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INVESTIGATING THE RELATIONSHIP BETWEEN PRODUCTION RATE AND INJECTION GAS VELOCITY: A NEW APPROACH TO DETERMINING THE OPTIMAL OPERATING MODE OF GAS-LIFT WELLS

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ABSTRACT

The article examines contemporary solutions for optimizing gas-lift well operation modes. By analyzing flow conditions and the upward gas flow equation, the process of liquid displacement by gas within the annular space toward the tubing shoe was evaluated. Based on wellhead parameters and the downward gas flow equation, gas pressure at the shoe of the second-string tubing in a concentric dual-string configuration was theoretically determined. Furthermore, the gas injection velocity (υ) at the shoe zone was calculated using a derived formula corresponding to the pressure at that depth. The correlation between gas velocity, liquid production, and gas injection rates was investigated. For this purpose, $Q = f(V)$ and $\upsilon = f(V)$ relationships were established for five gas-lift wells based on field data and wellhead parameters. Results revealed a specific correlation between gas velocity at the tubing shoe and production rate, indicating that injection velocity at the entry point can effectively characterize the well's operation mode. To determine the optimal operation mode for gas-lift wells, $Q = f(V)$ and $\upsilon = f(V)$ curves were plotted simultaneously. It was observed that the optimal mode determined from both graphs aligns at approximately the same point. Based on the results, it is concluded that the dependence of the liquid production rate on the operating gas injection rate can be substituted by the dependence of gas injection velocity on the gas injection rate for gas-lift wells.

Keywords: gas-lift wells; operating mode; tubing shoe; gas injection rate; gas injection velocity.

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Introduction

Currently, a significant portion of oil production from Azerbaijan's fields is attributed to gas-lift operations. This article explores scientific-theoretical models and provides a mathematical analysis of the gas-lift extraction method. A key focus in the application of the gas-lift method is the determination of the optimal operation mode. In many cases, the optimal mode is identified using the typical $Q = f(V)$ relationship [1-7]. Additionally, various existing methods for determining the optimal performance of gas-lift wells have been reviewed [8-10]. Despite these established approaches, it is essential to develop analytical methods based on field data to mitigate geological and technical complications and to precisely define the optimal operating modes for gas-lift wells.

In the gas-lift operation method, gas is compressed to high pressure via a compressor and injected into the well. At a specific depth, the gas mixes with the oil, reducing the density of the liquid column and causing the gas-liquid mixture to flow upward through the production tubing. To enhance gas-lift performance, numerous analytical models have been developed [11-13], and various methods for optimizing gas allocation within the gas-lift system using genetic algorithms have been investigated [14-16]. While many of these methods are theoretically advantageous, they are characterized in some cases by excessively complex calculations, as well as the extreme difficulty - and near impossibility - of accurately determining certain parameters under field conditions. Furthermore, previous researchers have addressed the diagnosis of operational interruptions and production complications in sand-producing gas-lift wells based on wellhead data analysis [17], the evaluation of gas-lift well performance based on the variability of operating parameters [18], and the stabilization of gas-lift optimization with varying amounts of available injection gas [19]. In contrast to the aforementioned studies, this article investigates how wellhead parameters depend on the operating gas performance indicators and the well's production rate. Consequently, the problem of determining the optimal operating mode for gas-lift wells based on the operating gas injection rates and wellhead parameters will be addressed.

Investigation of the correlation between gas velocity at the shoe zone and the well production rate in gas-lift wells

According to several studies [20], calculating the shoe pressure in gas-lift wells based on wellhead parameters is

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considered more appropriate, as it provides a more accurate representation of actual field conditions using the formula presented below.

$$P_{Sh} = P_a\left[1 - \frac{A_1 \dfrac{l}{Z_{w.h.}T_{w.h.}}\dfrac{\Delta T}{T_{w.h.}} + \dfrac{\Delta T^2}{3T_{w.h.}^2}A_2\dfrac{Z_{w.h.}T_{w.h.}}{P_{w.h.}^2}}{2 + \dfrac{\Delta T}{3T_{w.h.}} - A_2\dfrac{Z_{w.h.}T_{w.h.}}{P_{w.h.}^2}}\right] \quad (1)$$

where,

$A_1 = 2.3589 \cdot 10^{-3} \cdot M$;

$A_2 = 3.1632 \cdot 10^{-3} \cdot \dfrac{M \cdot Q_0^2}{d^4}$;

P_{Sh} – shoe pressure, MPa;

P_a – annular space pressure (or annulus pressure), MPa;

l – length of the second-string tubing, m;

M – molar mass of the injection gas;

Q_0 – gas injection rate at standard conditions, m³/day;

$Z_{w.h.}$ – gas compressibility factor at the wellhead;

$T_{w.h.}$ – injection gas temperature at the wellhead, K;

ΔT – temperature difference between shoe and wellhead, K.

Furthermore, based on the calculated shoe pressure and the injection gas rate, the gas injection velocity into the tubing at the tubing shoe zone was determined using the formula provided below.

$$\upsilon = 1.273\frac{Q_0}{d_e^2}\frac{P_0}{T_0}\frac{Q}{P}Z(P,T) \quad (2)$$

where,

d_e – equivalent diameter of the annular space cross-section;

P_0 – atmospheric pressure, MPa;

Z – gas compressibility factor;

T_0 – standard atmospheric temperature, K;

P and T – psressure and temperature of the gas at shoe conditions, respectively.

Precalculated values for the gas compressibility factor [21], depending on the corresponding pressure and temperature, were utilized in the study.

To determine the relationship between the gas injection velocity at the shoe and the well production rate, the gas velocity was calculated based on actual field data from selected wells operating under long-term stable conditions. The existence of a specific correlation between the liquid production rate, the injection gas rate $(Q = f(V))$, and the gas velocity at the shoe zone $(\upsilon = f(V))$ within these operating modes was investigated. For this purpose, the $Q = f(V)$ and $\upsilon = f(V)$ relationship for wells No. 650, 651, 669, 414, and 432, currently producing from the VII horizon of the "Sangachal-Deniz-Duvanny-Deniz-Khara-Zira" field, are presented in figures 1-5.

The obtained results indicate that the gas injection velocity at the point of entry can, to a certain extent, characterize the well's operating mode. The proposed method is precisely based on changes in the velocity of the gas flow injected into the well. It should be noted that in figures 4 and 5, the observed inverse relationship between gas velocity and well production rate at certain points is due to gas injection rates exceeding the optimal operating mode. In such cases, the gas fails to perform useful work; instead, it bypasses the liquid by overcoming the pressure of the rising fluid column from the bottomhole without effective mixing. Consequently, the gas velocity increases sharply while the liquid production rate declines.

In general, as the gas injection rate increases toward its

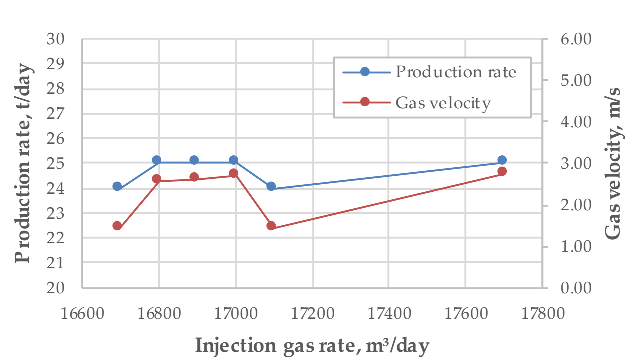

Fig. 1. Relationship between liquid production rate $Q = f(V)$ and gas injection velocity $\upsilon = f(V)$ for well No. 650

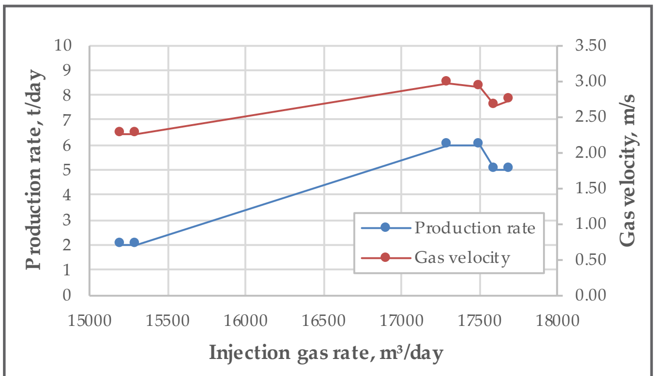

Fig. 2. Relationship between liquid production rate $Q = f(V)$ and gas injection velocity $\upsilon = f(V)$ for well No. 651

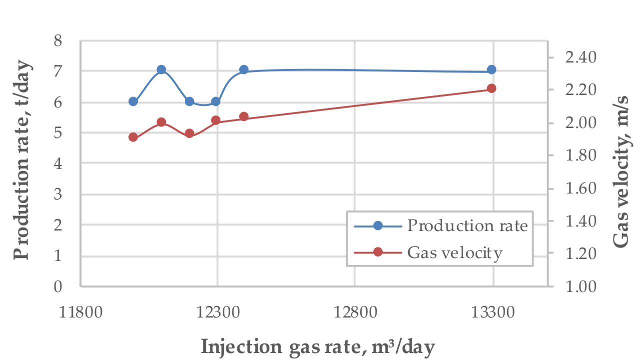

Fig. 3. Relationship between liquid production rate $Q = f(V)$ and gas injection velocity $\upsilon = f(V)$ for well No. 669

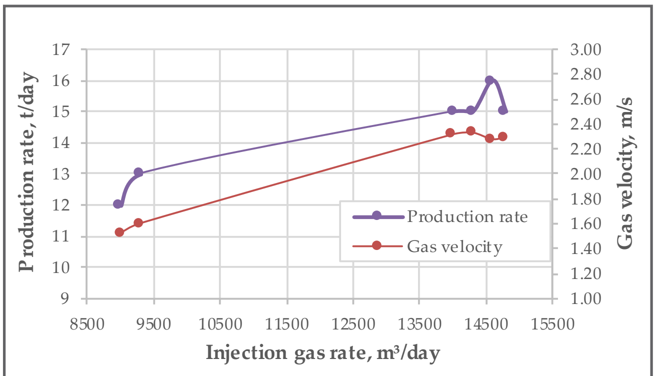

Fig. 4. Relationship between liquid production rate $Q = f(V)$ and gas injection velocity $\upsilon = f(V)$ for well No. 414

maximum, it can be stated that the growth rate of the gas velocity at the shoe zone increases analogously throughout the interval of rising liquid production. Our calculations and analysis demonstrate that the gas velocity at the tubing shoe characterizes the well's operating mode to a significant degree. In this regard, further extensive research and analysis of individual wells across consistently selected operating modes are necessary.

A new approach to selecting the optimal operating mode for gas-lift wells

To investigate well efficiency based on actual parameters and determine optimal operating modes, a joint analysis of these factors was conducted. Mathematical calculations were then used to develop a simplified method based exclusively on wellhead parameters.

For this purpose, based on field data obtained from the "SDXZ" field, the operating mode of gas-lift well No. 433, producing from the VII horizon, was investigated. The parameters of this well were measured across several consecutive operating modes. Information regarding the well's performance indicators under various operating modes is presented in the table below.

As shown in the table, the well was operated in several different modes for a specific period, and the wellhead data was recorded. The well production rate was measured for each operating mode, and a typical $Q=f(V)$ curve was constructed (fig. 6). Furthermore, based on the recorded wellhead data, the shoe pressure at the base of the second-string tubing was calculated using the method described in [19]. Based on the calculated shoe pressure, the gas injection velocity into the tubing at the shoe zone was determined corresponding to the respective injection gas rates. Subsequently, the $\upsilon=f(V)$ curve was analogously plotted for this well (fig. 7).

It was observed that the coordinates of the injection gas rate at the point of tangency, where tangents are drawn from the origin to each of the constructed curves, almost perfectly align (fig. 8).

Based on all the calculations and conducted research, it is concluded that the $Q=f(V)$ curve, traditionally used to determine the optimal operating mode of gas-lift wells, can be successfully substituted by the $\upsilon=f(V)$ curve. Furthermore, this approach can be effectively utilized under field conditions to determine the optimal operating mode of gas-lift wells based solely on wellhead parameters.

Table

Operating parameters of gas-lift well No. 433

Operating modes	Setting depth of the second-string tubing, m	Operating pressure, MPa	Shoe pressure, MPa	Daily oil production rate, t/day	Gas injection rate, m³/day	Specific gas consumption, m³/t	Gas-Liquid Ratio, m³/m³	Injection gas velocity at the shoe, (υ), m/s
1	4032	4.458	4.991	5	10000	2000	100	0.821
2		4.661	5.218	6	10500	1750	125	1.236
3		4.864	5.445	7	11000	1571	150	1.610
4		5.066	5.672	7.6	11500	1513	180	1.943
5		5.269	5.898	8.2	12000	1463	210	2.235
6		5.472	6.125	8.8	12500	1420	250	2.403
7		5.674	6.352	9.2	13000	1413	300	2.529
8		5.877	6.579	9	13500	1500	350	2.634
9		6.080	6.806	8.5	14000	1647	400	2.697

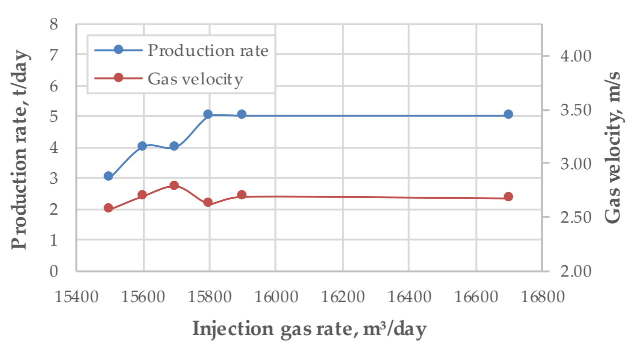

Fig. 5. Relationship between liquid production rate $Q=f(V)$ and gas injection velocity $\upsilon=f(V)$ for well No. 432

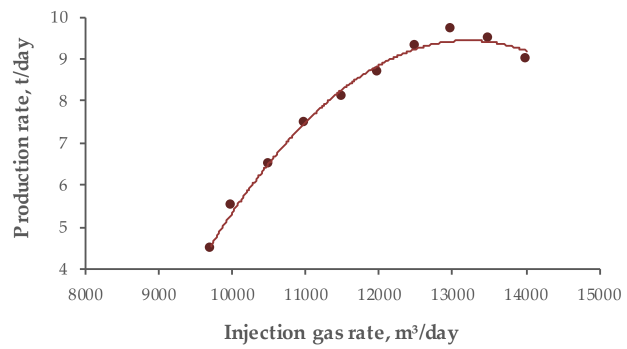

Fig. 6. Liquid production rate as a function of injection gas rate $Q=f(V)$ for well No. 433

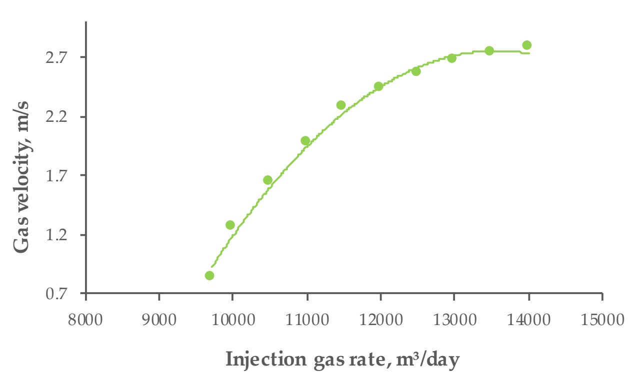

Fig. 7. Gas injection velocity as a function of injection gas rate ($\upsilon = f(V)$) for well No. 433

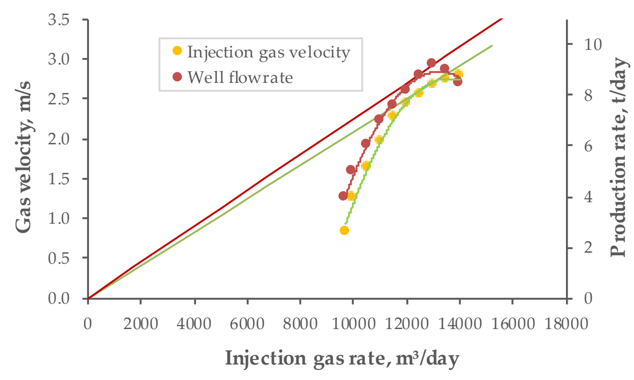

Fig. 8. Comparison of $Q = f(V)$ and $\upsilon = f(V)$ curves for well No. 433

Conclusions

1. Existing solutions for optimizing the operating modes of gas-lift wells were analyzed. Methods for calculating the gas pressure at the point of entry into the tubing – specifically, the shoe zone - within concentric dual-string gas-lift systems based on actual parameters were investigated. Using a selected formula favored for its parameter accessibility and detailed situational description, shoe pressures were calculated for various wells based on distinct wellhead and operating parameters. Subsequently, based on these shoe pressures and corresponding gas injection rates, the gas injection velocities were determined for various wells across different operating conditions.

2. Based on the actual operating parameters of the wells in different modes, $Q = f(V)$ curves were constructed, and concurrently, $\upsilon = f(V)$ curves were plotted using wellhead parameters for analogous wells and presented seperately . It was revealed that the gas injection velocity at the tubing shoe can, to a significant extent, characterize the well's operating mode.

3. To determine the optimal operating mode of a gas-lift well, the $Q = f(V)$ curve was plotted based on actual production data. Additionally, the pressure at the shoe of the second-string tubing and the corresponding gas injection velocity were calculated for each mode using wellhead parameters, and the $\upsilon = f(V)$ curve was constructed.

4. It has been demonstrated that the $Q = f(V)$ curve, traditionally used to determine the optimal operating mode in gas-lift wells, can be successfully substituted by the $\upsilon = f(V)$ curve. This method enables the determination of the optimal operating mode for gas-lift wells based solely on wellhead parameters, without the necessity of measuring the well production rate.

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