Journal of Mining Institute. 2021. Vol. 249. P. 386-392 DOI: 10.31897/PMI.2021.3.7
Vladislav I. Galkin, Dmitry A. Martyushev, Inna N. Ponomareva, Irina A. Chernykh

UDC 622.276.6

Developing features of the near-bottomhole zones in productive formations at fields with high gas saturation of formation oil

Vladislav I. GALKIN, Dmitry A. MARTYUSHEV✉, Inna N. PONOMAREVA, Irina A. CHERNYKH
Perm National Research Polytechnic University, Perm, Russia

***How to cite this article*:** Galkin V.I., Martyushev D.A., Ponomareva I.N., Chernykh I.A. Developing features of the near-bottomhole zones in productive formations at fields with high gas saturation of formation oil. Journal of Mining Institute. 2021. Vol. 249, p. 386-392. DOI: 10.31897/PMI.2021.3.7

Abstract. The article studies the formation features of the bottomhole zones in productive formations during operation of production wells in the north of the Perm Territory. Their distinctive feature is the high gas saturation of formation oil. The most widely used parameter in Russian and world practice – the skin factor was used as a criterion characterizing the state of the bottomhole zone. Analysis of scientific publications has shown that one of the main problems of applying the skin factor to assess the state of bottomhole zones is the ambiguity of interpretations of its physical meaning and the impossibility of identifying the prevailing factors that form its value. The paper proposes an approach to identifying such factors in the conditions of the fields under consideration, based on multivariate correlation-regression analysis. Choice of this tool is due to the complexity of the processes occurring in the "formation – bottomhole zone – well" system. When describing complex multifactorial processes, the chosen method demonstrates a high degree of reliability. For a large number of wells in the region, significant material was collected and summarized, including the results of determining the skin factor (1102 values) during hydrodynamic investigations, as well as data on the values of various geological and technological indicators, which can probably be statistically related to the value of the skin factor. A series of multidimensional mathematical models has been built; the skin factor was used as a predicted parameter, and data on the values of geological and technological indicators were used as independent indicators. Analysis of the constructed models is a key stage of this study. Set of parameters included in the multidimensional models, sequence of their inclusion and contribution to the total value of the achieved determination coefficient as the main indicator for the performance of the constructed models were studied. It has been established that the main factor influencing the state of the bottomhole zone is oil degassing. Significant differences in the formation features of the skin factor in the terrigenous and carbonate sediments at the fields under consideration have been determined.

***Key words*:** skin factor; hydrodynamic investigations of wells; multidimensional mathematical model; gas oil ratio; near-bottomhole zone

Introduction. Near-bottomhole zone (NBHZ) is the most important element of the "formation – well" hydrodynamic system. Its state largely determines the current values of the productive characteristics [6, 7]. Obtaining reliable information about the state of the near-bottomhole zone is one of the most important tasks in on-site control over the development and operation of hydrocarbon fields [4, 5, 8]. Determination of the skin factor S is one of the common methods for assessing the NBHZ hydrodynamic state [1, 9]. The data is obtained through the processing pressure build-up curves (PBC) obtained in the course of hydrodynamic investigations (HDI) of wells. This approach is not the only one. There are methods in the practice of petroleum engineering for interpreting the PBC, in which the assessment of the NBHZ is carried out according to other criteria, for example, by the dimensionless diagnostic feature d in the method of determined pressure moments [14] or by calculating the α_3 index in the Pollard method [24]. However, the method based on the determination of the skin factor has received the most widespread use in assessing the state of the NBHZ due to the relative simplicity of calculating the indicator itself and interpreting its value [13]. At the same time, a more detailed analysis of this approach allows outlining a number of rather serious problems [15].

One of the problems is the ambiguity of the physical meaning put into the term "skin factor" [21]. Originally, the term "skin factor" meant a thin zone of formation damage surrounding the wellbore. Later, the skin factor began to be used as a way to mathematically account for additional pressure losses [14] caused by formation damage due to primary and secondary drilling-in, violation of

the Darcy filtration law [11], non-radial flow geometry, etc. At present, it is the cumulative influence of these factors that is taken into account by the indicator S [16, 17].

Due to a wide variety of factors leading to additional pressure losses in the NBHZ, many researchers use several types of skin factors: general (total) [18] and specific [19]. Considerable attention is paid to the study of general and specific skin factors and the reasons for their formation in Russian and foreign literature. Thorough analysis of the particular components and their contribution to the overall value of the skin factor is of paramount importance according to [10, 22]. Authors of [24] point to the complex nature of the specific components influence on the total value and the inexpediency of their simple summation. Works [20, 25] are devoted to the comparative analysis of the specific components and the forecast of the total value of the skin factor. Researchers also outline the relevance of identifying particular reasons for the decrease in the permeability of the NBHZ for making engineering decisions during stimulation of oil production. Similar conclusions were obtained in [26]. The work considers the importance of a thorough analysis of the skin factor when planning and evaluating the results of measures to influence productive formations.

Thus, skin factor should be considered a parameter that is rather difficult to determine and even more difficult to interpret [11, 21]. In this regard, it seems interesting to conduct research that allows revealing the physical meaning of the skin factor and the reasons for the change in the state of bottomhole zones of productive formations in relation to the conditions of actual fields.

Methodology. The main idea of the study is as follows: skin factor is a parameter that affects all filtration processes in the drainage zone of a particular well. As a result, skin factor should be statistically related to certain geological and technological indicators. In turn, the presence of statistical links with indicators makes it possible to build multidimensional mathematical models – multiple regression equations.

In general, the multiple linear regression equation has the form:

$$Y = A_1X_1 + A_2X_2 + \dots A_KX_k + B,$$

where $X_1, X_2, \dots X_k$ – independent characteristics (indicators); $A_1, A_2, \dots A_K$ – coefficients for indicators; B – constant coefficient (free unit); Y – predicted value.

Purpose of the research in this work is to construct multiple regression equations, in which the skin factor is used as a dependent feature Y, and a set of geological and technological indicators that affect its value are used as independent factors X.

Analysis of the procedure for constructing and the type of the obtained models, including the list of those included in the equations as X-indicators, will make it possible to analyze in detail the process of forming the predicted value – the skin factor, in the fields under consideration, to highlight the prevailing factors influencing it. Thus, this work is reduced to the use of multivariate regression analysis in order to study the patterns of skin factor formation in the considered geological and physical conditions.

Research was carried out in relation to a group of oil fields located in the north of the Perm Region. Distinctive feature of these fields is the high gas saturation of oil in formation conditions. Commercial oil-bearing capacity of the fields is confined to the sediments of the Upper Devonian, Lower and Middle Carbon. Brief information on the geological and physical properties of the considered fields is presented in the table.

Study involved the materials of hydrodynamic investigations of wells for ten fields, processed by known methods [3] with the defining the value of the skin factor. Data for each well on the values of geological and technological indicators in the same periods of time, in which the hydrodynamic studies were carried out, were collected. They are: formation pressure P_f, MPa; annular pressure P_{an}, MPa; bottomhole pressure P_b, MPa; saturation pressure P_s, MPa; permeability coefficient of the remote formation zone k, μm^2; skin factor S, units; liquid flow rate Q_l, m^3/day; water cut in wells B, %;

porosity coefficient m, %; formation thickness h, m; formation oil viscosity μ, mPa·s; volumetric coefficient of oil b; piezoconductivity coefficient χ, cm^2/s; gas oil ratio G_f, m^3/t. It is assumed that statistically significant correlations can occur between these indicators and the value of the skin factor.

Geological and physical properties of oil fields

Parameter	Value	
	min	max
Reservoir type	Terrigenous, carbonate	
Depth, m	1590.0	2806.0
Porosity, %	4.0	23.7
Permeability, mD	17.0	175.7
Oil viscosity in formation conditions, mPa·s	0.72	19.83
Gas oil ratio, m^3/t	2.3	351.7
Volumetric coefficient of oil	1.02	1.71
Oil saturation pressure, MPa	10.3	18.5
Initial formation pressure, MPa	9.9	25.0

Values of the skin factor used in the course of the research were determined based on the materials of hydrodynamic investigations of wells by the pressure recovery method, carried out using high-precision bottomhole measuring devices. Interpretation of all involved investigations was carried out in one of the most modern software packages – Kappa Workstation (Saphir module). In this case, the use of modern measuring instruments and interpretation algorithms is the basis for considering the obtained skin factor values as reliable.

The models were built after a preliminary study of the correlations between all the listed parameters using stepwise regression analysis (SRA). This method is widely used to solve various production and technological problems, especially in the conditions of complex multifactorial processes [2, 12].

The most important element of the study is not only the construction of models, but also their analysis. Detailed analysis of the multidimensional regression equations allows solving the problem, i.e. to highlight the main indicators that affect the formation of the skin factor. List of parameters included in the model, order of their inclusion, as well as the contribution of the parameter to an increase in the resulting coefficient of determination R – one of the main criteria for the performance of the constructed model, are investigated within the framework of this analysis.

It is advisable to compare the model and actual values of the skin factor, for example, in the form of the corresponding correlation fields to assess the quality of modeling. Analysis of these fields will make it possible to assess the performance of the models at different ranges of skin factor variation.

Investigations were carried out with varying degrees for differentiation of the research objects. In this regard, concept of the level of modeling was introduced. At the first level, model is constructed for the entire sample, including the values of skin factors (n = 1102) and other geological and technological indicators for all wells in the development objects of the fields under consideration. At the second level, models are built specifically for each of the three main development objects: Famennian (n = 250), Visean (n = 312) and Bashkir (n = 540).

Results. Multidimensional mathematical model for determining the skin factor for all productive formations of the considered fields was built at the first level of the study.

Multidimensional model of the first level has the form:

$$S^{M1} = 1.1978m + 0.0448G_f - 0.8359P_s + 0.4555P_{an} + 4.4227b - 0.0922\mu + 0.0388h - 14.2904, \quad (1)$$

with R = 0.523, significance level $p < 0.0000$, standard error 6.571 units.

Model was formed in the sequence shown in the regression equation. Values of the coefficients R, describing the strength of statistical relationships, changed as follows: 0.457; 0.499; 0,514; 0.518; 0.520; 0.522; 0.523.

Comparison of the actually determined and model (calculated by equation (1)) values of the skin factor is shown in Fig.1.

The second level of the study involves the construction of models for particular development objects.

Model for development objects in the Famennian sediments has the form:

$$S^{M2\text{-}Fm} = 6.1606k + 15.2403b + 0.6851\mu - $$

$$- 0.0002\chi - 0.0067G_f + 0.1238m - 23.538, \quad (2)$$

with $R = 0.498$, $p < 0.0000$, standard error 3.294 units.

Model was formed in the sequence shown in the regression equation. Values of the coefficients R, describing the strength of statistical relationships, changed as follows: 0.319; 0.424; 0.465; 0.484; 0.493; 0.498.

Model values of $S^{M2\text{-}Fm}$ were calculated according to the formula (2). These values were compared with the actual values by constructing the correlation fields (Fig.2, *a*).

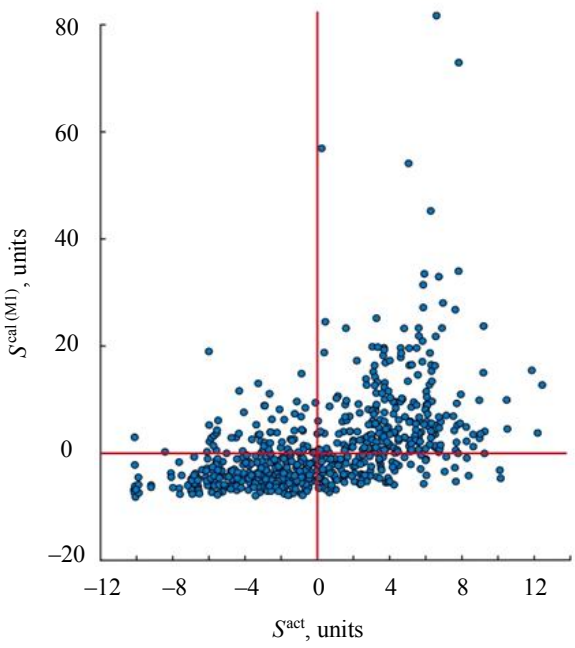


Fig.1. Correlation field of model and actual skin factor values (first level of modeling)

Model of the second level for development objects in Visean terrigenous sediments has the form:

$$S^{M2\text{-}Vs} = 0.0018\chi + 0.5366h - 8.7299k - 0.1026Q_l - 1.3213P_b + 0.9733P_f + 1.0489m +$$

$$+ 0.9363P_s - 26.045, \quad (3)$$

with $R = 0.528$, $p < 0.00000$, standard error 7.75 units.

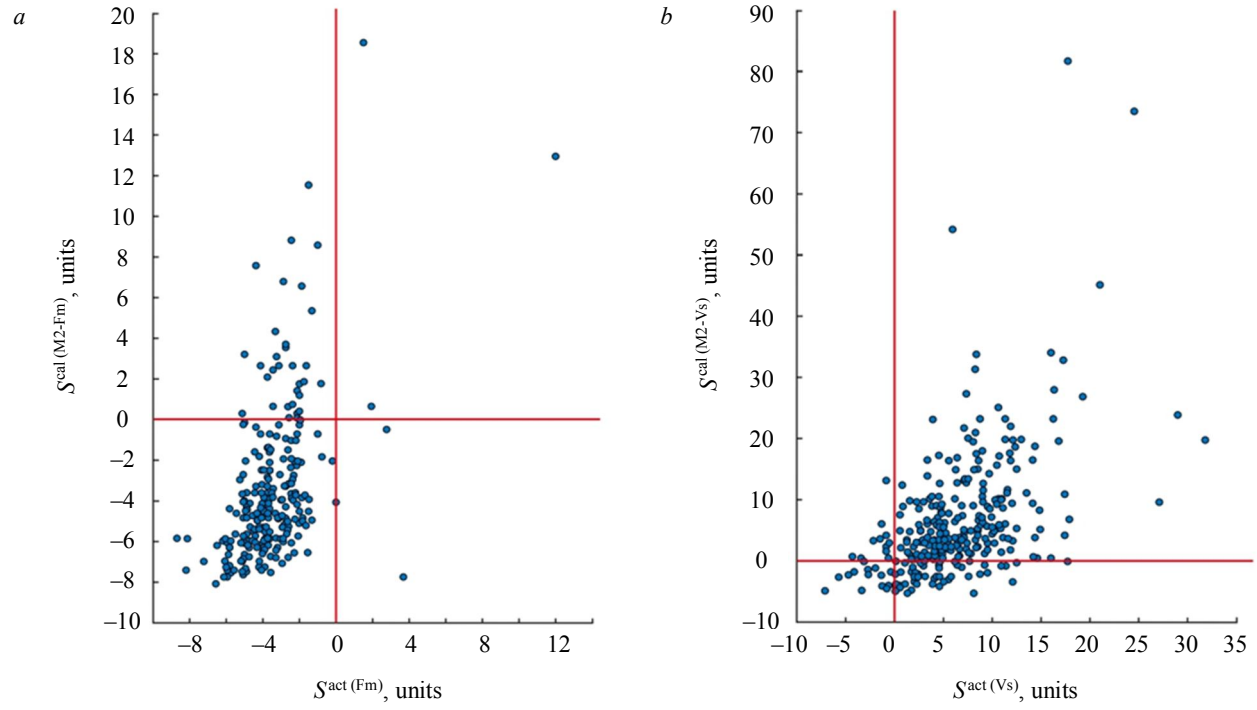


Fig.2. Correlation field of model and actual skin factor values (second level of modeling):
a – Famennian sediments; *b* – Visean sediments

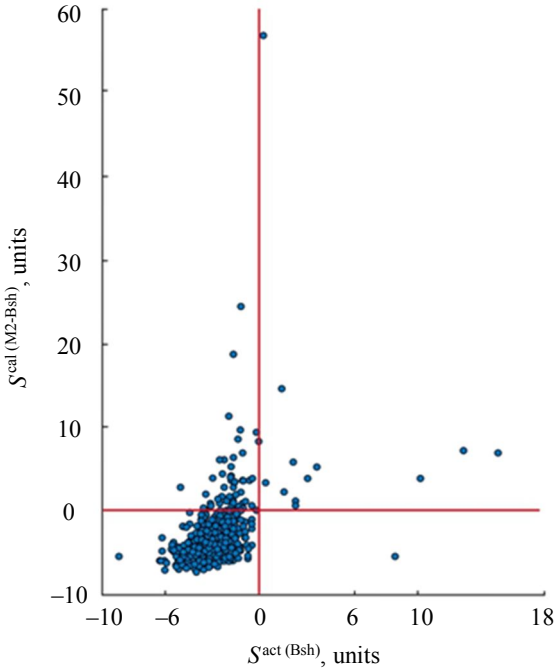


Fig.3. Correlation field of model and actual skin factor values (second level of modeling, Bashkir sediments)

Model was formed in the sequence shown in the regression equation. Values of the coefficients R, describing the strength of statistical relationships, changed as follows: 0.283; 0.363; 0.406; 0.456; 0.476; 0.492; 0.512; 0.528.

Model values of $S^{M2\text{-}Vs}$ were calculated according to the formula (3). These values were compared with the actual values for wells in Visean productive formations by constructing the correlation fields (Fig.2, *b*).

Model of the second level for productive sediments of the Bashkir age has the form:

$$S^{M2\text{-}Bsh} = 0.0027\chi - 8.8993k + 0.1928P_f + 0.2477m - 0.2150P_b + 4.3913b + 0.0896\mu + 0.0076B + 0.0393h - 0.0172Q_l + 0.0051G_f - 13.060, \quad (4)$$

with $R = 0.433$, $p < 0.00000$, standard error 3.872 units.

Model was formed in the sequence shown in the regression equation. Values of the coefficients R, describing the strength of statistical relationships, changed as follows: 0.240; 0.351; 0.397; 0.405; 0.413; 0.419; 0.422; 0.425; 0.428; 0.431; 0.433.

Model values of $S^{M2\text{-}Bsh}$ were calculated according to the formula (4). These values were compared with S by constructing the correlation fields (Fig.3).

Discussion. Thus, a series of multidimensional mathematical models for its determination was built in the course of studying the features of the skin factor formation during the operation of wells in the fields under consideration. Models were built both for the entire sample as a whole (first level), and differentiated, separately for the main objects of field development (second level).

Constructed models are linear multiple regression equations, including from 6 to 11 indicators as independent features. Such a large number of input parameters of the models indicates, first of all, the complexity of the skin factor formation process during the operation of production wells at the considered fields. Value of the skin factor is influenced by both geological and physical (characterizing the properties of the reservoir and fluid) and technological (well operation indicators) parameters.

Equation (1) demonstrates the features of the skin factor formation at the fields as a whole. According to it, the achieved degree of model performance is provided mainly by three indicators: porosity coefficient, gas oil ratio and saturation pressure. Inclusion of other indicators in the model provides only a slight increase in the coefficient of determination R. Analyzing the type of the multidimensional model, it can be concluded that the state of the near-well zones of productive formations at the fields under consideration is influenced by the reservoir properties and the oil degassing process. That is, the presence of additional pressure losses in the NBHZ is largely due to the release of free gas. This conclusion is quite logical in the context of the key feature of the region's fields, which is the high gas saturation of the formation oil.

Properties of the reservoir and the formation fluid also appear in the first places of the resulting multidimensional equation (2), which characterizes the features of the skin factor formation for the wells of Famennian carbonate sediments. It should be noted that for the Famennian sediments, which are characterized by natural fracturing, the reservoir properties are taken into account by means of the permeability coefficient. This conclusion is also logical, since the permeability of the pore and the permeability of the fractured reservoir are characterized by different values. Equation (2) also contains a gas oil ratio, i.e. the NBHZ condition for wells operating the

Famennian sediments determines the reservoir properties, as well as the properties and composition of the fluid.

At the fields under consideration, Visean productive sediments are represented mainly by sandstones (purely porous reservoirs). Model of skin factor formation for wells operating Visean sediments equally includes geological-physical and technological parameters. In this case, the model is formed according to a special scenario: inclusion of each indicator sequentially and approximately equally contributes to an increase in the coefficient of determination, i.e. each of the indicators has a significant impact on the resulting value.

Model built for the wells of the Bashkir development objects includes the maximum number of input parameters (11 indicators), which emphasizes the complexity and multifactorial nature of the NBHZ formation process. The first positions of the model are the reservoir characteristics. It should also be noted the presence of reservoir and bottomhole pressures and their influence on the value of the skin factor, which indicates possible deformation processes as the cause of changes in the NBHZ state. It is also necessary to note the presence of the water cut of the well production in the model for the Bashkir sediments, in addition to the gas oil ratio. That is, proximal presence of three phases – oil, gas and water in the cavern space – has an integrated effect on the filtration processes and pressure losses in the NBHZ.

Regularities established in the analysis of correlation fields should be noted separately. The most number of both model and actual values of skin factors for wells operating carbonate reservoirs in both Bashkir and Famennian sediments are in the area of negative values, while for Visean terrigenous ones – in the area of positive values. That is, skin factors for wells operating carbonate reservoirs, regardless of their age, rather rarely take high positive values. In addition, skin factor in carbonate sediments of both Famennian and Bashkir ages is formed according to similar scenarios. Correlation fields between actual and model values have a similar form. Regularities of the skin factor formation in terrigenous sediments differ from carbonate sediments much more significantly than between carbonate reservoirs of different ages. The skin factor for wells in terrigenous reservoirs varies in a much wider range compared to carbonate ones. This conclusion, known to specialists in the field of data interpretation for hydrodynamic investigations, in this case received mathematical confirmation.

Conclusion. This article proposes an approach to the study of the skin factor formation for wells at oil fields in the north of the Perm Territory. This approach is based on the construction and analysis of multidimensional mathematical models. Basis was in significant experience of field and hydrodynamic investigations (1102 values of the skin factor), as well as in the ambiguity in the interpretation of the physical meaning for the parameter under study. Tool used – multidimensional mathematical modeling – is one of the most effective ways to study processes characterized by the complex influence of numerous factors. As a result of the study, it was found that one of the prevailing factors that determine the change in reservoir properties in the formation zones near wellbore is oil degassing. It is advisable to take this conclusion into account when solving various technological problems, especially when planning geological and technical measures. For example, acid treatment to eliminate high skin factor values, if it is caused by oil degassing, will lead to a lack of technological and economic effect.

It is advisable to use this approach to solve other numerous problems of field geology and the development of oil fields in the case when investigated processes proceed in a complex multifactorial system.

REFERENCES

1. Andaeva Ye.A. The method of on-line monitoring of bottom hole area condition for low-rate wells. *Territoriya NEFTEGAZ Journal*. 2016. N 3, p. 140-144 (in Russian).

2. Virstyuk A.Yu., Mikshina V.S. Application of regression analysis to evaluate the efficiency of oil well operating with the paraffin oil. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*. 2020. Vol. 331. N 1, p. 117-124. DOI: 10.18799/24131830/2020/1/2453 (in Russian).

3. Dziubenko A.I., Nikonov A.N., Merson M.E. Increase in efficiency of methods of bottomhole formation zone treatment in active wells by information technique. *Vestnik Permskogo natsionalnogo issledovatelskogo politekhnicheskogo universiteta. Geologiya. Neftegazovoe i gornoe delo*. 2017. Vol. 16. N 2, p. 148-157. DOI: 10.15593/2224-9923/2017.2.5 (in Russian).

4. Dorfman M.B., Sentemov A.A. Influence of reservoir properties of the bottomhole zone on acidizing efficiency. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*. 2020. Vol. 331. N 2, p. 124-130. DOI: 10.18799/24131830/2020/2/2488 (in Russian).

5. Rogov E.A. Study of the well near-bottomhole zone permeability during treatment by process fluids. *Journal of Mining Institute*. 2020. Vol. 242, p. 169-173. DOI: 10.31897/PMI.2020.2.169

6. Salavatov T.S. Features of productivity stabilization regulation the skin factor control. *Geologiya, geofizika i razrabotka neftyanykh i gazovykh mestorozhdenii*. 2020. N 7, p. 67-70. DOI: 10.30713/2413-5011-2020-7(343)-67-70 (in Russian).

7. Salavatov T.Sh., Dadashzade M.A., Aliyev I.N. Well productivity with account for the skin-zone. *Neftegazovoe delo*. 2018. Vol. 16. N 3, p. 6-10. DOI: 10.17122/ngdelo-2018-3-6-10 (in Russian).

8. Altunina L.K., Kuvshinov V.A., Stayeva L.A., Kuvshinov I.V. Enhanced oil recovery from high-viscosity oil deposits by acid systems based on surfactants, coordining solvents and complex compounds. *Georesursy*. 2019. Vol. 21. N 4, p. 103-113. DOI: 10.18599/grs.2019.4.103-113

9. Ramana Murthy R.V.V., Katari N.K., Satya Sree N., Jonnalagadda S.B. A novel protocol for reviving of oil and natural gas wells. *Petroleum Research*. 2019. Vol. 4. Iss. 3, p. 276-281. DOI: 10.1016/j.ptlrs.2019.04.001

10. Huang Sh., Zhu Yu., Ding Ju. et al. A semi-analytical model for predicting inflow profile of long horizontal wells in super-heavy foamy oil reservoir. *Journal of Petroleum Science and Engineering*. 2020. Vol. 195. N 107952. DOI: 10.1016/j.petrol.2020.107952

11. Hyati-Jafarbeigi S., Mosharaf-Dehkordi M., Ziaei-Rad M., Dejam M. A three-dimensional coupled well-reservoir flow model for determination of horizontal well characteristics. *Journal of Hydrology*. 2020. Vol. 585. N 124805. DOI: 10.1016/j.jhydrol.2020.124805

12. Al-Rbeawi S. New technique for determining rate dependent skin factor & non-Darcy coefficient. *Journal of Natural Gas Science and Engineering*. 2016. Vol. 35. Part A, p. 1044-1058. DOI: 10.1016/j.jngse.2016.09.028

13. Liu X., Li D., Zha W. et al. Automatic well test interpretation based on convolutional neural network for infinite reservoir. *Journal of Petroleum Science and Engineering*. 2020. Vol. 195. N 107618. DOI: 10.1016/j.petrol.2020.107618

14. Bela R.V., Pesco S., Barreto A.Jr. Determining skin zone properties from injectivity tests in single- and multilayer reservoirs. *Journal of Petroleum Exploration and Production Technology*. 2020. Vol. 10, p. 1459-1471. DOI: 10.1007/s13202-019-00808-0

15. Wang X., Zhang F., Jiang Y. et al. Calculation of skin factor of contaminated cores. *Natural Gas Industry*. 2012. Vol. 3. Iss. 12, p. 52-54. DOI: 10.3787/j.issn.1000-0976.2012.12.010

16. Chen C.-Sh., Chang C.-C. Theoretical evaluation of non-uniform skin effect on aquifer response under constant rate pumping. *Journal of Hydrology*. 2006. Vol. 31. Iss. 3-4, p. 190-201. DOI: 10.1016/j.jhydrol.2005.05.017

17. Todaro V., D'Oria M., Nanda M.G., Gomez-Hernandez J.J. Ensemble smoother with multiple data assimilation for reverse flow routing. *Computers & Geosciences*. 2019. Vol. 131, p. 32-40. DOI: 10.1016/j.cageo.2019.06.002

18. Silva T.M.D., Bela R.V., Pesco S., Barreto A. Jr. ES-MDA applied to estimate skin zone properties from injectivity tests data in multilayer reservoirs. *Computers & Geosciences*. 2021. Vol. 146. N 104635. DOI: 10.1016/j.cageo.2020.104635

19. Salimidelshad Y., Moradzadeh A., Kazemzadeh E. et al. Experimental investigation of changes in petrophysical properties and structural deformation of carbonate reservoirs. *Petroleum Exploration and Development*. 2019. Vol. 46. Iss. 3, p. 565-575. DOI: 10.1016/S1876-3804(19)60036-4

20. Fan Z., Parashar R. Transient flow to a finite-radius well with wellbore storage and skin effect in a pyroclastic confined aquifer. *Advances in Water Resources*. 2020. Vol. 142. N 103604. DOI: 10.1016/j.advwatres.2020.103604

21. Guo J., Xiao Y., Wang H. Stimulation for minimizing the total skin factor in carbonate reservoirs. *Journal of Natural Gas Science and Engineering*. 2014. Vol. 21, p. 326-331. DOI: 10.1016/j.jngse.2014.08.017

22. Kabir C.S., Ismadi D., Fountain S. Estimating in-place volume and reservoir connectivity with real-time and periodic surveillance data. *Journal of Petroleum Science and Engineering*. 2019. Vol. 7. Iss. 2, p. 258-266. DOI: 10.1016/j.petrol.2011.05.017

23. Shi W., Cheng S., Meng L. et al. Pressure transient behavior of layered commingled reservoir with vertical inhomogeneous closed boundary. *Journal of Petroleum Science and Engineering*. 2020. Vol. 189. N 106995. DOI: 10.1016/j.petrol.2020.106995

24. Rahman M.A., Mustafiz S., Koksal M., Islam M.R. Quantifying the skin factor for estimating the completion efficiency of perforation tunnels in petroleum wells. *Journal of Petroleum Science and Engineering*. 2007. Vol. 58. Iss. 1-2, p. 99-110. DOI: 10.1016/j.petrol.2006.11.012

25. Ren J., Fang N., Zheng Q. et al. Semi-analytical model of a multi-wing fractured vertical well in linear composite reservoirs with a leaky fault. *Journal of Petroleum Science and Engineering*. 2020. Vol. 191. N 107143. DOI: 10.1016/j.petrol.2020.107143

26. Liu Q., Lu H., Li L., Mu A. Study on characteristics of well-test type curves for composite reservoir with sealing faults. *Petroleum*. 2018. Vol. 4. Iss. 3, p. 309-317. DOI: 10.1016/j.petlm.2018.03.011

***Authors*: Vladislav I. Galkin,** *Doctor of Geological and Mineralogical Sciences*, *Professor*, *vgalkin@pstu.ru*, *https://orcid.org/0000-0003-4867-2298* (*Perm National Research Polytechnic University, Perm, Russia*), **Dmitry A. Martyushev,** *Candidate of Engineering Sciences*, *Associate Professor*, *martyushevd@inbox.ru, https://orcid.org/0000-0002-5745-4375* (*Perm National Research Polytechnic University, Perm, Russia*), **Inna N. Ponomareva,** *Doctor of Engineering Sciences*, *Professor*, *permpolitech@gmail.com*, *https://orcid.org/0000-0003-0546-2506* (*Perm National Research Polytechnic University, Perm, Russia*), **Irina A. Chernykh,** *Candidate of Engineering Sciences*, *Associate Professor*, *permpolitech@gmail.com, https://orcid.org/0000-0001-8343-4805* (*Perm National Research Polytechnic University, Perm, Russia*).

The authors declare no conflict of interests.

The paper was received on 9 September, 2020.
The paper was accepted for publication on 29 March, 2021.