + \beta_1 \ln V + \beta_2 (\ln V)^2 \quad (1)$$

One of the main parameters characterizing the operating mode of a gas-lift well is the specific consumption of the working agent R, which in this case is defined as:

$$R(V) = V / Q(V) = V /(\beta_0 + \beta_1 \ln V + \beta_2 (\ln V)^2) \quad (2)$$

To obtain the dependence of the well flow rate on the flow rate of the injected gas, the research process requires long-term experiments associated with the overconsumption of the working agent and the loss of oil production, and in some cases with the risk of disrupting the technological regime of the well. Under these conditions, the issues of determining the coefficients of the mathematical model based on the data of normal operation of wells without introducing deliberate disturbances become urgent. The coefficients, $\beta_0, \beta_1, \beta_2$, are determined by various identification methods based on the quantitative results of natural science experiments, technical data of observations and measurements (Table 1). The use of modern statistics makes it possible to more accurately and fully use the information extracted from observations by the least squares method, and to better understand the meaning and significance of the data obtained by this method.

The task of identifying the characteristics of a gas-lift well, due to the inaccuracy of the survey data and conducting a survey in a narrow range, in some cases, turns out to be incorrectly set. The incorrectness of the characteristic identification problem is mainly manifested in the fact that, based on the processing of research data, an inverted parabola is obtained, for which the characteristic feature is the positiveness of the coefficient β_2.

In this regard, the task is to determine the coefficients of the mathematical model of a gas-lift well based on the least squares criterion. Table 1 of technical data of daily observations and measurements of system parameters is presented below:

Table 1. Technical data of daily observations and measurements of system parameters.

V, m³/day.	Q (V), m³/day
20	65
23.1	62.1
25	58.3
17.1	66
14.6	64
12.7	62.5
11.3	57
9.6	38

As a result of applying the above least squares method, based on the quantitative results of natural science experiments, technical data of observations and measurements indicated in Table 1 the coefficients (β_0, β_1, β_2), are determined, characterizing the initial parabolic function of the dependence of the well flow rate on the flow rate of injected gas:

$$\beta_0 = -567.5299;\ \beta_1 = 435.2467;\ \beta_2 = -74.7523$$

Thus, we obtain a general view of the function of the dependence of the well flow rate on the flow rate of the injected gas:

$$Q(V) = -567.5299 + 435.2467 \ln V - 74.7523(\ln V)^2$$

Therefore, the specific consumption of injected gas is represented by the following relationship:

$$R(V) = V / Q(V) = V /(-567.5299 + 435.2467 \ln V - 74.7523(\ln V)^2).$$

Based on the research results, control curves are built (the construction can be carried out both in Microsoft EXCEL and in the MATLAB software package) (Figures 3 and 4).

The extremum on the curve (Q=66.0282 m³/day) corresponds to the maximum feed of the lift (point B). The perpendicular drawn through this point to the tangent at the intersection of the curve Q(V)=f(V) gives a point corresponding to the optimal lift feed.

The above optimal and maximum parameter values can be calculated using the following formulas:

$$\overline{V} = e^{\frac{-\beta_1}{2\beta_2}}.$$

$$\overline{Q} = \beta_0 - \beta_1^2 / 4\beta_2^2.$$

$$\underline{V} = e^{1-\frac{\beta_1}{2\beta_2}-\sqrt{(\frac{\beta_1}{2\beta_2})^2-\frac{\beta_0}{\beta_2}+1}}. \tag{3}$$

$$\underline{Q} = 2\beta^2 + \sqrt{\beta_1^2 - 4\beta_0\beta_2 + 4\beta_2^2}.$$

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$$\overline{R} = \frac{e^{\frac{-\beta_1}{2\beta_2}}}{\beta_0 - \beta_1^{\,2} / 4\beta_2^{\,2}}.$$

$$\underline{R} = \frac{e^{1-\frac{\beta_1}{2\beta_2}-\sqrt{(\frac{\beta_1}{2\beta_2})^2-\frac{\beta_0}{\beta_2}+1}}}{2\beta^2 + \sqrt{\beta_1^{\,2} - 4\beta_0\beta_2 + 4\beta_2^{\,2}}}.$$

In field conditions, as a rule, the well operation mode is selected in the interval $\underline{V}, \overline{V}$ and is intermediate between points A and B. However, in conditions of a sharp lack of incoming gas, it may become less than the sum of the lower flow rates, which may necessitate turning off one or several wells. This decision is irrational since the restart of the well is associated with certain difficulties. Under these conditions, the possibility of expanding the ranges of well operation modes becomes important, i.e., the possibility of well operation at values of the injected gas volume is less than optimal, which will be associated with a certain increase in the specific flow rate. Studies show that, on average, the expansion of the range for the considered wells is 60% of the original. It shows that it is possible to increase the range of changes in the supply of the working agent by one and a half times without the need to shut down wells that are not prone to plugging. Under normal conditions, the expansion of the dynamic range of the well will increase the depth of redistribution of the working agent to optimize production.

Thus, in addition to the correct choice of the observation interval, when using averaged daily data for statistical identification of the parameters of the mathematical model of gas lift wells, it is necessary to carefully analyze the initial data to ensure their necessary information content. If these requirements are not met, it is not advisable to use the identification results for automatic control of gas-lift wells. In this case, the results of identification are used to roughly determine the range of change in the consumption of the working agent for the purposes of conducting active experimental studies.

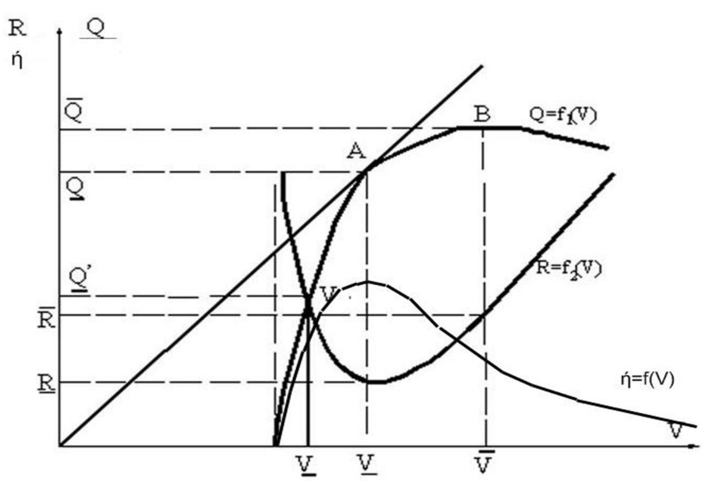

Fig. 3. Characteristic dependences of the parameters of gas-lift wells.

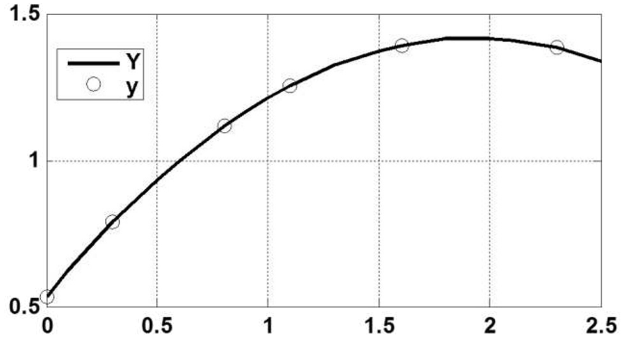

Fig. 4. Approximation with the polyfit function**.**

4 Solution of the problem of optimal distribution of the working agent

To comprehend the above theory and terms of reference, we will solve a specific problem of optimizing experimental studies of the gas lift process: the process of measuring the parameters of a gas lift well is given, which are necessary for deciding and plotting the dependence of the well flow rate on the flow rate of the injected gas. Measurements consist of three main components (stages of measurement types). All components are interconnected, therefore, an error in readings at any one stage leads to a violation of the curve of the relationship between the flow rate of the well (lifter supply) and the flow rate (volume) of the injected gas. The reliability of instrument readings can be improved by duplicating each measurement in steps. Based on this, measurements can be carried out repeatedly. The result is shown in Figure 5.

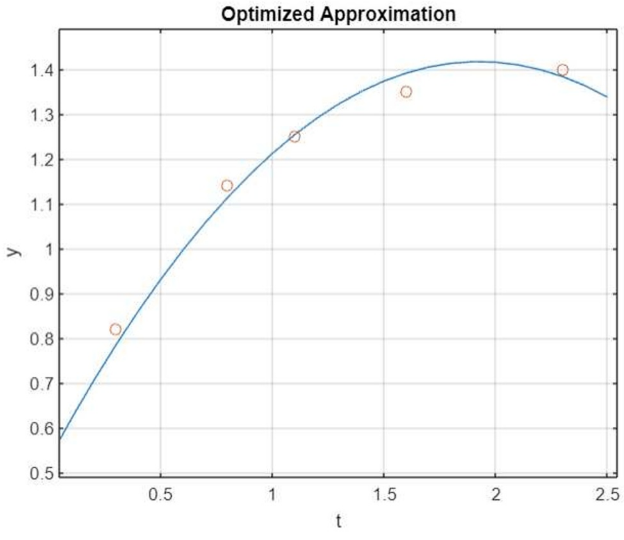

Fig. 5. Optimization approximation.

As we can see, the experimentally obtained values of the variable y are practically located on the approximating curve. Below is a program by which coefficients are calculated and control curves are plotted.

5 Conclusion

To understand the stated theory and technical specifications, a specific problem of optimizing experimental studies of the gas-lift process has been solved: the process of measuring the parameters of a gas-lift well necessary for solving and plotting the dependence of the well flow rate on the flow rate of injected gas is given. The measurements consisted of three main components (stages of types of measurements). It is indicated that all components are interconnected, therefore, an error in readings at any one stage leads to a violation of the relationship curve between the well flow rate (lifter supply) and the flow rate (volume) of injected gas. The reliability of the instrument's readings can be increased by duplicating each measurement step by step. As a result of the research, a method was indicated to improve the technical and economic indicators of the gas-lift method of oil production.

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