SOCAR

SOCAR Proceedings

Reservoir and petroleum engineering

journal home page: http://proceedings.socar.az

INDEXED IN EMERGING SOURCES CITATION INDEX THOMSON REUTERS

Scopus

IDENTIFYING THE OPTIMAL OPERATING REGIME OF PRODUCTION WELLS BASED ON THE ANALYSIS OF WELLHEAD PRESSURE FLUCTUATIONS

Sh. Z. Ismayilov, A. A. Suleymanov*

Azerbaijan State Oil and Industry University, Baku, Azerbaijan

A B S T R A C T

The article presents the results of field experimental studies of wellhead and bottomhole pressure fluctuations at different operating modes of gas-liquid lift. As a result of the research, it was found that at the optimal operating mode of gas lift well there is minimum amplitude and maximum frequency of wellhead and bottomhole pressure fluctuations, which agrees well with the results of previously, conducted theoretical and experimental laboratory studies. It is shown that the increase in the amplitude and decrease in the frequency of wellhead and bottomhole pressure fluctuations is observed when gas injection deviates from the optimal one, both in the direction of increasing and decreasing gas injection. The possibility of assessing the optimal operating mode of gas-lift and flowing wells on the basis of analyzing the fluctuations of technological parameters during normal operation without special testing operations has been established. A methodology for assessing the efficiency of gas-lift and flowing wells operation mode based on the application of various methods of time series analysis was created.

Keywords: gas lift well; gas-liquid flow; optimal rate; wellhead pressure; fluctuation.

Introduction

In oil production practice, the results of field studies and various hydrodynamic models of formation fluid flow in the bottomhole zone and wellbore are used to diagnose well operation mode [1, 2].

It should be noted that field studies are associated with certain technical and technological difficulties, material and financial costs, undesirable well shutdowns, complications in the operation of wells, etc. [3-6].

As it is known, changes in the main technological parameters of well operation have a fluctuating (oscillating) character [7-12]. This is associated with the nature of gas-liquid mixtures movement in the bottom-hole zone of wells and tubing. Such character of changes in wellhead parameters determines the relevance of application of diagnostic methods in the analysis of these processes, which make it possible to assess the state of the «reservoir-wellbore» system on the basis of studying the features of fluctuations and make a timely and reasonable decision to regulate well operation.

The fluctuating nature of technological processes of hydrocarbon production was established quite a long time ago [7-12], but only with the development of technical capabilities to control the dynamics of changes in well performance and information technology, including data processing, it became possible to use field measurements in diagnostic and prognostic tasks [13, 14].

Speaking about the causes of the fluctuating nature of the dynamics of technological indicators, it should be noted that the very process of multiphase (oil. gas, water) flow of reservoir fluids in porous medium leads to fluctuations in flow rate, pressure, density, temperature, etc. [2, 7].

But many other physical processes of oil and gas production can also lead to fluctuations and change the features of fluctuations of technological indicators.

For example, during the flow of multiphase flow of formation fluids in lift pipes, various modes of flow of gas-liquid mixture are observed, some of which are accompanied by non-uniform flow of liquid and gas, fluid retention at certain intervals of the wellbore and its ejection, creating fluctuations in density, bottomhole pressure, flow rate, etc. [15-17].

The nature of oscillations in gas-liquid mixture movement in lift pipes becomes more complicated when the well is watered down, when water (as a separate phase and/or as an oil-water emulsion) is added to the oil and gas [14].

In the work of A. H. Mirzajanzadeh, the auto-oscillating mode of operation of a producing well with a sand plug [7]. Changes in the density of the mixture in the wellbore due to the accumulation and removal of sand lead to fluctuations in the mode of operation of wells. In addition, sand remaining in tubing can be in suspended (fluidized) or packed (sand plug) states, which leads to changes in mixture density, fluctuations in bottomhole pressure and production rate [14, 15, 18, 19].

Another source of flow rate fluctuations in production wells is the accumulation of gas in the annulus [7, 17].

In the process of operation of flowing and gas-lift wells

**E-mail:* petrotech@asoiu.az

http://dx.doi.org/10.5510/OGP20240100941

fluctuations of technological parameters of different origin can occur simultaneously in one well and create a difficult to analyze fluctuation process. In addition, the fluctuating nature of operation adversely affects the condition of downhole and surface equipment [18-21], and may also lead to bottomhole zone destruction and complications in well operation.

Analysis of complex multifactor fluctuation processes of changes in the dynamics of technological parameters makes it possible to diagnose well operation complications in advance and make an informed decision on changing the operation mode and impact on the «reservoir-well» system.

Field studies of fluctuating features of gas lift well performance

It is important to note that when conducting field studies of fluctuations of technological parameters based on data of normal well operation, the accuracy and frequency of measurements are important. A large amount of data is necessary to analyze well conditions using probabilistic-statistical and mathematical methods [22, 23].

Modern methods of measuring pressure (e.g. piezoelectric pressure sensors) and temperature have low inertia and sufficiently high accuracy even at short intervals between measurements.

Therefore, when analyzing the state of the system «reservoir-well» and diagnosing and selecting the optimal mode of operation of wells according to the data of normal operation based on the application of mathematical and statistical methods, it is relevant to use pressure measurements (wellhead, in the annular space, etc.) [14].

To confirm the obtained conclusions, we analyzed the measurements of wellhead pressure fluctuations in the gas lift well of «Neft Dashlary» («Oil Rocks») field at different injected gas flow rates - below, above and at the optimal injected gas flow rate (fig. 1 -3) [14].

As can be seen from the presented data, at the optimal operation mode of the gas lift well, the minimum amplitude and maximum frequency of wellhead pressure fluctuations are observed, which agrees well with the results of theoretical and laboratory studies [13, 14].

An increase in the amplitude and decrease in the frequency of wellhead pressure fluctuations are observed when gas injection deviates from the optimum both in the direction of increasing and decreasing gas injection.

Table 1 presents the values of standard deviation σ and Theil's index (U_T) [24] for wellhead pressure fluctuations at different operating modes of a gas lift well.

Similar studies were carried out for the gas lift well of the Chirag field. Figures 4-9 shows the dynamics of gas lift wellhead pressure change.

As can be seen from the presented data, at the optimal operation mode of the gas lift well the amplitude of oscillations decreases, which corresponds to the results of theoretical and experimental laboratory studies.

Fluctuation analysis of gas lift performance

As it was shown above, complex multifactor fluctuation processes are observed during the movement of multiphase systems in the porous medium and in the wellbore. To study such fluctuations, a combined method based on the application of different approaches to analyzing the dynamics of technological parameters is required [14]. The application of single-type methods does not allow to obtain an adequate description of complex fluctuation processes [25].

Various approaches to the analysis of fluctuation processes can be used to assess the well operation mode based on the study of the dynamics of the main technological indicators of normal well operation.

Application of dynamic analysis methods for diagnostics of fluctuation processes.

The principles of dynamic analysis of oil and gas production processes were developed by A. H. Mirzajanzadeh and representatives of his school and are based on the inhomogeneity, nonlinearity, and non-equilibrium of the «reservoir-well» system [1, 2].

Table 1

Values of standard deviation and Theil's index at different operating modes

Mode	σ	U_T
$V_{gas} < V_{opt}$	2.076	0.278
$V_{gas} = V_{opt}$	0.616	0.083
$V_{gas} > V_{opt}$	2.663	0.376

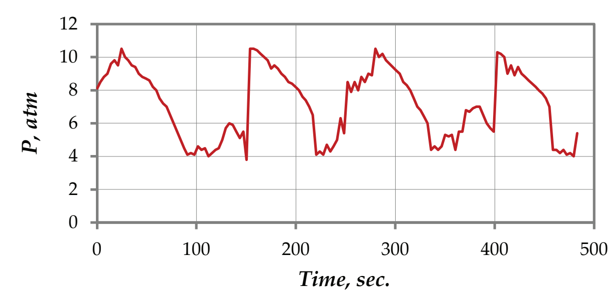

Fig. 1. Wellhead pressure fluctuations ($V_{gas} < V_{opt}$)

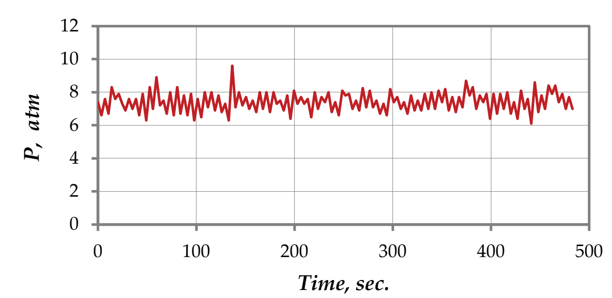

Fig. 2. Wellhead pressure fluctuations ($V_{gas} = V_{opt}$)

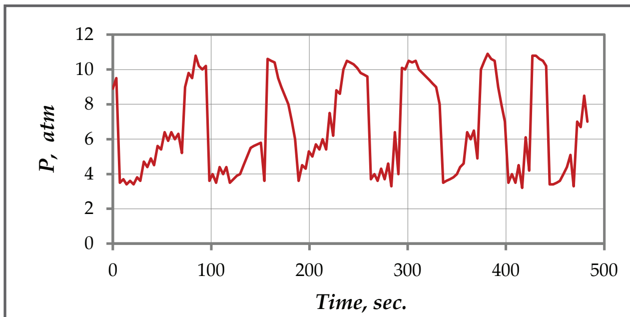

Fig. 3. Wellhead pressure fluctuations ($V_{gas} > V_{opt}$)

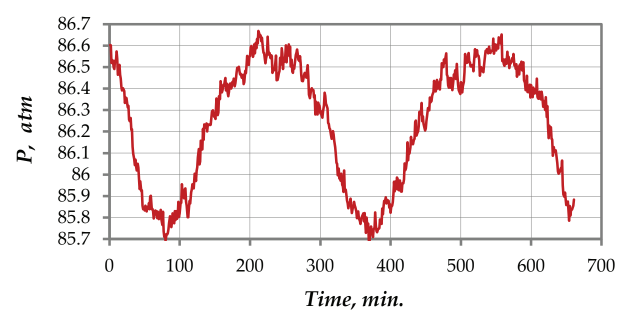

Fig. 4. Bottomhole pressure fluctuations ($V_{gas}<V_{opt}$)

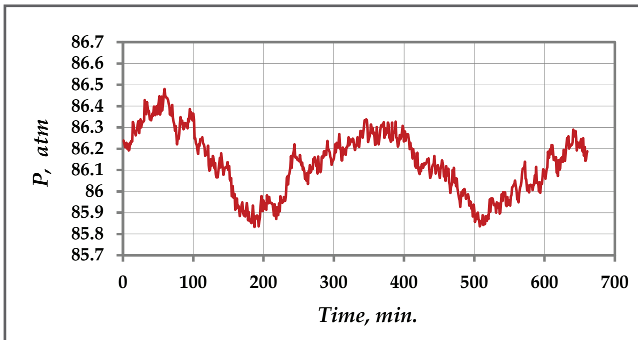

Fig. 5. Bottomhole pressure fluctuations ($V_{gas}=V_{opt}$)

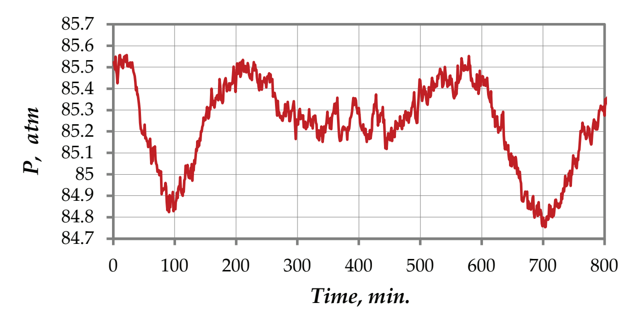

Fig. 6. Bottomhole pressure fluctuations ($V_{gas}>V_{opt}$)

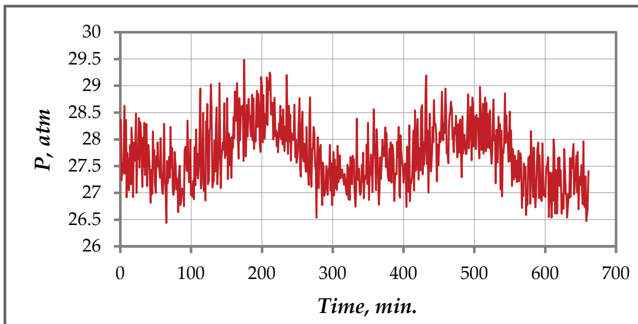

Fig. 7. Wellhead pressure fluctuations ($V_{gas}<V_{opt}$)

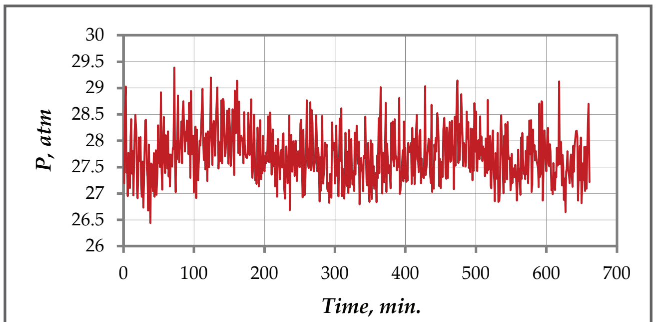

Fig. 8. Wellhead pressure fluctuations ($V_{gas}=V_{opt}$)

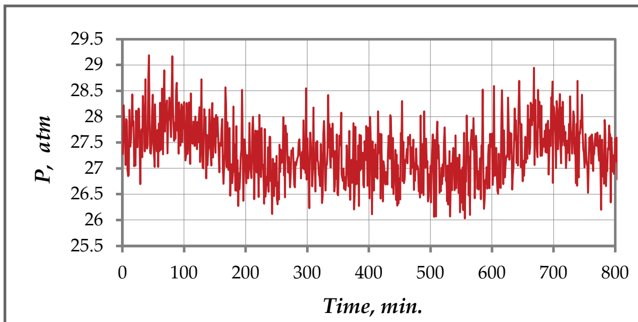

Fig. 9. Wellhead pressure fluctuations ($V_{gas}>V_{opt}$)

The degree of self-organization and orderliness of the system can be assessed by changes in the value of some indicators, such as entropy, Gini coefficient, fractal characteristics and others. This approach makes it possible to identify the main trends in the evolution of the system and make timely informed decisions on its management [26].

To analyze the data obtained from the study of gas lift well at different modes, the values of Gini coefficient and entropy were calculated (fig. 10 and table 2).

Similar calculations were carried out for the gas lift well of the Chirag field (table 3)

As can be seen from the results obtained, the minimum values of the Gini coefficient and entropy correspond to the optimal regime.

Fractal analysis of fluctuation processes. Nowadays fractal theory is applied in many fields of science and technology [27]. Methods of fractal geometry are also used in solving various problems of oil production [13].

It should be noted that in this case it is necessary to analyze the time series of dynamics of technological indicators, which imposes some limitations on the applied methods and algorithms.

In this paper, a non-parametric indicator of variation of time series is used to estimate the features of fluctuations of technological parameters [28]:

Table 2

Values of Gini coefficient and Entropy at different operating modes («Oil Rocks» field)

Mode	Gini Coefficient	Entropy
$V_{gas}<V_{opt}$	0.354	2.281
$V_{gas}=V_{opt}$	0.264	1.850
$V_{gas}>V_{opt}$	0.443	2.106

Table 3

Values of Gini coefficient and Entropy at different operating modes (Chirag field)

Mode	Gini Coefficient	Entropy
$V_{gas}<V_{opt}$	0.185	1.854
$V_{gas}=V_{opt}$	0.136	1.614
$V_{gas}>V_{opt}$	0.161	1.824

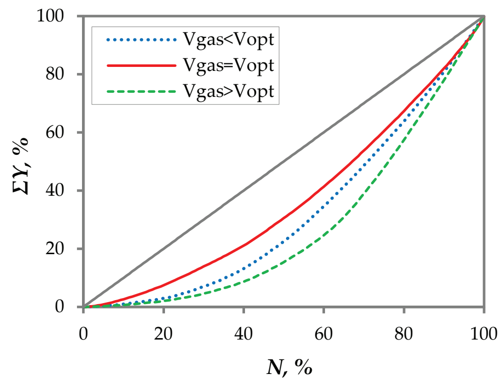

Fig. 10. Calculation of Gini coefficient at different operating modes of a gas lift well

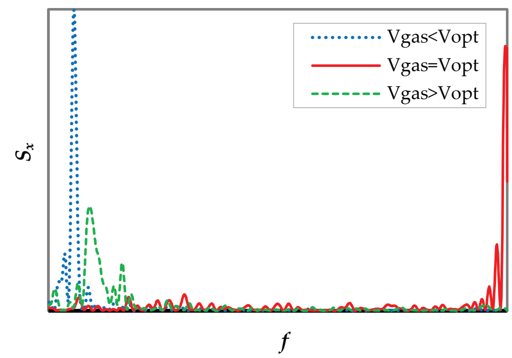

Fig. 11. Spectral analysis of fluctuations at different operating modes of the gas lift well

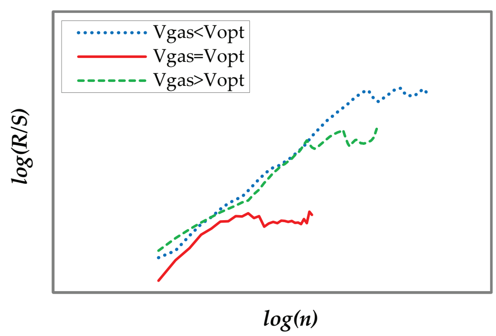

Fig. 12. R/S analysis of fluctuations at different operating modes of the gas lift well

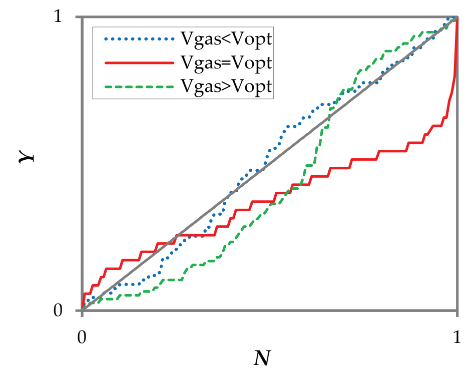

Fig. 13. Ranked fluctuation data for different gas lift well operating modes

$$l=\frac{\sum_{i=1}^{n-1}|y_i-y_{i+1}|}{n-1}=\frac{|y_1-y_2|+|y_2-y_3|+...+|y_{n-1}-y_n|}{n-1}$$

where y_1 – time series values of some dynamic process measured at equal time intervals; n – number of measurements.

It should be noted that when normalized values are used, the variability criterion l varies between 0 and 1 [25].

The results of calculations of fluctuation variability criterion for different gas lift well modes are presented in table 4.

Table 4

Values of fluctuation variability criterion at different operating modes

Mode	l
$V_{gas}<V_{opt}$	0.075
$V_{gas}=V_{opt}$	0.280
$V_{gas}>V_{op}$t	0.137

As can be seen from the presented data, the value of the criterion is maximized at the optimal operation mode of the gas lift well.

Spectral analysis of fluctuations of technological indicators allows estimating the frequency composition of the time series [29]. The basis of classical spectral analysis is the Fourier transform, which connects the time series with its representation in the frequency domain.

Figure 11 shows the results of spectral analysis of fluctuations at different operating modes of gas lift well.

It follows from the obtained data that the optimal mode is characterized by the maximum frequency of oscillations [14].

Fractal characteristics also include the Hurst index and its various modifications [27]. It has been found that with the help of R/S -analysis it is possible to estimate long-term memory, and characteristic time of periodic and non-periodic (chaotic) cycles [27]. This is especially valuable when analyzing complex multifactor fluctuations, as it allows us to estimate the periods (cyclicity) of each of several, simultaneously occurring fluctuation processes.

Figure 12 shows the results of R/S analysis calculations of gas lift wellhead pressure fluctuations.

As can be seen from the obtained data, at the optimal mode of well operation the lowest amplitude and the highest frequency of wellhead pressure fluctuations are observed, which agrees well with the data of experimental and theoretical studies [13, 14].

Application of nonparametric criteria for diagnosing fluctuation processes.

In probabilistic-statistical data analysis, different types of criteria are used, for example, parametric, based on statistical parameters of a given sample, and nonparametric, representing functions that depend directly on the values of the data under study. An important advantage of nonparametric criteria is that their application is correct regardless of the type of data distribution [28].

We apply for data analysis the non-parametric criterion for evaluating the type of data distribution [28]. The value of criterion S varies in the range from 0 to 1.

Figure 13 and table 5 show the results of the calculations.

As can be seen from the presented data, the optimal operation mode of the gas lift well corresponds to the maximum value of criterion *S*.

The analysis of the obtained results shows that the optimal operation mode corresponds to the minimum (standard deviation, Theil's criterion, Gini coefficient, etc.) or maximum (variation index, *S* criterion) values of the criteria.

Accordingly, the use of various methods and approaches to analyze wellhead data allows for a reasonable diagnosis of the well operation mode.

Table 5

Values of non-parametric criterion S at different operating modes

Mode	*S*
$V_{gas} < V_{opt}$	0.06
$V_{gas} = V_{opt}$	0.28
$V_{gas} = V_{opt}$	0.18

Conclusions

1. As a result of field studies, it was found that at the optimal operating mode of gas lift well there is a decrease in amplitude and increase in frequency of wellhead and bottomhole pressure fluctuations, which agrees well with the results of theoretical and experimental laboratory studies.
2. It is shown that the increase in amplitude and decrease in frequency of wellhead and bottomhole pressure fluctuations is observed when gas injection deviates from the optimal one, both in the direction of increasing and decreasing gas injection.
3. A methodology for assessing the efficiency of the operating mode of gas-lift and flowing wells based on the application of non-parametric criteria, including fractal methods of identifying changes in the character of technological indicators fluctuations.

References

1. Mirzadjanzade, A. Kh., Ametov, I. M., Bokserman, A. A., Filippov, V. P. (1993). New perspective trends of research in oil and gas recovery. In: *7th European Symposium on Improved Oil Recovery. Russia: Moscow.*

2. Mirzadjanzade, A. Kh., Akhmedov, Z. M., Gurbanov, R. S., et al. (1971). On the special features of oil and gas field development due to effects of initial pressure gradients. WPC-14249. In: *8th World Petroleum Congress. Moscow.*

3. Hernandez, A. (2016). Fundamentals of gas lift engineering. *Elsevier, Gulf Professional Publishing.*

4. Golan, M., Whitson, C. H. (1996). Well performance. *Prentice-Hall.*

5. Beggs, H. D. (2003). Production optimization: using NODAL analysis. *USA, Tulsa: OGCI, Petroskills Publications.*

6. Brill, J. P., Mukherjee, H. (1999). Multiphase flow in wells. *Society of Petroleum Engineers.*

7. Suleimanov, B. A., Veliyev, E. F., Vishnyakov, V. V. (2022). Nanocolloids for petroleum engineering: Fundamentals and practices. *John Wiley & Sons.*

8. Suleimanov, B. A., Guseynova, N. I. (2019). Analyzing the state of oil field development based on the Fisher and Shannon information measures. *Automation and Remote Control*, 80(5), 882-896.

9. Suleimanov, B. A., Huseynova, N. I. (2023). The entropy analysis of changes in the distribution of the formation fluid filtration characteristics for oilfield development management. SPE-217607-MS. In: *SPE Caspian Technical Conference and Exhibition. Baku, Azerbaijan.*

10. Suleimanov, B. A., Huseynova, N. I. (2023). Visualization of reservoir fluid filtration characteristics distribution, as a method of oil field development management. *SOCAR Proceedings*, SI1, 27-37.

11. Suleimanov, B. A., Huseynova, N. I. (2023). Method for operative estimation of current reservoir pressure distribution based on the wells normal production data. *SOCAR Proceedings*, SI2, 12-19.

12. Suleimanov, B. A., Ismailov, F. S., Dyshin, O. A., Huseinova, N. I. (2012). Analysis of oil deposit exploration state on the base of multifractal approach. *SOCAR Proceedings*, 2, 20-26.

13. Suleymanov, A. A., Abbasov, A. A., Ismaylov, A. J. (2009). Fractal analysis of time series in oil and gas production. *Chaos, Solitons, Fractals*, 41, 2474–2483.

14. Abbasov, A. A., Ismayilov, Sh. Z., Suleymanov, A. A., et al. (2022). Gas lifted well performance evaluation based on operational parameters' fluctuations. *SOCAR Proceedings*, 3, 54-60.

15. Slupphaug, O., Bjune, B. (2006). Active slug management. SPE-96644-MS. In: SPE Annual Technical Conference and Exhibition. *USA: San Antonio, Texas.*

16. Gang, Z., Golan, M. (1989). Criteria for operation stability of gas lift wells. In: *SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.*

17. Asheim, H. (2000). Criteria for gas-lift stability. *Society of Petroleum Engineers.*

18. Hu, B., Golan, M. (2003). Gas-lift instability resulted production loss and its remedy by feedback control: dynamic simulation results. SPE-84917-MS. In: *SPE International Improved Oil Recovery Conference in Asia Pacific. Malaysia: Kuala Lumpur.*

19. Xu, Z. G., Golan, M. (1989). Criteria for operation stability of gas lift. SPE-19362. *Society of Petroleum Engineers.*

20. Abdullayev, V. J. (2021) Comparative study of the operational properties of deviated and straight gas-lift wells and sensitivity analysis of pressure gradient. *Scientific Petroleum*, 1, 46-51.

21. Abdullayev, V. J. (2022). Special borehole flow regulator for gas-lift wells. *Scientific Petroleum*, 1, 46-51.

22. Jensen, J. L., Lake, L. W., Corbett, P. W. M., Goggin, D. J. (2000). Statistics for petroleum engineers and geoscientists. *Amsterdam: Elsevier.*

23. Shestopalov, Y., Shakhverdiev, A. (2021). Qualitative theory of two-dimensional polynomial dynamical systems. *Symmetry*, 13(10), 1884.

24. Theil, H. (1967). Economics and information theory. *Amsterdam: North-Holland.*

25. Suleymanov, A. A., Abbasov, A. A. (2011). Diagnosis of well production operations on the basis of nonparametric criteria of production data variations. *Petroleum Science and Technology*, 29(22), 2377-2383.

26. Gini, C. (1936). On the measure of concentration with special reference to income and statistics. *Colorado College Publication*, 208, 73–79.

27. Peters, E. (2003). Fractal market analysis. *New York: John Wiley&Sons.*

28. Suleymanov, A. A., Abbasov, A. A. (2011). The identification of data distribution in oil production. *Petroleum Science and Technology*, 29(23), 2480-2486.

29. Jenkins, G. M., Watts, D .G. (1969). Spectral analysis and its applications. *London: Holden-Day.*