Technical Parameters Modeling of a Gas Probe Foaming Using an Active Experimental Type Research

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Abstract. The present paper deals with a current and complex topic, namely - a technical problem solving regarding the modeling and then optimization of some technical parameters related to the natural gas extraction process. The study subject is to optimize the gas probe sputtering using experimental research methods and data processing by regular probe intervention with different sputtering agents. This procedure makes that the hydrostatic pressure to be reduced by the foam formation from the water deposit and the scrubbing agent which can be removed from the surface by the produced gas flow. The probe production data was analyzed and the so-called candidate for the research itself emerged. This is an extremely complex study and it was carried out on the field works, finding that due to the severe gas field depletion the wells flow decreases and the start of their loading with deposit water, was registered. It was required the regular wells foaming, to optimize the daily production flow and the disposal of the wellbore accumulated water. In order to analyze the process of natural gas production, the factorial experiment and other methods were used. The reason of this choice is that the method can offer very good research results with a small number of experimental data. Finally, through this study the extraction process problems were identified by analyzing and optimizing the technical parameters, which led to a quality improvement of the extraction process.

1. Introduction

Natural gas has been known since antiquity, both in the form of unspoiled fires and in the form of near-surface sprays. These were used by the Chinese with 2000 years of heating and were transported by bamboo strains. Natural gas entered the energy balance very late in Romania. The same has happened in the case of their use as raw material in the chemical industry. These have a great importance also for the caloric power they have up to 13,500 kcal/m³. The methane gas discovery in our country was made in 1909 with a helping probe in the Sarmasel town. This was prospecting for potassium salts. Indications of the presence of natural gas existed before their discovery through the manifestations of "muddy volcanoes" or "live fires" located in different areas of Romania.

The first chapter involves the theoretical considerations regarding experimental research and data processing. Statistical processing of experimental data is the object of a specific branch of mathematics and it is called mathematical statistics. This is related to the probability theory. The
second chapter refers to the active experiment - a beneficial solution for experimental testing and data processing. The factorial experiment, was choose to carry out this research because factorial experimentation can be achieved most easily by addressing and solving problems that appear relatively simple, but they are intuitive [1, 2]. In the third chapter introducing, the composition and importance of natural gas, was presented. I also have been highlighted their importance and made a short history of natural gas in Romania [3]. Natural gas is a complex mixture of saturated hydrocarbons (mainly methane and different amounts of ethane, propane, butane or other higher molecular weight hydrocarbons), small quantities of hydrocarbon-free gases (hydrogen, sulphide, carbon dioxide) and even gases neutral ones such as nitrogen and helium. For the exploitation of natural gas fields, a complex surface infrastructure is needed and it develops with the change of the number of productive wells, the dynamics of the pressure of the wells and the pressure from the collection system to which the deposit is granted. The natural gas extraction process brings to the surface a mixture of products in gaseous, liquid and solid form, which requires producers to condition their natural gas before handing them over to the distributor, consumer or carrier.

Generally formed from gaseous hydrocarbons in which carbon has an important part, with 80-99% of its composition, natural gas, as it is known, especially under the name of "methane gas", is found to accumulate in large quantities in the bark of the globe, or in most cases in the interplay with oil deposits [4]. Methane is a first-rate fuel, a renewable energy source, a material already considered in the third decade of the century - ideal for hygienic lighting and heating, easy to transport through pipelines, uninfluenced by external weather, exploited by its own its tension in the reservoir, and as a raw material of overwhelming importance for the chemical industry, that is methane gas, or the natural gas encountered in considerable quantities in the basement of Transylvania [5].

2. The factorial experiment method
Factorial experiments show their effectiveness where they want to study the influence of two or more factors on an objective function. Identifying the main concepts and notions with which the factorial experiment is currently practiced can be easily achieved by addressing and solving relatively simple but intuitive problems [6]. The optimal strategy provided by the EFC process involves the use of a minimal number of attempts, which is done after an optimal strategy, and the regression polynomial corresponding to this type of experiment provides information on the direction to be optimized [7]. In the first step, modeling with the help of factorial experiments refers to the correct and complete definition of the problem to be solved, the specification of the interesting objective function for the researcher regarding the description of the object, the phenomenon or the process to be analyzed. In the second important step in the application of factorial experimentation is the identification of the influence factors of each objective function of the ones to be analyzed [8].

3. The factorial experiment method-performing the experiment, processing and data optimizing
Identifying the main concepts and notions with which the factorial experiment is currently practiced can be easily achieved by addressing and solving relatively simple but intuitive problems [7]. In 1918 a pipeline was built between the Bazna and Medias localities that transformed the locality of Târnava Mare into a powerful industrial center. Methane gas is one of the most important factors in the economic development of Mediașul in the period between the two world wars. The need to modernize and streamline the oil and gas industry in Romania has led to the conclusion of partnerships with world-recognized companies in the field. Romgaz has formed an association with the largest service company in the field, Schlumberger, for the optimization of the Laslau Mare gas field in Mureș County. Schlumberger Limited is the world leader in industrial and gas industry services, providing technology, solutions and integrated project management that optimize the performance and exploitation of customer reserves in the field. Laslau Mare gas field has been explored since 1960. 88 exploration and exploitation drills have been excavated. The field includes 54 probes, out of which 48 assets. The probes exploit productive horizons grouped into 4 operating packages. These are referred to as the deadlines of each productive layer. These depths range from 1,800 m to 3,000 m. Each
mining package has characteristics of nearby reservoir formations. Between packages, these features are differentiated but not radically. Active probes can also be divided into exploration wells and exploration wells that have been converted to exploitation [9].

3.1. Object definition and measurement mode
After more than 40 years of exploitation, the Laslău Mare reservoir has reached an advanced degree of depletion, current flows are maintained only with regular or exceptional interventions. Regular activities include:

- Spumogenic intervention;
- Measurement of probe parameters - Tube pressure, column pressure, daily flow and deposit water production;
- Gas drying and compression in order to optimize for transportation in the gas-gating system and to consumers;
- Separating, measuring and removing deposit water from the gas stream.

The object of this study is to make regular interference with wells with various sputtering agents. This procedure makes hydrostatic pressure reduced by forming a foaming water and the scrubbing agent that can be removed from the surface of the gas flow produced. On the Laslau Mare gas field are used foaming agents of several types:

- Solid density solids that sink into water and form foam on the bottom of the well;
- Solid lightweight agents floating on the water foam on the surface of the liquid column;
- A sparkling liquid, injected into column wells and used in the case of mechanical restraints that do not allow the solid foaming agent to reach the liquid level in the well.

Next it is wanted to analyze the results of probe spraying using experimental and data processing methods. Depending on the results, the investigation to other sample specimens will be extended, so that in the end this process can be optimized according to the exploitation package and the type of foam agent for the entire Laslau Mare gas field. The result should be reflected in the maximization of gas production and discharge of deposit water wells.

3.2. The factors selection and their values to be tested
Consider an active deep-water well with a medium gas flow and medium water storage for a period of one year. Given the limitations of the program of analysis, the data will be taken every 5 calendar days. Tubing pressure, column, difference between column pressure and tube (indicates the degree of water load of the probe), the amount of daily sparkling will be considered as inputs or factors, and daily flow and daily water production will be considered as objective, resulting. The data submitted were previously verified and validated by a pre-selection process.

| Pt (bar) | Pc (bar) | Pc-Pt (bar) | Spum. (m³) | Dt (m³/h) | Apa (m³) |
|---------|---------|------------|------------|----------|----------|
| 9.9     | 12.8    | 2.9        | 0.01       | 9.03     | 20       |
| 8.6     | 12.3    | 3.7        | 0.01       | 9.64     | 40       |
| 7.4     | 11.5    | 4.1        | 0.01       | 9.67     | 0        |
| 6.5     | 11.5    | 5          | 0.01       | 9.99     | 0        |
| 6.9     | 11.3    | 4.4        | 4          | 10.67    | 250      |
| 6.8     | 10.9    | 4.1        | 1          | 10.16    | 50       |
| 6.4     | 10.9    | 4.5        | 4          | 9.4      | 240      |
| 6.6     | 10.9    | 4.3        | 1          | 10.51    | 100      |
| 7       | 11.6    | 4.6        | 0.01       | 10.23    | 0        |
Table 1. General data.

| Pt (bar) | Pc (bar) | Pc-Pt (bar) | Spum. (m$^3$) | Dt (m$^3$/h) | Apa (m$^3$) |
|----------|---------|-------------|---------------|-------------|-------------|
| 8.1      | 11.5    | 3.4         | 1             | 10.35       | 70          |
| 7.5      | 11.4    | 3.9         | 1             | 10.26       | 40          |
| 7.2      | 11.2    | 4           | 1             | 10.32       | 120         |
| 7        | 11.6    | 4.6         | 1             | 10.52       | 20          |
| 6.6      | 11.4    | 4.8         | 1             | 10.74       | 0           |
| 6.5      | 11      | 4.5         | 1             | 10.77       | 160         |
| 6.8      | 11.7    | 4.9         | 1             | 10.71       | 50          |
| 7.8      | 10.7    | 2.9         | 1             | 10.04       | 50          |
| 10       | 13.5    | 3.5         | 1             | 9.51        | 40          |
| 6.5      | 10.7    | 4.2         | 1             | 10.58       | 60          |
| 7.2      | 11.2    | 4           | 1             | 9.82        | 0           |
| 7.9      | 11.3    | 3.4         | 1             | 10          | 20          |
| 7.2      | 11.6    | 4.4         | 1             | 9.86        | 80          |
| 7.4      | 11      | 3.6         | 2             | 9.74        | 100         |
| 6.3      | 10.4    | 4.1         | 2             | 9.95        | 100         |
| 6.4      | 11.1    | 4.7         | 2             | 10.46       | 150         |
| 6.5      | 11.2    | 4.7         | 0.01          | 10.31       | 0           |
| 7.2      | 11.4    | 4.2         | 0.01          | 9.87        | 20          |
| 6.3      | 11.3    | 5           | 0.01          | 9.79        | 0           |
| 6.2      | 11.6    | 5.4         | 0.01          | 9.49        | 40          |
| 8.2      | 11.6    | 3.4         | 4             | 9.69        | 190         |
| 6.6      | 11      | 4.4         | 4             | 10.2        | 200         |
| 6.9      | 11.4    | 4.5         | 4             | 10.21       | 320         |
| 7        | 11.7    | 4.7         | 0.01          | 10.8        | 20          |
| 6.7      | 11.1    | 4.4         | 0.01          | 10.86       | 60          |
| 7.2      | 12.2    | 5           | 0.01          | 10.55       | 0           |
| 7.2      | 11.6    | 4.4         | 3             | 10.53       | 110         |
| 7.7      | 11.9    | 4.2         | 3             | 10.11       | 160         |
| 6.8      | 12.2    | 5.4         | 0.01          | 9.6         | 0           |
| 7.2      | 13.4    | 6.2         | 0.01          | 9.98        | 0           |
| 7.1      | 11.6    | 4.5         | 0.01          | 9.34        | 0           |
| 7        | 12.8    | 5.8         | 0.01          | 8.48        | 0           |
| 7.3      | 12.3    | 5           | 0.01          | 8.35        | 0           |
| 7.2      | 13      | 5.8         | 0.01          | 8.08        | 0           |
| 7.2      | 13.2    | 6           | 0.01          | 7.88        | 0           |
| 7.6      | 10.4    | 2.8         | 0.01          | 8.84        | 60          |
Table 1. General data.

| Pt (bar) | Pc (bar) | Pc-Pt (bar) | Spum. (m$^3$) | Dt (m$^3$/h) | Apa (m$^3$) |
|----------|----------|-------------|----------------|---------------|-------------|
| 7.8      | 10.6     | 2.8         | 1              | 8.57          | 70          |
| 7.6      | 10.5     | 2.9         | 1              | 8.55          | 30          |
| 7.8      | 10.4     | 2.6         | 1              | 8.26          | 60          |
| 7.5      | 10.1     | 2.6         | 1              | 8.15          | 70          |
| 8.8      | 11.2     | 2.4         | 1              | 7.87          | 50          |
| 8.4      | 11.1     | 2.7         | 1              | 8.02          | 50          |
| 8.2      | 10.8     | 2.6         | 1              | 7.96          | 90          |
| 7.4      | 12.7     | 5.3         | 1              | 7.67          | 100         |
| 7.6      | 12       | 4.4         | 1              | 7.78          | 40          |
| 6.7      | 10       | 3.3         | 1              | 8.53          | 20          |
| 7.2      | 9.9      | 2.7         | 1              | 8.51          | 60          |
| 8.1      | 11       | 2.9         | 3              | 7.94          | 170         |
| 7        | 9.9      | 2.9         | 3              | 8.28          | 170         |
| 7.9      | 11.2     | 3.3         | 3              | 7.65          | 170         |
| 8.5      | 11.8     | 3.3         | 3              | 11            | 170         |
| 8        | 11.2     | 3.2         | 3              | 11.57         | 180         |
| 8.4      | 11.3     | 2.9         | 3              | 11.44         | 170         |
| 7.7      | 14.3     | 6.6         | 3              | 11.64         | 100         |
| 8.2      | 12       | 3.8         | 3              | 10.88         | 150         |
| 8.8      | 11.9     | 3.1         | 3              | 11.16         | 100         |
| 8        | 11.9     | 3.9         | 3              | 10.92         | 140         |
| 8.2      | 12       | 3.8         | 3              | 10.61         | 90          |
| 8.1      | 11.1     | 3          | 3              | 10.3          | 120         |
| 8.5      | 11.6     | 3.1         | 3              | 10.02         | 120         |
| 8.3      | 11.3     | 3          | 3              | 9.69          | 130         |
| 8.8      | 12       | 3.2         | 3              | 9.87          | 80          |
| 8.4      | 11.3     | 2.9         | 3              | 9.31          | 80          |
| 7.5      | 9.7      | 2.2         | 3              | 9.79          | 80          |
| 7.4      | 10.2     | 2.8         | 3              | 9.41          | 100         |
| 10.4     | 12.1     | 1.7         | 3              | 8.65          | 70          |
| 7.9      | 10.7     | 2.8         | 3              | 8.02          | 100         |
| 8.6      | 10.9     | 2.3         | 3              | 8.71          | 90          |
| 7.8      | 10.9     | 3.1         | 3              | 8.73          | 90          |
| 8.2      | 11.2     | 3          | 3              | 8.58          | 70          |
| 8.5      | 11       | 2.5         | 3              | 8.42          | 80          |
| 8.5      | 11.3     | 2.8         | 3              | 8.52          | 100         |
Table 1. General data.

| Pt (bar) | Pc (bar) | Pc-Pt (bar) | Spum. (m³) | Dt (m³/h) | Apa (m³) |
|----------|----------|-------------|------------|-----------|----------|
| 7.9      | 10.9     | 3           | 3          | 8.55      | 80       |
| 8.7      | 11.3     | 2.6         | 3          | 8.55      | 70       |
| 8.4      | 11.2     | 2.8         | 3          | 8.58      | 110      |

3.3. The experience plan selection

From the analysis of the wells production data, the candidate for this research was obtained. Due to the intensified depletion of the gas field, the flow of the wells and the start of their loading with deposit water were recorded. At that time, it was necessary to smooth the wells of the wells, to optimize the daily production flow and to eliminate the accumulated water in the wellbore. A research plan with 4 factors and 2 objective functions, with 84 levels, representing a set of data every 5 days, over a calendar year, is resulting. Given the existence of measured data, try to adapt the experimental plan to analyze it as they are, without imposing limits or thresholds of attention. The descriptive statistical indicators of the process are set in the table. It can be noted that all 84 cases are valid. For each parameter, the mean, median, or minimum and maximum values were generated, the variance and standard deviation were calculated, and skewness (karyotype) and kurtosis (skewness) were also calculated. The skewness value denotes an inclination to the left, except for the flow function, which is tilted to the right. The small, near-zero values have a distribution close to the median. The exception is the deposit water function, where it can be observed a very large standard deviation, due to the large range of values of this objective function. The kurtosis value has a more plastic distribution than the normal distribution, with greater disproportion around the mean.

Table 2. Descriptive statistical indicators of the process.

| Valid N | Mean   | Median | Minimum | Maximum | Variance | Std. Dev. | Skewness | Kurtosis |
|---------|--------|--------|---------|---------|----------|-----------|----------|----------|
| PT      | 84     | 7.610  | 7.500   | 6.200   | 10.400   | 0.730     | 0.854    | 0.732    | 0.838    |
| PC      | 84     | 11.409 | 11.300  | 9.700   | 14.300   | 0.678     | 0.823    | 0.813    | 1.620    |
| PC-PT   | 84     | 3.798  | 3.750   | 1.700   | 6.600    | 1.079     | 1.038    | 0.477    | -0.370   |
| Spum    | 84     | 1.692  | 1.000   | 0.010   | 4.000    | 1.774     | 1.332    | 0.128    | -1.484   |
| Flow    | 84     | 9.554  | 9.765   | 7.650   | 11.640   | 1.105     | 1.05133  | -0.138399| -1.054   |
| Water   | 84     | 80.47619| 70.00000| 0.000000| 320.0000 | 4380.493  | 66.18530 | 0.970108 | 1.22320  |

Figure 1. Gas Flow Histogram.

Figure 2. Water Production Histogram.
The first histogram, as far as the gas flow is concerned, can be seen in Figure 1 that it was measured in meters per hour, and after the graph the values are in the range of 7.5 to 12.0 but focus more on the intervals 9.5-10.0 and 10.5 -11.0. In the second histogram (Figure 2) the production of deposit water can be seen that was measured in m$^3$ and it is evident that the recorded values of the deposit of water production are concentrated in the range of -50 to 350, but most relevant samples contained values of water production breakdown in two ranges, namely 50-100 and 0-50.

The above histograms show the statistical variation of the parameters analyzed over the data unfolding interval. From the histogram analysis it can be seen the distribution of values, the minimum and maximum values, and the number of observations of each value.

In Figure 3 is graphically represented the function of the flow target being influenced by the pressure and the column pressure. The maximum flow rate in this case is 12 and the minimum value is -4 depending on the tube pressure and the column pressure. The highest recorded flow rate corresponds to 15 bar and 8.5 bar, respectively. It can be seen in Figure 4 maximizing the gas flow at column pressures above 10 bar and tube pressures up to 7 bar. The section presented brings added value and a relaxation of the 3D graphics rendering.

In figure 5 is graphically represented the function of the flow objective being influenced by the pressure and the pressure difference. The maximum flow rate is 10 and the minimum value of 6 is based on the pressure and refinement difference. The highest flow record is 4.5 m$^3$ and 5 bar differential pressure. We notice increasing gas flow to a differential pressure of between 4 and 5 bar. It is also noted that a plateau area is formed at foams of between 4 and 5.5 units. Under these conditions, it is recommended to use up to 2 units of foam / day to avoid creating other mechanical problems due to over-spraying.
3.4. The results analysis and the results configuration defining

Considering all the data presented, continuous spraying and large amounts of foam agent would give the best results. However, the need not to immerse the probe in spumogenic substances and the variation in the pressure of the tube caused by the whole field pressure leads to a cautious approach to this conclusion. Continuous monitoring of parameters and prompt response to accumulation of water in the wellbore, as well as repeating the analysis will lead to continuous improvement of the process. The analysis should also be extended to several probes with the same characteristics to confirm or invalidate the conclusion of the particular analysis of the probe presented.

4. Conclusions

Natural gas fuels come from free natural gas fields, they do not contain other heavy hydrocarbons in liquid state. Condensed gas deposits contain, in addition to natural gas and light liquid hydrocarbons, separate in the extraction process.

The exploitation of the deposits is done by means of probes. The gas probes are very similar to the oil wells, the difference being that at the gas probes, the columns inserted are cemented to the surface.

In order to exploit and monitor under optimal conditions the components of the surface installations related to the production wells within the gas-generating structures, they are grouped spatially in number, varying in particular the distance between them, forming so-called groups of probes.

The analysis of the studied process was based on data from Romgaz, which formed an association with the largest service company in the field, Schlumberger, for optimizing and improving the Laslau Mare gas field in Mureș County.

The subject of this study is regular interference with probes with different sputtering agents. This procedure causes the hydrostatic pressure to be reduced by the formation of foam from the deposit water and the scrubbing agent which can be eliminated at the surface by the gas flow produced.

The probe sputtering results using experimental research methods and data processing, were analyzed. Depending on the results the investigation to other representative wells will be extended so that in the end this process can be optimized according to the exploitation package and the spumogen type of the entire Laslau Mare gas field. The result should be reflected in the maximization of gas production and the discharge of deposit water wells.

Tubing pressure, column, difference between column pressure and tubing (indicates the degree of water load of the probe), the amount of daily frothing will be considered input parameters or factors, and the daily flow and daily water production will be considered objective, resulting functions. The data submitted were previously verified and validated by a pre-selection process.

Following the realization of their graphs and their analysis, it was found that continuous spraying with large amounts of foam agent would yield the best results. However, the need not to immerse the probe in spumogenic substances and the variation in the pressure of the tube caused by the whole field pressure leads to a cautious approach to this conclusion. Continuous monitoring of parameters and prompt response to accumulation of water in the wellbore, as well as repeating the analysis will lead to continuous improvement of the process. The analysis should also be extended to several probes with the same characteristics to confirm or invalidate the conclusion of the particular analysis of the probe presented.

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