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Research Article

OIL AND GAS FIELDS SURFACE SUBSIDENCE AND CONNECTION AMONG PETROPHYSICAL PARAMETRS OF ROCKS

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ABSTRACT
The dependence of oil and gas deposits on the surface subsidence on petrophysical parameters is examined. In this, based on the results of the experiments conducted by the authors, known from the literature, the influence of factors such as the thickness of productive layers, the average porosity of these layers, and the duration of geodetic measurements on the subsidence of the surface of oil and gas fields was analyzed by mathematical modeling. These studies show that the mathematical model of oil and gas deposits is nonlinear (second-order) in the first approximation, and if other geological, geophysical and geomechanical characteristics are added to the list of factors, the accuracy of the model will increase.

Keywords: *Subsidence, petrophysic, oil and gas fields, geodynamics*

Introduction. The surface subsidence of oil and gas fields can be influenced by various factors. It is influenced by geodynamics, oil and gas extraction and other man-made processes, and each factor contributes. During the intensive exploitation of hydrocarbon deposits, the properties of the surrounding geological environment and its geodynamic balance change significantly due to the decrease in formation pressure, and vertical and horizontal shifts occur. This leads to the formation of dangerous geodynamic processes and the number of seismic events and several times increase of intensity in the areas where hydrocarbons are extracted [Razumov and Xasin, 1991]. From this point of view, the subsidence of surface parts of hydrocarbon deposits is one of the urgent issues to be researched from a theoretical and practical point of view.

Relevance of the theme: The study of modern geodynamic processes in oil and gas areas is carried out in two main directions:

1) geodynamic assessment of oil and gas prospects of the studied areas;

2) assessment of ecological-geodynamic risks in oil and gas fields as a result of the study of deformations occurring in the ground and long-term exploitation of oil and gas fields.

A lot of work has been done in the first direction, (Abidov, 2002; and Khodzhimetov, 2004) in this article, the researches were carried out mostly in the second direction.

As a result of long-term exploitation of oil and gas fields, along with various risks (large deformation of above-ground structures; casing fractures; pipeline breaks; siltation and flooding of submerged areas; hydrosphere and soil pollution; atmospheric pollution due to burning of bound gas), fields the subsidence of the upper parts and the assessment of seismic activity in these areas are urgent tasks.

It is very important to study the subsidence of the surface of oil and gas fields, and the geodynamic condition of the fields in general, and to determine the presence or absence of risks based on this, and as a result of these studies, it will be possible to prevent catastrophic situations.

Main part. Surface subsidence in long-term oil and gas fields in the United States, Venezuela, the North Sea, and other regions has been well studied and shown to be associated with reduced formation pressures in piles as a result of dug oil and gas production (Kashnikov and Ashikhmin, 2007; Viktorova *et al.*, 2004; Ashikhmin, 2008).

For many fields, the surface subsidence rate is 1-2 cm/year, and the accumulated subsidence does not exceed 1 m. Subsidences of several 10 m are very rare, but these subsidences are extremely dangerous and have

negative effects on the ecosystem, socio-economic conditions today and in the near future. As a result of summarizing the research conducted in several field, the sedimentation in them was analyzed by Kashnikov Yu.A. and Ashikhmin S.A[4]. Measurements are given in Wilmington oil field in USA, Oil and gas field near Houston, Inglewood oil field Ekofisk oil field in the North Sea, Oil field in Lake Maracaibo (Venezuela), Lac oil and gas field (France), Groningen gas field (Holland), Surakhan oil fields in the Apsheron (Azerbaijan), Gazli gas field (Uzbekistan), Anastasia oil field and Shebelin gas field (Ukraine) and this analysis carried out above, dedicated to the assessment of the subsidence of the surface of the earth as a result of the development of hydrocarbon deposits over a long period of time, made it possible to determine the following:
- surface subsidence due to the development of oil and gas fields is common, the value of this subsidence has a wide range.
- intensive man-made subsidence (more than 1-2 m) is relatively less observed, but very large damages were seen from them;
- the problems of forecasting of the subsidence of large surface areas have not yet reached a reliable level.

In general, as a result of the analysis of the available data, it was found that the large-scale subsidence of the surface of the earth in long-term cultivated fields occurs together with the following conditions: sufficient mining area; sufficient thickness of the productive layer; the heap should be located at a depth; high porosity of reservoir rocks; anomalous high formation pressure in the heap and a significant rapid decrease of this pressure during the development of the field.

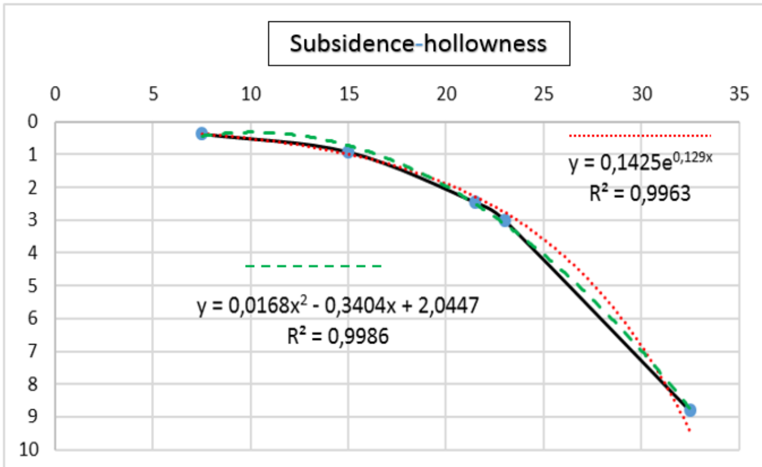
The main purpose of the research presented in this article is to analyze the subsidence of the surface of the earth caused by man-made causes in the oil and gas fields according to the information presented in the literature and to create a mathematical model for forecasting these subsidences. Using the results of foreign and local observations, the main attention is focused on the analysis of the porosity of the productive layer, which is presented in most of them. In this case, oil and gas deposits were selected where the surface subsidence was more observed (Kashnikov and Ashikhmin, 2007; Viktorova *et al.*, 2004), and on the basis of other available data on these deposits (Table 1), their interrelationship was analyzed.

Table 1. Oil and gas fields and information about them [4, 5]

№	**Name of fields**	**Maximum subsidence(м)**	**Thickness of Productive layer (м)**	**Duration of geodetic measurements (years)**	**Hollowness (%)**
1	Wilmington (USA)	8,8	1070	38	32,5
2	Lagunials (Venezuela)	4,1	900	54	22
3	Erofisk (Norway)	2,6	3000	1	37,5
4	Surahani (Azerbaijan)	3	2470	60	23
5	Balakhani (Azerbaijan)	2,45	1100	35	21,5
6	Goose Creek (USA)	1	600	12	30
7	Severo-Stavropol (Russia)	0,92	580	23	15
8	Shelebin (Ukraine)	0,37	600	17	7,5

First of all, in order to qualitatively analyze the dependence of the sedimentation of the surface part of the fields on the hollowness of the productive layer, we tried to express the graphs of the relationship between them in MS Excel and this graph by means of an exponential function and a second-order polynomial (Figure

1) (Bashina and Spirina, 2007, Voskoboynikov, 2016). The conducted analysis showed that there is a connection between the surface area of the fields and the hollowness of their productive layers, and this connection is defined by the exponential function $y = 0{,}1425 \cdot e^{0{,}129x}$ and by the quadratic function $y = 0{,}0168 \cdot x^2 - 0{,}3404 \cdot x + 2{,}0447$, and the reliability level of this association was greater than ($R^2=0{,}99$). In Figure 1, the vertical axis shows the subsidence of the surface of the fields, and the horizontal axis shows the hollowness of the productive layers.



1 – picture. Surface sedimentation of fields(vertical axis)
and the relationship between the porosity of the productive formation

In table 1, other parameters besides the hollowness of the productive layer are presented, and in order to determine the connections between them, we will discuss the issues of correlation and regression analysis using the MS Excel program (Voskoboynikov, 2016).

To perform mathematical modeling, we enter the following signs: maximum subsidence - y, thickness of productive layer - x_1, duration of geodetic measurements - x_2, hollowness of rocks - x_3. Since these variables are in different measurement units, we can convert them to unitless quantities - standard quantities using mathematical statistics formulas, the quantity is z which we have observed, then the corresponding standard quantity is:

$$\bar{z} = \frac{z - Mz}{\sigma_z} \qquad (1),$$

Here Mz is the mathematical expectation of the quantity z, σ_z is the mean square deviation. (1) based on the formula and accepted designations we can make the table 1 look like this:

Table 2: Values of parameters of oil and gas fields of standard sizes

y	x_1	x_2	x_3
2,35	-0,25	0,42	0,98
0,48	-0,45	1,25	-0,18
-0,12	1,97	-1,51	1,53
0,04	1,36	1,56	-0,07
-0,18	-0,22	0,26	-0,24
-0,76	-0,80	-0,94	0,71
-0,79	-0,82	-0,36	-0,95
-1,01	-0,80	-0,68	-1,78

First of all, we will create a correlation table for these quantities (Table 3).

Table 3: Correlation table

	y	x_1	x_2	x_3
y	1,00			
x_1	0,14	1,00		
x_2	0,43	0,00	1,00	
x_3	0,51	0,56	-0,18	1,00

It is known that correlation analysis is a statistical data processing method that measures the strength of the relationship between two or more variables. Moreover, the absence of correlation between two quantities does not mean that there is no relationship between them. For example, the relationship may have a complex non-linear nature, which the correlation does not reveal.
According to the table 3, $r_{yx1}=0,14$, it shows that the relationship between y and x_1 is weak, $r_{yx2}=0,43$ and $r_{yx3}=0,51$, which indicates that these relationships are much stronger and this relationship has a non-linear nature.
After this analysis, it is possible to proceed to the mathematical representation of the relationship among the variables, namely to construct the multivariable function $y = f(x_1, x_2, x_3)$. Taking into account that correlation and regression analyzes are closely related to each other, using MS Excel program, we make linear and non-linear regression equations based on the data presented in Table 2. First, let's make a linear regression equation (Table 4).

Table 4: Results of linear regression analysis

RESULTS			
Regression statistics			
Multiple R	0,775569036		
R-square	0,60150733		
Normalized R-square	0,302637828		
Standard error	0,892740354		
Observations	8		
	Coefficient	*Standard error*	*t-statistics*
Y- intersection	-8,70467E-17	0,315631379	-2,75786E-16
x_1	-0,29588443	0,382901677	-0,772742582
x_2	0,568261399	0,323013817	1,759247965
x_3	0,776273295	0,388980686	1,995660254

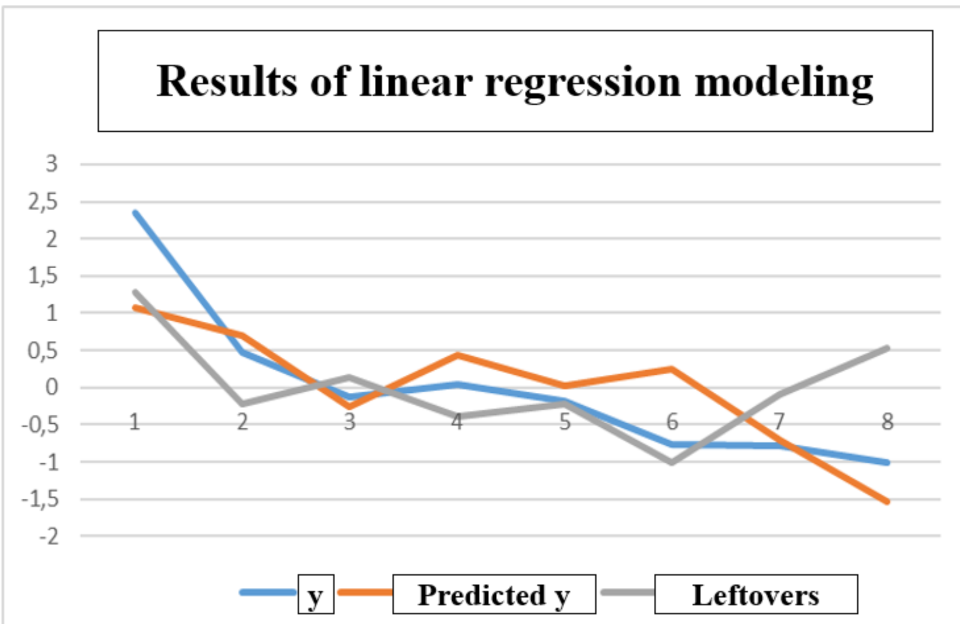
In this table, the necessary data for analysis are: coefficient of determination (R-squared) and coefficients of the linear regression equation (Coefficients). Regression equation:

$$y = -0{,}296 \cdot x_1 + 0{,}568 \cdot x_2 + 0{,}776 \cdot x_3 - 8{,}70467 \cdot 10^{-17} \qquad (2)$$

From the table, $R^2=0,6051$. This is a very small value and indicates that the obtained regression equation does not describe the process being studied well. Indeed, if we construct a graph representing the true values of y (Table 2) and (2) values determined using the regression equation ("Predicted y" in Table 5), as well as the differences between them ("Leftovers " in Table 5), given the differences between y and its values calculated using the model is clearly visible (Figure 2).

Table 5

Result of leftover		
Observation	*Predicted y*	*Leftovers*
1	1,073971516	1,272707254
2	0,704074629	-0,228369603
3	-0,250886259	0,129472005
4	0,431571045	-0,39375349
5	0,030415575	-0,211541756
6	0,250097715	-1,0084392
7	-0,705409638	-0,084778209
8	-1,533834583	0,524702999



Picture 2. Results of linear regression modeling

Therefore, regression equation, as we mentioned above, can have a complex linear character. In the second approximation, we add their squares to the series of linear independent variables. First, we determine the correlation between these quantities (Table 6).

Table 6: Correlation table for non-linear variables

	y	x_1	x_2	x_3	x_1^2	x_2^2	x_3^2
y	1,00						
x_1	0,14	1,00					
x_2	0,43	0,00	1,00				
x_3	0,51	0,56	-0,18	1,00			
x_1^2	-0,19	0,87	-0,41	0,47	1,00		
x_2^2	-0,04	0,81	0,17	0,40	0,75	1,00	
x_3^2	-0,26	0,08	-0,69	-0,19	0,39	-0,05	1,00

From table 6, it can be seen that there is a relationship between the studied function and the variable, even if it is weak. If we construct the nonlinear regression equation as before, the result will be as shown in Table 7.

Table 7: Results of second-order regression analysis

RESULTS			
Regression statistics			
Multiple R	0,999091		
R- square	0,998183		
Normalized R- square	0,987282		
Standard error	0,120559		
Observation	8		
	Coefficients	Standard error	*t-statistics*
Y- intersection	-0,54082	0,183593	-2,94578
x1	-0,72935	0,225783	-3,23032
x2	1,798776	0,171175	10,5084
x3	1,347319	0,078718	17,11587
x1^2	0,732746	0,252992	2,896323
x2^2	-1,00266	0,142718	-7,0255
x3^2	0,81074	0,067586	11,99575

From this table, for the case study, $R^2=0,998$, which means that the approximation equation has satisfactory accuracy, and this equation:

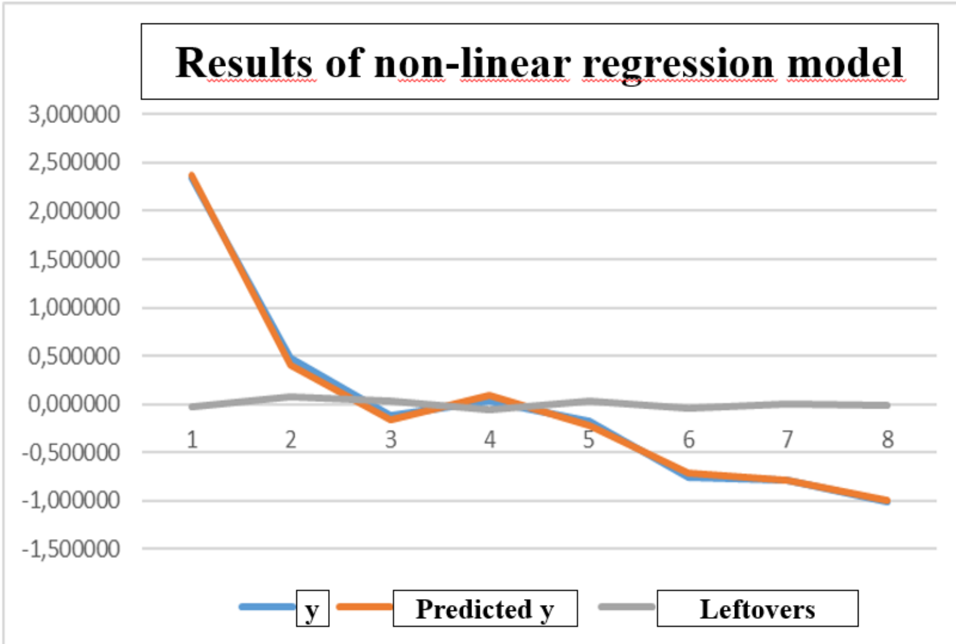
$$y = -0{,}739x_1 + 1{,}79x_2 + 1{,}347x_3 + 0{,}73x_1^2 - 1{,}003x_2^2 + 0{,}81x_3^2 - 0{,}541 \quad (3)$$

has appeared. The difference between the actual values of *y* and the values calculated using equation (3) is presented in Table 8.

Table 8

Results of leftover			
Observation	*y*	*Predicted y*	*Leftovers*
1	2,346679	2,370933	-0,024254
2	0,475705	0,401402	0,074303
3	-0,121414	-0,155817	0,034403
4	0,037818	0,097438	-0,059620
5	-0,181126	-0,217116	0,035990
6	-0,758341	-0,710832	-0,047510
7	-0,790188	-0,788335	-0,001852
8	-1,009132	-0,997673	-0,011459

If we make these quantities using Table 8, we will see how accurately the obtained nonlinear regression equation describes the studied situation (Figure 3).



Picture 3. Results of non-linear regression model

From the figure, it can be seen that the given values of y and its values calculated using formula (3) almost overlap.

CONCLUSION

The results presented in the article showed that the subsidence of the surface of the oil and gas fields is closely related to the thickness of the productive layer, its hollowness and the duration of geodetic measurements, and this relationship is non-linear. However, these studies are based on the first approximation of the mathematical model of surface sedimentation of oil and gas fields (3), and if other geological, geophysical and geomechanical characteristics are added to the list of factors, the accuracy of the model will increase. Today this work is the basis of the research conducted by the authors.

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