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***M. I. Fyk**, PhD (Technics),*
******Stefan Palis**, Junior-Professor,*
*******Ju. I. Kovalchuk**, PhD (Technics),*
**V. N. Karazin Kharkiv National University,*
***Otto-von-Gerikeg University, Magdeburg (Germany),*
****Kyiv National University of Construction and Archiecture*

GAS WELL PRODUCTION ENHANCEMENT ON THE APPLICATION OF INNOVATIVE STRUCTURAL AND THERMAL INSULATION NANO-COATINGS

М. І. Фик, Стефан Паліс, Ю. І. Ковальчук. ЗБІЛЬШЕННЯ ДЕБІТУ ГАЗОВОЇ СВЕРДЛОВИНИ ПРИ ЗАСТОСУВАННІ ІННОВАЦІЙНИХ СТРУКТУРНО-ТЕПЛОІЗОЛЮЮЧИХ НАНО-ПОКРИТТІВ. *Наведено результати розробки спрощеної прикладної математичної моделі неізотермічного свердловинного ліфтингу природного газу в умовах розробки виснаженого газоконденсатного родовища. Спрощене моделювання базувалося на відомих рівняннях Дарсі, Бернуллі, Адамова, Веймаута, Шухова і Рейнольдса. Базові рівняння бралися в нелінійній формі з перевіреними в промисловій практиці спрощеннями, що значно скоротило час обчислень і дало можливість вирішувати завдання в загальній постановці. При цьому враховували також застосування трьох основних покриттів: гладкі, теплоізолюючі і турбулізуючі. Велика частина параметрів і вихідних даних – типові для родовищ України з середньою величиною запасів. Представлено перевірку теоретичних експериментів ключових параметрів моделі і ефектів від застосування різних спеціальних сучасних покриттів труб. Модель побудована на базі емпіричних формул, перевірених промислової практикою. Показано, що можливий підбір комбінацій спеціальних властивостей покриттів для отримання максимального економічного ефекту в натуральних одиницях сирої продукції, особливо, на етапі останньої стадії компресорної розробки родовища.*

***Ключові слова**: видобуток газу, компресор, температурний градієнт, свердловина, ізоляція, шорсткість поверхні, покриття.*

М. И. Фык, Стефан Палис, Ю. И. Ковальчук. УВЕЛИЧЕНИЯ ДЕБИТА ГАЗОВОЙ СКВАЖИНЫ ПРИ ПРИМЕНЕНИИ ИННОВАЦИОННЫХ СТРУКТУРНО-ТЕПЛОИЗОЛИРУЮЩИХ НАНО-ПОКРЫТИЙ. *Приведены результаты разработки упрощенной прикладной математической модели неизотермического скважинного лифтинга природного газа в условиях разработки истощенного газоконденсатного месторождения. Упрощенное моделирование базировалось на известных уравнениях Дарси, Бернулли, Адамова, Веймаута, Шухова и Рейнольдса. Базовые уравнения брались в нелинейной форме с проверенными в промышленной практике упрощениями, что значительно сократило время вычислений и дало возможность решать задачи в общей постановке. При этом учитывали также применение трех основных покрытий: гладких, теплоизолирующих и турбулизирующих. Большая часть параметров и исходных данных – типичные для месторождений Украины со средней величиной запасов. Представлено проверку теоретическим экспериментом ключевых параметров модели и эффектов от применения различных специальныхсовременных покрытий труб. Модель построена на базе эмпирических формул, проверенных промышленной практикой. Показано, что возможен подбор комбинаций специальных свойств покрытий для получения максимального экономического эффекта в натуральных единицах сырой продукции, особенно, на этапе последней стадии компрессорной разработки месторождения.*

***Ключевые слова**: добыча газа, компрессор, температурный градиент, скважина, изоляция, шероховатость поверхности, покрытие.*

Introduction

At the late stage of gas condensate fields exploitation a deterioration of hydraulic and gas-dynamic efficiency of jointing flow line pipe lifts and gas collectors leads to the decrease the total flow rates of pattern wells. There are many technical ways to improve a hydraulic efficiency of complicated gas collecting systems in gas condensate fields. The cardinal method of diameters increase and additional link is expensive or impossible in some cases. It is enough difficult to replace installed flow compressor pipes (FCP) into wells, subways, special ducts with other diameter, as well as to build locks or correction of structure in the complicated terrain conditions.

As for the thin coatings with specific thermo-physical, geometrical and structural properties, there is an opportunity to have more simple solutions to optimize hydraulic efficiency of pipe system and particular pipeline sections. The most popular methods of field experience include thermo-insulation, smooth coating and turbulence-insulating coating [1-6].

Because of a complicated strict mathematical modelling it is often a problem to evaluate the effects of the standard pipes replacement into the pipes with special coatings. The simplified modeling of complex results when using multiple technologies at the same time is a rare case of the sequential but not simultaneous implementation of certain technologies. However, new materials such as nanoceramics and ceramic insulation require new approaches to modelling and forecasting economic effects.

In many fields of the former CIS countries, as well as the former German Democratic Republic in the transition to a compressor stage of oil-gas field development, it is necessary to consider several methods of parallel hydraulic optimization in conditions of a lower operating pressure wells and manifolds.

Nevertheless, the work`s authors made some attempts to analyze the correlation between the results from different methods to optimize hydraulics using nanotechnology and other modern coatings. The result had been obtained suddenly and some positive effects sharing the technology are exposed briefly in this article. The main fact is that the calculations result - a significant increase of computational and theoretical well production in complex use of the special few (two or three) coatings in comparison with the particular applied coatings.

1. The basic elements of research problem description

The base application object is averaged well in Mashevsky field in Poltava region in Ukraine. The general description of the field is following: the average depth of productive horizons up to 4 km; the length of particular gathering lines up to 2.5 km; the used FCP diameter- 63 mm; the reservoir temperature - 70-80 degrees Celsius and wellhead pressures 1-3 MPa. The wells work quite steadily with the consequent pressure reduction at the wellhead and in the layer.

Simplified modelling is based on known equations by Darcy, Bernoulli, Adam, Weymouth, Shukhov and Reynolds. The basic equations were taken in a non-linear form with proven simplifications in a field experience that significantly reduced the computing time and made it possible to solve problems in a general setting. In this case the use of three main surfaces are considered: smooth, heat-insulating and turbulizing. The most part of the parameters and initial data - typical for Ukrainian deposits with an average value of mass flow rate.

The universal formula of Higher Scientific Research Institute of gas [16-17] is taken as the base to evaluate the hydraulic efficiency dependence on the rough surface. The choice is explained by the gas velocity increase and Reynolds` numbers at the late stage of field exploitation, under conditions of relatively dry gas. The thermal conductivity was calculated by Shukhov`s formula with generalized parameter from the external environment to the transported working substance. The degree of turbulence is characterized and modelled by the traditional Reynolds` number. The main work`s task is the coating modelling with the inner surface of the FCP with a thin ceramics coating with specific properties. This makes certain changes in well production from the modified geometry and physical properties of the inner surface of the tubing.

2. Hypothesis and the main exploration objectives

The authors suggested that the combined methods application to increase the hydraulic efficiency of jointing flow lines pipe lifts and gas gathering collectors may differ slightly from the last one method. Thus, the formulas structure has shown that the total effect of several technological coatings in parametric data conditions may exceed the effect of a partial coating application, for example, smooth coating with low equivalent roughness. The hypothesis has been shortened to a possible profitable coating use only in the area of inflow by the vertical section of tubing gas well. In the authors` opinion the problem shortening to the narrow application will allow to show the results with economic effect determination in natural calculation of the additional natural gas production (daily production rate), excluding other cases with hydraulic losses.

3. Relevance

The general relevance is to reduce production costs and transport of different gas mixtures. Under certain conditions, this also allows you to reduce the used pipe diameters, the total cost of transport networks. In particular, the problem is relevant when the production intensification and petroleum products transportation are taken place, especially when the pipes are placed inaccessible places. Since it is very costly to conduct the general repair and replacement pipes.

Scientific relevance is to solve the gas dynamic problem by means of empirical and linear equations without many other possible solutions, such systems equations solutions stability testing. The authors didn’t find the analogues of simultaneous solution of these inflow problems into the reservoir and the horizontal layer, lifting on tubing, flowline transport in the conditions of declining gas production in the gas condensate field.

The relevance in an applicationed sense, is to suggest a theoretical development under optimal properties and coating the inner surface of the pipe with a few calculated properties (structural and geometric, stylus, thermo-physical) that it can be done with one nonoceramic layer. On the base of the proposed model forecasting of the new hydraulic properties after application nanoceramics is implemented , the right "drawing", thickness, smoothness and thermal coating conductivity. At this the layer may be one, but the material itself in the various sections of the pipe can be different substantially different by the set of gas-dynamic and thermal properties. From an economic and technological point of view, of course, it is important to assess a priori the advantages of different combinations of several new coating properties.

In a particular problem formulation improving gas well operation has been determined that the thermal insulation is more important in the upper part of the lifting tube (from the middle to the wellhead) and the flow pattern improving with correct "drawing" and roughness is critical for a lower part (at the borehole bottom). It is necessary to mark the experimental works, confirming the importance of the turbulizating site installation with the intensification of heat exchange process [9, 11, 14, 18].

4. The mathematical model description

In some scientific works a significant difference in viscosity and flow resistance coefficient is pointed out under non-isothermal flow of hydrocarbon mixture within the reservoir drainage area and the lifting tubes with vertical, inclined and horizontal sections [7-12]. For a variety of fields a mathematical model will be effective that takes into account the proven empirical dependence and equations of non-isothermal lifting. So as far the temperature difference between bottom hole and the wellhead is considerably bigger than temperature difference between the reservoir and the bottom hole. There is a case for small flow rates and reservoir pressure depletion at the late stage of gas condensate fields exploitation. We distinguish the following scientific and applied analytics to non-isothermal flow of a dual mode according to [13-16]:

1. If there are two modes in the pipeline, the flow temperature at the end of the pipeline with a non-isothermal current[13]:

$$t_\kappa = t_0 + (t_H - t_0) \cdot e^{S_{u.l}} \cdot \left(\frac{t_{KP} - t_0}{t_H - t_0}\right)^{1 - \frac{S_{u.l}}{S_{u \cdot t}}} \qquad (1)$$

Where $S_{u.l}$, $S_{u.t}$- Shukhov parameter at laminar and turbulent flow regime.

To determine the hydraulic resistance coefficient of non-isothermal flow based on experimental data the formula was obtained [14]:

$$\lambda_\Gamma = a^\bullet \left(\frac{8\,\mathrm{Re}}{I + 2\left(1 + \sqrt{9 + I}\right)} \right)^{b^\bullet} \left(\frac{\mu_\omega}{\mu_f} \right)^{0,62} \qquad (2)$$

Where $a^\bullet = 2{,}9He^{-0{,}403}$; $b^\bullet = 1{,}26He^{-0{,}265}$; He - Hedstrema number

2. Physical formula of wellhead pressure for non-isothermal downhole lifting [7, 15]:

$$P_2 = P_1^2 \cdot \left(\frac{T_1}{T_2}\right)^\psi - \frac{8\lambda\_(P,T,\upsilon,z\_D,k\_) \cdot Zskv(\mathrm{P},\mathrm{T})^2 \cdot R\_^2 \cdot \left(\frac{T_1 - T_2}{\ln\left(\frac{T_1}{T_2}\right)} \right)^2}{9{,}8 \cdot D^5 \cdot \pi^2} (Mqs\_)^2 \cdot \left[\left(\frac{T_1}{T_2}\right)^2 - \left(\frac{T_1}{T_2}\right)^\psi \right] \qquad (3)$$

They are as functions of the following variables:

$$\psi = \frac{-2 \cdot 9{,}8 \cdot Hskv}{Zskv\left[\frac{2}{3} \cdot \left[P_1 + \frac{(P_2)^2}{P_1 + P_2} \right], \frac{T_1 - T_2}{\ln\left(\frac{T_1}{T_2}\right)} \right] \cdot R\_ \cdot (T_1 - T_2)} \qquad (4)$$

$$Zskv(P,T) := \frac{0{,}1 \cdot P}{Pnk} + \left(0{,}4 \cdot \log\left(\frac{T}{Tnk}\right) + 0{,}73 \right)^{\frac{P}{Pnk}} \qquad (5)$$

$$\lambda\_(P,T,\upsilon,z\_,D,k\_) := 0{,}067 \cdot \left(\frac{158}{\mathrm{Re}\_(P,T,\upsilon,z\_,D)} + \frac{2 \cdot k\_}{\mathrm{D}} \right)^{0,2} \qquad (6)$$

Where the first level functions are set:

$$\mathrm{Re}\_(P,T,\upsilon,z\_,D) := \left(\frac{D \cdot \upsilon \cdot P}{\eta\_(P,T) \cdot z\_ \cdot R\_ \cdot T} \right) \qquad (7)$$

$$\eta\_(Psr,Tsr) := 5.1 \cdot 10^{-6} \cdot \left[1 + \rho\_n \cdot (1.1 - 0.25 \cdot \rho\_n)\right] \cdot \left[0.037 + \frac{Tsr}{Tnk} \cdot \left(1 - 0.104 \cdot \frac{Tsr}{Tnk}\right) \right] \cdot \left[1 + \frac{\left(\frac{Psr}{Pnk}\right)}{30 \cdot \left(\frac{Tsr}{Tnk} - 1\right)} \right] \qquad (8)$$

Where the following parameters identifier and functions are used:

$P, P_1, P_2, P_{sr}, P_{nk}$ – bottom hole pressure, wellhead, the average in the pipe, pseudocritical; $T, T_1, T_2, T_{sr}, T_{nk}$ – working gas temperature, surface gas temperature, the average pressure piping, pseudocritical; D – pipe diameter; Z_{skv}, z_ - compressibility; H_{skv} – depth; R_-gas constant; u-gas Velocity; k_-roughness; M_{qs}_-mass gas flow rate; q_n - density at normal conditions; Re_ - Reynolds number; η_- dynamic viscosity.

3. Tested experimental formula (7.20) there is the mathematical model of unsteady nonisothermal motion of a gas-liquid mixture in the book by Yakovleva E.I. [16].

To close the equations system (1-4) it is necessary to note that the equation (2-3) takes into account the law of conservation of mass and mechanical energy, and the equation (1-4) - heat balance and impulses movement. In equation (3) it is also taken into account the equation of state crude product - a mixture. Thus, when considering the first system of equations (1-4) is represented fully closed, but as far as the equation (2) is based on the dynamics and the dynamic viscosity differences, the mathematical model is supplemented by another appropriate equation based on empirical research, about a point of dry gas [17].

Nonlinear equations systems solution given by a mathematical model of non-isothermal lifting in condensate wells is done by using advanced algorithmic techniques in Mathcad program, by rank-Kut 4th order with the addition developed by the authors of the initial and boundary conditions in accordance with the physical sense.

5. The research results

1. Downhole lifting studies were made with using developed mathematical models by objects of Mashevsky gas field development, which showed a good value for the simulation adequacy and close agreement between calculated and measured thermometer, manometric and flow-measuring parameters.

There presented the dependences in Fig. 1-2, gas condensate wells change debit at changing the roughness of the inner surface of the pipe and the thermal insulation coating (temperature changes in the wellhead);

2. Diagram 1-2 shows that the technological ways correlation to improve the hydraulics by coating has a positive sign. For example, Figure 1 shows that roughness reducing in the inner tube surface heat insulation begins to work better (continuous red line), the diagram 2- wellhead gas temperature increasing contributes to a better effect from the smooth surface, etc. [19].

Three simultaneous technological coatings use with roughness minimization heat loss and turbulence condensation of towards the axis direction exceeds the total effect than for each parameters individually (using specific technologies).

It should be noted that the difference between the classical isothermal methods of "medium depth well" flow rate calculation (logarithmic temperature averaging) and author's "analog well" flow rate calculation reaches 30% (for the late operation stage).

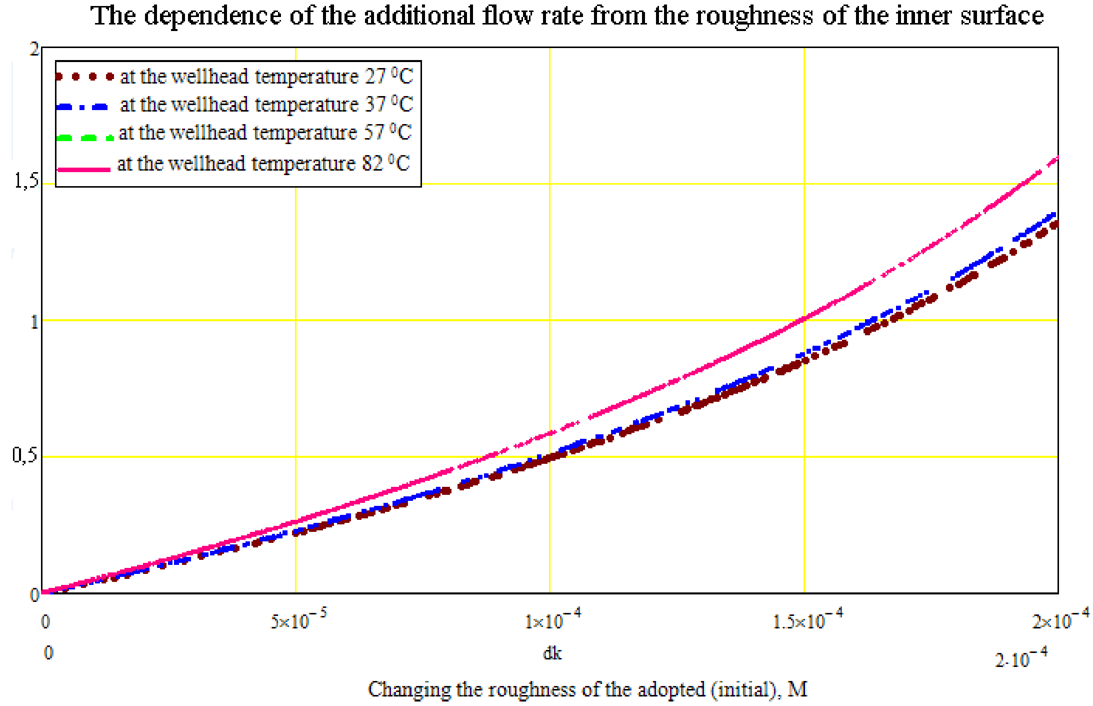

Fig. 1. Dependence of extended flow rate from the roughness changes in the internal tubing surface (compared with the standard) at different temperatures in the wellhead

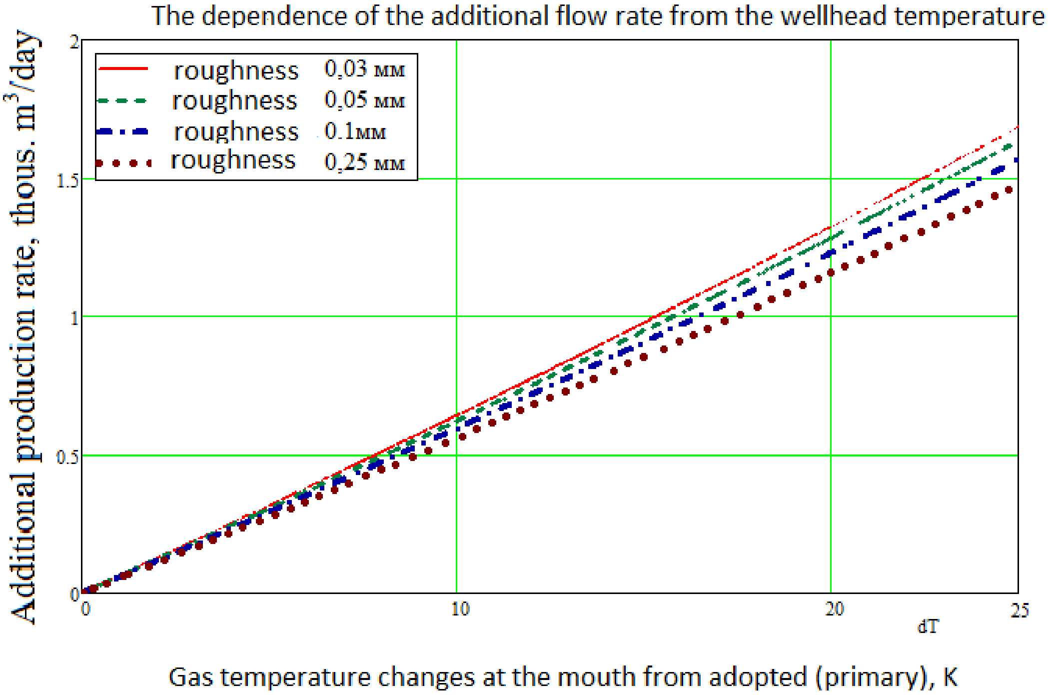

Fig. 2. Dependence of extended flow rate from the temperature variation at the wellhead (compared to the actual average) with different surface roughness of the inner tubing

When FCP is used with an inner polymer (smooth) nano-coating, thermal insulator from the top of the nano-ceramics tubing, where the lower part of it is narrower by the diameter with turbulizing "figure." The intense turbulence flow can be carried out by conventional methods with the special liners installation. However, according to the authors` calculations, "figure" in the form of a ceramic spiral at calculation step and the projection height, which is applied along the tubing at the first few hundred meters, will work better. At the same time the most important operational parameters to be taken into consideration in the physical and mathematical models calculation, where the water of production stream by water and hydrocarbons, is geothermal gradient by the actual depth. At the bottom of the tubing after passing through the perforations and the filter at the bottomhole the gas is cooled by Joule-effect where it requires to heat a gas by deep heat at the first section of lifting up. Such selfheating can be "organized" by a heat-conducting plug installation in the space near the bottom hole.

As far as great pressure drops are presented inside of the lifting tube, periodic removal of abrasive mechanical impurities is possible so the inner coating should be made with severe environment, where innovative metal-ceramic coating, nano-ceramic and nano-composite materials correspond to it good.

These facts show that "classical" methods of the field development indicators calculation at a substantially non-isothermal-lifting at the late operation stage are impossible to apply and also in the conditions of use special intensification methods at bore-hole gas production. The authors recommend to using the more accurate express-predicting method with precision engineering, with more sensitive to the basic regime and physic-chemical parameters of the mathematical model. It is based on adapted empirical formulas and equations in relation to the non-isothermal transport of wet gas-mixtures.

Conclusions

1. Author's lifting modelling in the gas condensate well at the late field operation stages gives the difference (correction) in the production rate by 15-30% relative to analogues of conditionally non-isothermal type. The essential difference is the moisture content rate, viscosity and the actual geothermal gradient in the dynamics.

2. Test results of the theoretical developed model at Mashevsky`s condensate field wells make it possible to assert that its high efficiency and sufficient accuracy for engineering and applied calculation.

3. The modelling use allows to choose more optimal pipes of well tubing (gas condensate wells) by geometrical, heat and hydraulic parameters. This will allow increasing the production rate of wells, at equal conditions by 10-15%.

4. Technical key activities to a significant flow rate increase of the gas condensate wells at the late operation stage might be nano-technological coating.

5. The developed mathematical model can be used for other non-isothermal gas-mixtures transport intensification calculating in the conditions of constant or variable longitudinal thermo-gradients.

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