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ADAPTATION OF A GAS POOL MATERIAL BALANCE TO THE DYNAMICS OF GAS PRESSURE CHANGES

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Based on the analysis of the main methodological uncertainties in the material balance method, their influence on errors in the estimation of the drained volume of a gas pool depending on the stage and actual information about its operation is determined. An important aspect of estimating reserves and predicting technological indicators of gas production is the correct adaptation of the material balance model to the actual history of extraction. Examples of typical cases of adaptation of the forecasting model of gas pools development indicators for the Dnieper-Donets Basin were given in accordance with the actual measurements of reservoir pressure in wells; they indicate the wide possibilities of the method especially at the later stages of pool's development.

Keywords: field, development system, material balance, hydrodynamic modelling, engineering solutions, forecasting, formation pressure, well production rate, reserves, formation, approximation, algorithm

АДАПТАЦІЯ МАТЕРІАЛЬНОГО БАЛАНСУ ГАЗОВОГО ПОКЛАДУ ЗА ДИНАМІКОЮ ПЛАСТОВОГО ТИСКУ

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На основі аналізу основних методичних невизначеностей методу матеріального балансу визначено їх вплив на похибки в оцінці дренованого обсягу газового покладу в залежності від стадії і фактичної інформації про його експлуатацію. Важливим аспектом оцінки обсягів запасів і прогнозування технологічних показників видобутку газу є коректна адаптація моделі матеріального балансу до фактичної історії розробки.

Наведені у статті приклади характерних випадків адаптації моделі прогнозування показників розробки газових покладів родовищ Дніпровсько-Донецької западини безпосередньо за даними фактичних замірів пластового тиску в свердловинах свідчать про широкі можливості цього методу особливо на пізніх стадіях розробки покладів.

Ключові слова: родовище, система розробки, матеріальний баланс, гідродинамічне моделювання, інженерні рішення, прогнозування, пластовий тиск, дебіт, запаси, пласт, апроксимація, алгоритм

АДАПТАЦИЯ МАТЕРИАЛЬНОГО БАЛАНСА ГАЗОВОЙ ЗАЛЕЖИ ПО ДИНАМИКЕ ПЛАСТОВОГО ДАВЛЕНИЯ

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На основе анализа основных методических неопределенностей метода материального баланса определено их влияние на погрешности в оценке дренированного объема газовой залежи в зависимости от стадии и фактической информации о ее эксплуатации. Важным аспектом оценки объемов запасов и прогнозирования технологических показателей добычи газа является корректная адаптация модели материального баланса на фактическую историю разработки.

Приведенные примеры характерных случаев адаптации модели прогнозирования показателей разработки газовых залежей месторождений Днепровско-Донецкой впадины непосредственно по данным фактических замеров пластового давления в скважинах свидетельствуют о широких возможностях этого метода особенно на поздних стадиях разработки залежей.

Ключевые слова: месторождение, система разработки, материальный баланс, гидродинамическое моделирование, инженерные решения, прогнозирование, пластовое давление, дебит, запасы, пласт, аппроксимация, алгоритм

Introduction

Formulation of an effective system of oil or gas field development and its management involves the use of analytical methods to predict the results of design and implemented technological and engineering solutions. Forecasting is carried out by:

- approximation of the actual dynamics of production with subsequent extrapolation for a set period in a time domain;
- simplified modelling by material balance methods based on mass conservation equations;
- modelling by using the corresponding hydrodynamic simulations.

Due to its relative simplicity, time function is used to approximate the actual production dynamics for the operational analysis for extrapolation for small time steps. The capabilities of these methods are significantly limited by the time steps in the system of field development and well operation that have no significant changes. Methods that are based on the systems of material balance equations allow changes in the development system during the forecasting period; still, quantitative estimates lack differential nature, but rather refer to the object (a reservoir) of development as a whole or on average. Detailed hydrodynamic modelling is carried out on numerous three-dimensional models of fields/reservoirs. Each of the forecasting methods solves the certain problems and has its own usage. Usage of the detail hydrodynamic modelling results in combination with simplified methods of analysis is an example of inductive and deductive methods in analysis and forecasting during the engineering development of oil and gas reservoir.

Material and methods of research

System of material balance equations for gas pool

The method of material balance is an effective tool for the operational analysis of the state and forecasting of the main indicators of the development of gas fields. Primarily because it follows the fundamental physical law of conservation of mass. For a gas pool in which there are no sources of matter, this means that the sum of the masses of the residual gas in the formation and the gas extracted from it is equal to the mass of the initial gas reserves. When one uses the generalized provisions of the Mendeleev-Clapeyron equation adjusted for real gas in the capacity of the general gas equation, the material balance can be represented in the following form (Zarubin, Gunda, Nikolaychuk, Lastovetska, 2017):

$$\frac{p_{st}V_{prod}}{T_{st}z_{st}} = \left(\frac{p_{in}}{z_{in}T}\right)V_{in} - \left(\frac{p_t}{z_tT}\right)V_t, \tag{1}$$

where p_{st}, T_{st} stands for pressure and temperature for the standard conditions of produced gas metering; V_{prod}– the accumulated volume of produced gas; p_{in}– the initial formation pressure; z_{in}, z_t, z_{st}– gas super-compression factor in the initial and current formation conditions and at the standard conditions, respectively; p_t– current formation pressure; T- formation temperature, V_{in}, V_tinitial and current formation pore volume that is filled with gas.

Formula (1) is sufficient to establish the relationship between the volume of produced gas and formation pressure, and therefore it is the basis for calculating the gas reserves in the gas development mode and analysing the dependence of the formation pressure (p/z) to the volume of produced gas.

After supplementing the material balance equation with the equations of gas flow in the formation and the wellbore, a closed system of equations is formed, which allows to predict general indicators of the development of gas pool.

In general, the flow of gas to the bottom of wells is described by the two-part formula of gas flow according to Forchheimer's law:

$$p_c{}^2 - p_{wb}{}^2 = Aq + Bq^2, \qquad (2)$$

where p_c and p_{wb} stand for formation and bottom hole pressure, respectively; A , B - coefficients of filtration resistance

The coefficients of filtration resistance are defined as a result of exploration survey of wells in steady-state operating mode. Due to the fact that the left side is calculated as the difference of squared value of pressures in the quadratic form of Forchheimer's law, the determination procedure for the filtration resistance is extremely sensitive to the accuracy of the input data. Therefore, if possible, one-term flow formulae are used for the equation of gas motion in formations, according to Darcy's law (Akulshin, 1988; Zheltov, 1986; Kanevskaya, 2003):

$$q = K_0[p_c{}^2 - p_{wb}{}^2]. \qquad (3)$$

where K_0 stands for well productivity coefficient.

To describe the flow of gas in the wellbore the Adamov's explicit formula is often used, which correlates the bending pressure with the well head pressure and it production rate. It is obtained as a result of the approximate integration of the differential equation of isothermal conservation of mechanical energy. In the system of SI units, it looks as follows:

$$p_{wb}^2 = p_h^2 \exp\left[\frac{0.0683\rho L}{Tz}\right] + 9.9143\cdot 10^3 \lambda \frac{T^2 z^2}{d^5} Q^2 \left[\exp\left(\frac{0.0683\rho L}{Tz}\right) - 1\right], \qquad (4)$$

where stands for wellhead working pressure; L- well depth, T is a averaged wellbore temperature; Q - is a well production rate; z - is a averaged over-capacity ratio of gas in the wellbore; λ– is a coefficient of hydraulic resistance in the pipes; ρ – is a relative gas density; d– is a diameter of the lift pipes.

Finite-difference approximation of the material balance equation for the transition from time step (interval) t_{i-1} to time step t_i leads to a convenient algorithm for calculating the dynamics of the volume-weighted reservoir pressure depending on the gas extraction from the reservoir. The recurrent formula of material balance has the following form:

$$\frac{p(t_i)}{z[p(t_i)]T_{in}}[Vpor(t_i) - We_{\Delta t}] = \frac{p(t_{i-1})}{z[p(t_{i-1})]T_{in}}[Vpor(t_{i-1})] - \frac{p_{st}}{z(p_{st})T_{st}}\Delta V_{prod}(t_i), \quad (5)$$

where $\Delta \mathrm{V}_{\mathrm{prod}}(\mathrm{t_i})$, – gas production over a period of time $\Delta \mathrm{t_i} = \mathrm{t_i} - \mathrm{t_{i-1}}$; $\mathrm{Vpor(t)}$ – gas pore volume occupied by gas at the appropriate time; $\mathrm{We}_{\Delta \mathrm{t}}$ – volume of water influx to the gas volume over a period of time $\Delta \mathrm{t_i}$.

The volume of pores occupied by gas in the recurrent algorithm is easy to calculate, by using the drained over the appropriate time gas reserves $Rzv(t)$:

$$\frac{p(t)}{z[p(t)]T_{in}}Vpor(t) = \frac{p_{st}}{z(p_{st})T_{st}}Rzv(t). \quad (6)$$

There are several reasons that lead to changes in the drained volume. Many of these reasons include, for example: compression of the rock mass, compression of residual water, retrograde phenomena. Many of these phenomena can be neglected without losing the accuracy of the material balance. Though, it is unacceptable to neglect the changes in the drained volume associated with the influx to the productive area from surrounded by water-bearing rocks called aquifer, or with including or excluding some individual producing reservoir seams.

Inflow of aquifer water

While calculating the pore space volume that is filled with gas in material balance method, it is important to consider the volume of water influx to the pool due to the reduced formation pressure.

Application of the Fetkovich model (Fetkovich, 1971) allows to shift away from using algorithmically inconvenient method of superposition without a significant loss of accuracy and use a simple recurrence scheme instead in order to calculate the volume of water for the next time step:

$$We(t_i) = We(t_{i-1}) + We_{\Delta t}\,. \tag{7}$$

According to Fetkovich, in order to calculate the volume of water influx, $We_{\Delta t}$ for the period of time Δt, average formation pressure in the aquifer is used according to the formula:

$$We_{\Delta t} = \frac{W_{ei}}{p_{in}}\,(\bar{p}_t - p_c)\,\left[1 - \exp\left(-\frac{j_w p_{in}}{W_{ei}}\Delta t\right)\right], \tag{8}$$

where p_{in}- initial formation pressure; - W_{ei}potential and j_w- productivity index of the aquifer, respectively.

Providing that we have constant time steps, productivity index of the aquifer can be continently represented as following:

$$Jw = \left[1 - \exp\left(-\frac{j_w p_{in}}{W_{ei}}\Delta t\right)\right] \tag{9}$$

The weighted average pressure in the aquifer area $\bar{p}_t$ is determined by the material balance between the initial elastic water reserves in it $W_{ei}$and the total amount of water influx to the the productive part during the entire period of development of the object (a pool) We_t:

$$\bar{p}_t = p_{in}\left[1 - \frac{We_t}{W_{ei}}\right]. \tag{10}$$

Drained gas reserves

As a rule, the subject of the analysis of the material balance method is the object of development, which is understood as artificially allocated productive part of the field, which is operated as a single system, primarily as a single system of wells. Naturally, the definition of drained reserves and formation pressure in the material balance is attributed to the pore volume of the selected development object. Complex heterogeneities of the geological structure of the development object, various hydrodynamic and physical phenomena in gas production are sometimes accompanied by changes in the pore volume, and thus drained reserves as well, the mechanism of which is sometimes difficult to explain. To explicit the reasons of the change of the drained volume during the development process we can include the introduction of new wells, the work on the effects of bottom-hole zone, repertory productive intervals of the formations, a substantial adjustment of wells operating modes. Some phenomena, such as crack closures due to reduced reservoir pressure, can reduce drained volumes. Apparently, the change of drained reserves of the development object often has an instantaneous, catastrophic character. However, for large objects with a long drilling period it can be evolutionary. All these changes have a significant impact on the dynamics of formation pressure for the selected object of development and is considered in the calculations.

Material balance algorithm

At the beginning of the new time step "i", the reservoir pressure that is equal to that calculated at the previous time step and the residual gas considering their increase or decrease due to changes in the drained pore volume should be both calculated:

$$Rzv_i = Rzv_{i-1} + \Delta grw, \tag{11}$$

where Rzv_i, Rzv_{i-1} - gas reserves at the beginning of the new and the end of the previous time step, respectively; Δgrw- changes of the gas reserves due to changes in the drained pore volume .

The formula (6) is used to calculate pore volume filled with gas, which is taken constant for the entire time step. For every time step it is important to consider well performance indices for equations (2) or (3), lift characteristics for equation (4), well operation mode, for example, wellhead working pressure or bottom hole pressure, or pressure drawdown. The properties of the aquifer are set according to the method used to calculate the water influx into the gas-saturated formation volume. When using the Fetkovich method, this is the potential and productivity index of the aquifer.

The system of material balance equation (5), water inflow (9), gas inflow to the well (2) or (3) and pressure losses in the wellbore (4) is solved with respect to residual reserves and formation pressure at the end of the time step. Simultaneously, average flow rate and total gas extraction are being calculated for the time step, which corresponds to the formation pressure, performance and operating conditions of wells, the amount determined by water influx into the productive part due to lower formation pressure and the corresponding characteristics of the aquifer region.

Main results

Risks of adaptation

When adapting mathematical models to compare calculated reservoir pressures with actual data, problems arise due to several methodological uncertainties. It should be noted that the term "formation pressure" carries uncertainty. Even in a pool that is not in development, the formation pressure differs in both thickness and area, by the magnitude of the gravitational component. In mathematical modelling, the result, which is determined as formation pressure, is usually a pore-weighted average of the formation volume. The value of the reduced formation pressures in the reservoirs that are used to determine the gas reserves, according to their relations with the accumulated selections, should also be weighted by the pore volume, but they are replaced by the weighted average of the accumulated gas selections in specific wells where the formation pressure was determined.

The most reliable are formation pressures measured by depth gauges when recording pressure recovery curves, but their value is spoiled by values for the neighbouring ones, especially high-rate wells. The accuracy of estimates of bottom-hole pressure in a stopped well by the pressure value at its head is influenced by the assumptions adopted in the derivation of the barometric formula, which is usually used for this, as well as the lack of information on the presence of liquid in its face. The formation pressure values used to calculate gas reserves should be adjusted to a specific depth. In practice, sometimes, being guided by financial criteria, one may disclose and enter simultaneously into the joint operation of several productive layers without separate accounting of products and this makes it extremely difficult to correctly determine the formation pressure on the object of development.

Formally, in order to predict the main indicators of gas pool development for the next time step, it is enough to specify the formation pressure and residual reserves at the beginning of the step. Their accuracy is dependent on the correctness and reliability of the forecast. The best way to determine or refine the source data is to adapt the model to a previous development history. Application of material balance method is reduced to the determination of the initial gas in place reserves and the initial formation pressure, at which for a given dynamics of gas extraction, the calculated formation pressure is adequate for the given criteria, characterizes its actual dynamics. The actual formation pressure can be taken as its actual measurements in wells or determined in a certain way by using the weighted average pressure calculated for the object.

As examples, specific cases of adaptation of the forecasting model for the development of gas fields in the Dnieper-Donets Basin based on the material balance equation are given.

Examples of adaptation

Shebelinske gas field.

The biggest gas field in Ukraine - Shebelinske gas field is located in Kharkiv Oblast and has been in development since 1956. The volume of natural gas reserves is determined as unique (Rules..., 2017). When the field was put into development, its reserves were estimated at 129.5 billion m^3. In the process of exploration and industrial development (drilling) reserves were constantly revised upwards. The last official estimate was 712 billion m^3 of gas.

The pool has three stratigraphic horizons, which are related to the industrial gas content in the sediments of Svyatogorsk sub-suite and Kartamysh suite of the Lower Permian area and Araucarian Suite of Upper Carboniferous rock sequence. Currently, the current fund has more than 546 wells, all three pools are operated simultaneously by many wells, and the field is considered as a single object of development.

During the development of the field, the significant historical experience of well operation has been accumulated, more than 14,000 formation pressure measurements have been performed.

An important feature of the history of the Shebelinske gas field development is the constant growth of drained reserves, which is clearly reflected in the dynamics of formation pressure. Figure 1 shows the results of the adaptation of the input data of the material balance model for more than 14,000 measurements of formation pressure in the wells of the Shebelinske gas field. In the model, the monotonic nature of the increase in reserves is used. It is being axiomatized, that the increase in reserves $\Delta\mathrm{grw}(\Delta\tau)$ for the time step of $\Delta\mathrm{t}$ is proportional to residual volume of stocks potential growth, defined as the difference of potential Πt_{grw} and the realized $Sgrw_{i-1}$ volumes of reserves, relative to changes in formation pressure at the time step, and the coefficient (index) I_{gr}, characterizing the rate of reserves growth.

$$\Delta grw(\Delta\tau) = \left[\Pi t_{grw} - Sgrw_{i-1}\right] \frac{[p_{in} - p(t_i)]}{p_{in}} I_{gr} \Delta t. \qquad (12)$$

Adaptation was carried out by selecting: 1) the initial formation pressure; 2) the volume of drained reserves at the time of field development; 3) the value of the expansion potential of reserves; 4) the index of the rate of expansion of reserves, where the total discrepancy between the forecast and the actual weighted average formation pressures for the entire period of the history of the development is minimized.

According to the results of adaptation at the time of development of the field, the initial drained gas reserves were 522 billion m^3 at a weighted average formation pressure of 23.8 MPa. The potential expansion of reserves is estimated to be 385.5 billion m^3, and the expansion rate index is $3{,}75 \cdot 10^{-3}$billion m^3 / (MPa·month).

In the material balance model, the expansion of the drainage volume provides an almost complete coincidence of the forecasted material balance method of average pressure with its weighted average before sampling value is used to calculate reserves.

The mean square discrepancy between the forecast and actual weighted average reservoir pressures was 0.28 MPa.

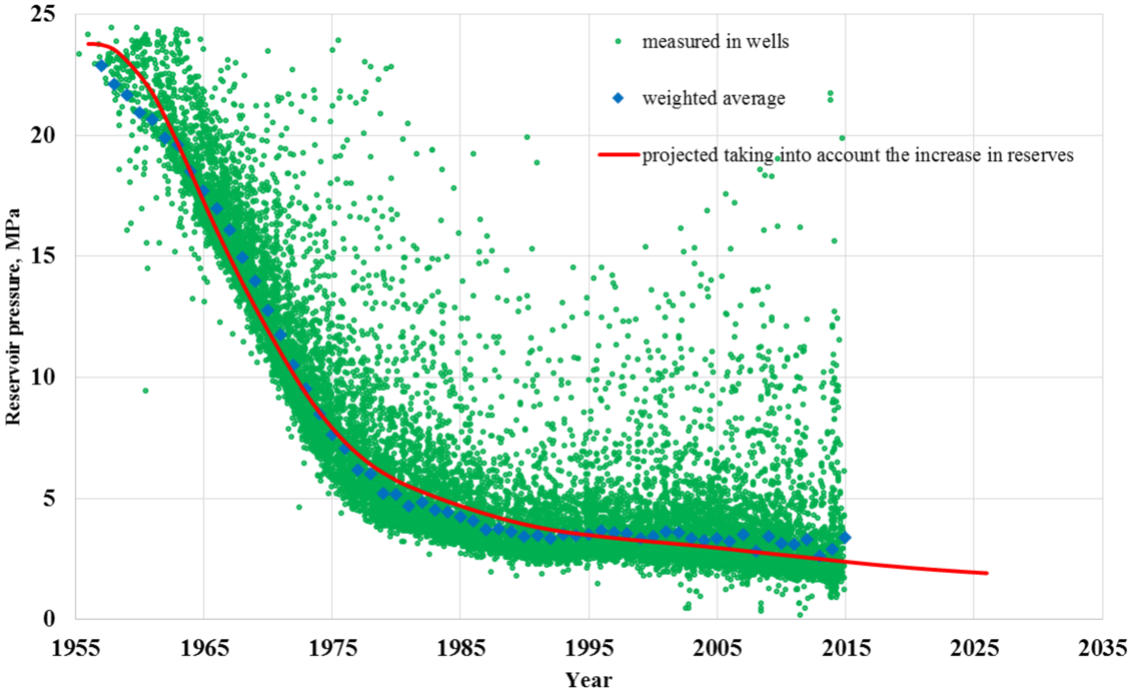

Fig. 1. Dynamics of formation pressure in the wells of the Shebelinske gas field and the results of its forecast by the material balance method, considering the increase in gas reserves due to the expansion of the drained volume

Belske oil-gas condensate field

The field is in Poltava Oblast of Ukraine. It is interesting for testing of the material balance method as a result of long breaks of operation of producing facilities.

Object III (horizon B-15b of the Visean lower Carboniferous rocks, blocks 2A and 2B under consideration) was commissioned by well No. 150 in 1984. The initial formation pressure in it was 45.40 MPa. In 1990, the well was decommissioned due to flooding. Reservoir pressure currently was 9.85 MPa. In total, the well produced 554.89 million m^3 of gas.

Gas production from the facility resumed in 2009 after the recompletion of the well No.171. The formation pressure measured in this well was 10.89 MPa, which is close to the last measurement of 19 years ago in the well No.150. The obtained results clearly indicate the absence of aquifer activity in this productive horizon. In 2014, another well No. 181 was transferred to this development facility.

The purpose of adapting the initial data to use the system of material balance equations was to determine the initial formation pressure and initial gas reserves at which the predicted formation pressure is best consistent with the values of formation pressures measured by a depth gauge in wells No. 171 and No. 181 in the period of 2009-2014. The adaptation criterion was the minimum standard deviation between the calculated and actual data.

The adaptation of the material balance equations did not require the introduction of a correction for the expansion of the drainage zone (increase in reserves) during development, including after the putting well No. 181 into production in 2014. The coordination of the calculated and actual formation pressures did not require the adjunction of the active aquifer (Fig. 2).

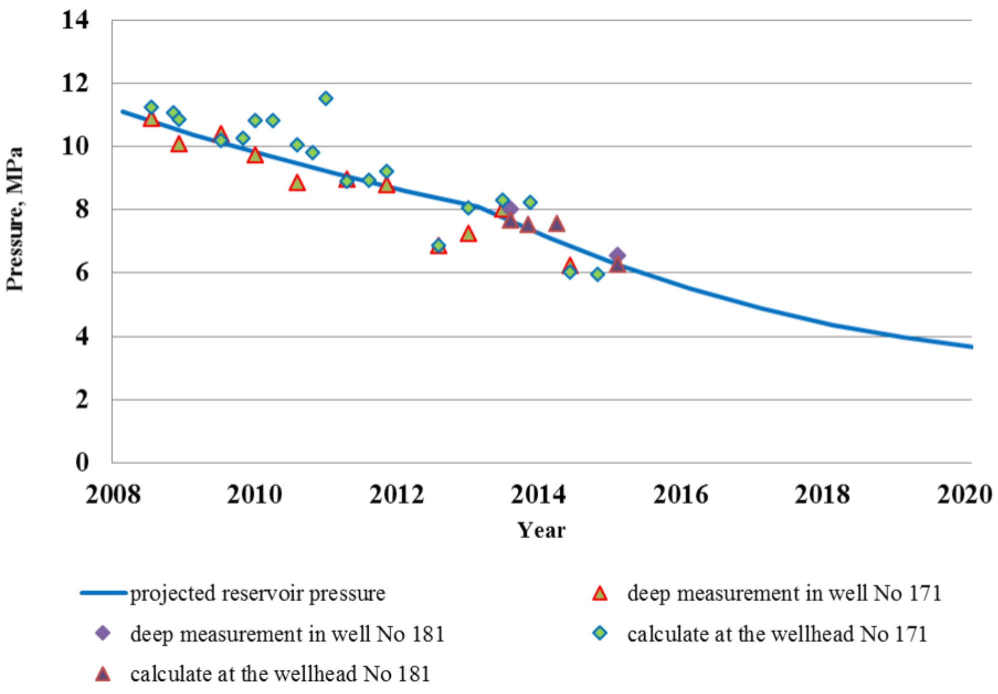

Fig. 2. Changes in formation pressure in wells of the 3rd object of development of the Belske gas field and the results of its forecast by the material balance method

After a 19-year break in gas production, the pressure in the reservoir was similar to the material balance for the gas depletion procedure. According to the results of adaptation, the initial formation pressure was 54.4 MPa, and the initial reserves in the field were estimated to be 755.0 million m^3, which coincides with the previously calculated by volumetric method.

A similar situation exists in the development of the 4th object of the Belske gas field (horizon-14 of the lower Carboniferous Visean sequence, block B1).

Production at this development site began in 1990 with well No. 151. The initial formation pressure in the reservoir was 40.18 MPa. As a result of the accident took place in 1994, after having produced 552.6 million m^3 of gas, the operation of well was stopped. After 5 years, the development of the object was restored in 2000 with wells No. 165 and No.166. In 2010, another well No. 162 was put into production. Minimizing the standard deviation between the actual dynamics of the weighted average pressure and calculated by the material balance method without taking into account the increase in reserves after the resumption of development by commissioning of new wells gave an estimate of the initial drained reserves of 1328 million m^3 at an initial reservoir pressure of 38.0 MPa. The latter is slightly lower than the initial recorded in 1990 (40.18 MPa). The standard deviation between the actual and design pressure is 0.60 MPa.

Similarly, the adaptation method of material balance (Fig.3) taking into account the expansion of reserves, has estimated the initial reserves of 1274 million m^3 at an initial formation pressure of 39.8 MPa, followed by an increase in reserves by another 599 million m^3, and the standard deviation between the actual and calculated weighted average pressures decreased to 0.18 MPa. Thus, the residual recoverable reserves by the material balance method are estimated to be 1873 million m^3, which is more than previously estimated by the volume method.

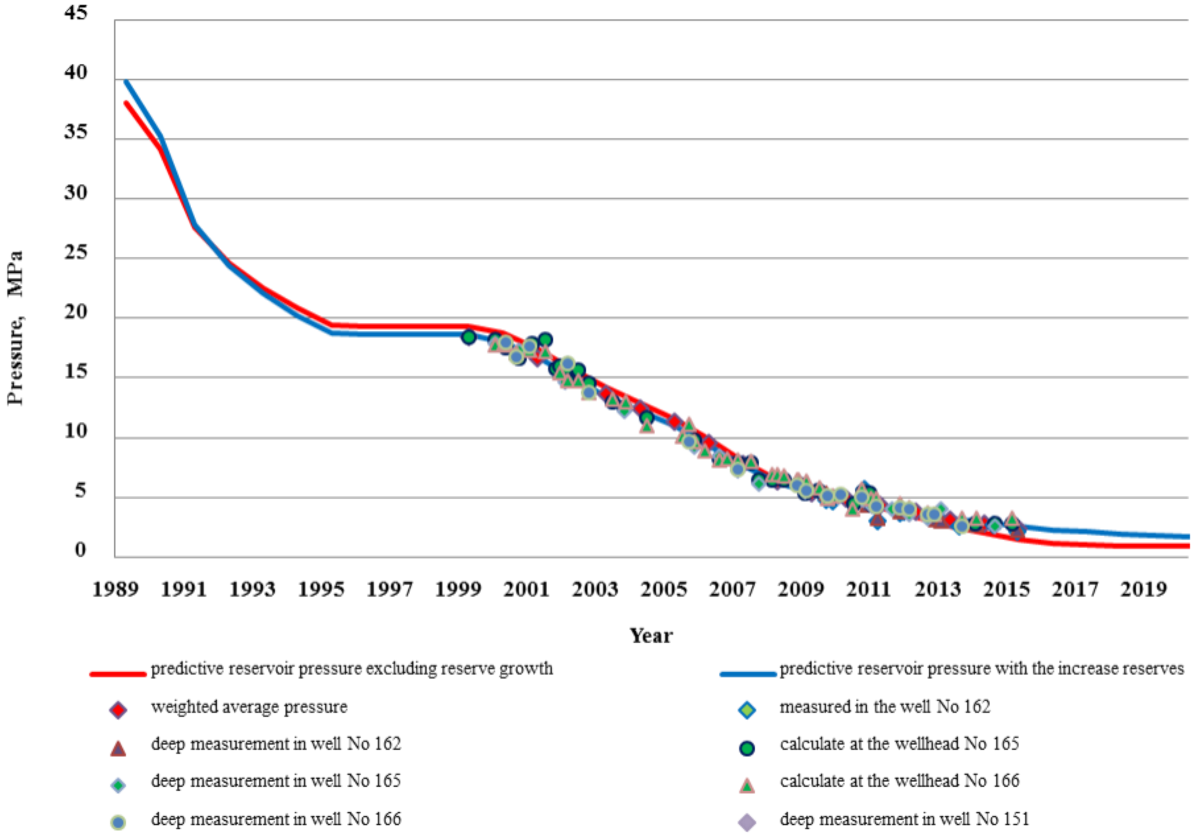

Fig. 3. Changes in formation pressure in wells of the 4th object of development of the Belske gas field and the results of its forecast by the material balance method

Ulyanivske gas field

The field is located in Dnipro Oblast of Ukraine. The object of development (horizon S-17a Serpukhov reservoir of early Carboniferous age) has been produced since 2004 with one well and is a typical example of an increase in drained reserves for no apparent reason. In the dynamics of formation pressure and, accordingly, depending on the reduced formation pressure and accumulated production, two time zones were distinguished. The first one is in the period from 2004 to 2005 with an intense drop in formation pressure, and the second one is revealed since 2006, a sharp slowdown in the rate of decline, is associated with a sharp increase in the volume of drained reserves.

Adaptation was performed via two models. In the first model the reserves were drastically changed in 2006, while for the second one they were changed monotonically according to the formula (10). Both adaptations have produced similar results.

According to the results of adaptation for the formation pressure dynamics model after the well developed, the drained gas reserves were amounted to 48.3 million m^3 thus increased to 212.6 million m^3 in 2006, which determined the corresponding dynamics of formation pressure (Fig.4).

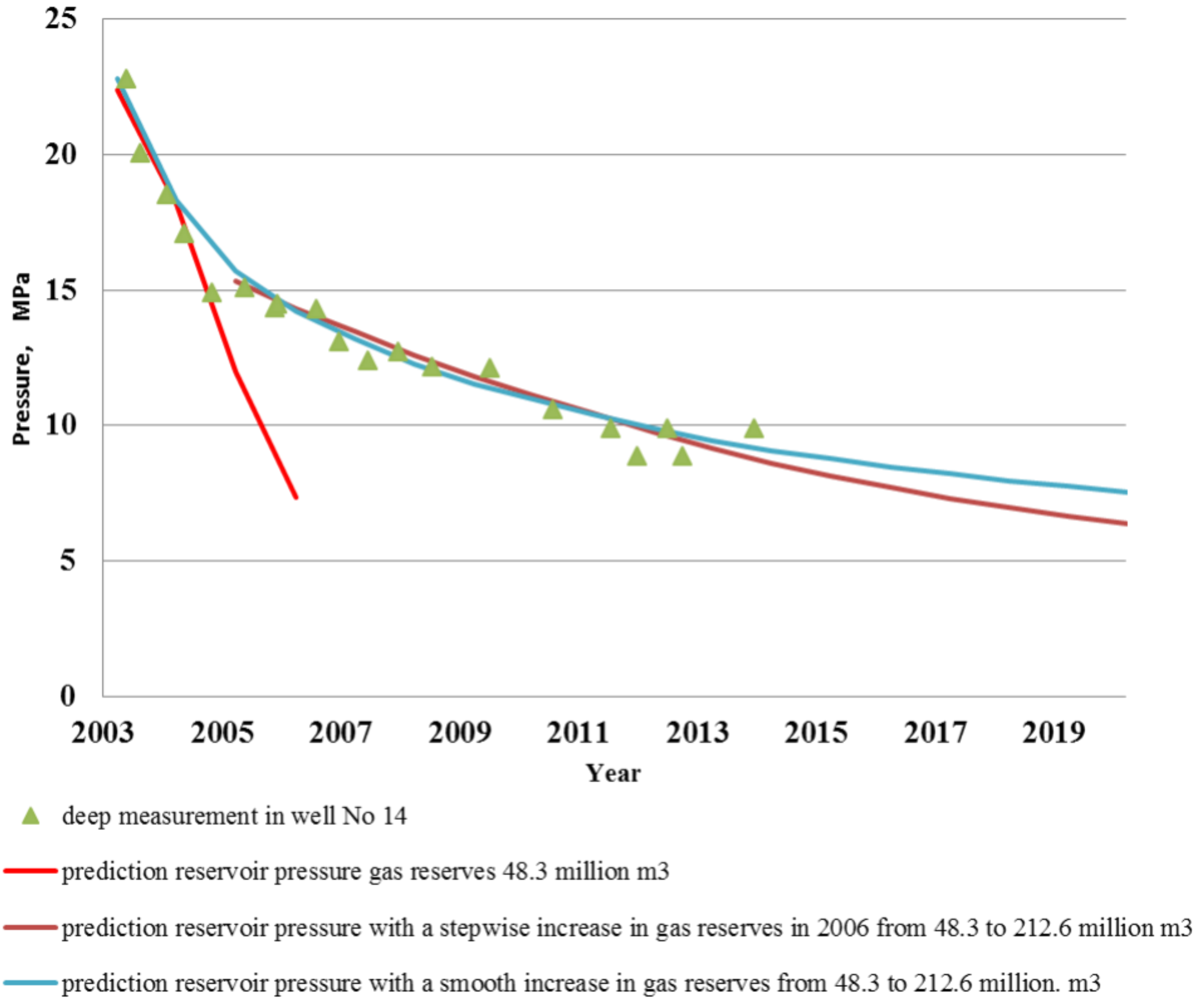

Fig. 4. Formation pressure change in well No. 14 of the field and the results of its forecast by the material balance method

Vishnevsky gas condensate field

The field is located in the Kharkiv Oblast of Ukraine. Development has continued since 1993.

Two objects of development are hydrodynamically separated in the different structural blocks of the field.

In the first object of development, the dynamics of reservoir pressure fully corresponds to the balanced ratio with a constant value of drained reserves. The increase in the number of wells that has been operating the facility in 2001-2015 from 2 to 5 did not affect the change of drained reserves.

According to the results of adaptation of the material balance model (Fig. 5) to the criterion of the minimum standard deviation between the actual and calculated weighted average for the formation pressure and producing gas reserves has been estimated to be 4784 million m^3, which is close to the current geological model.

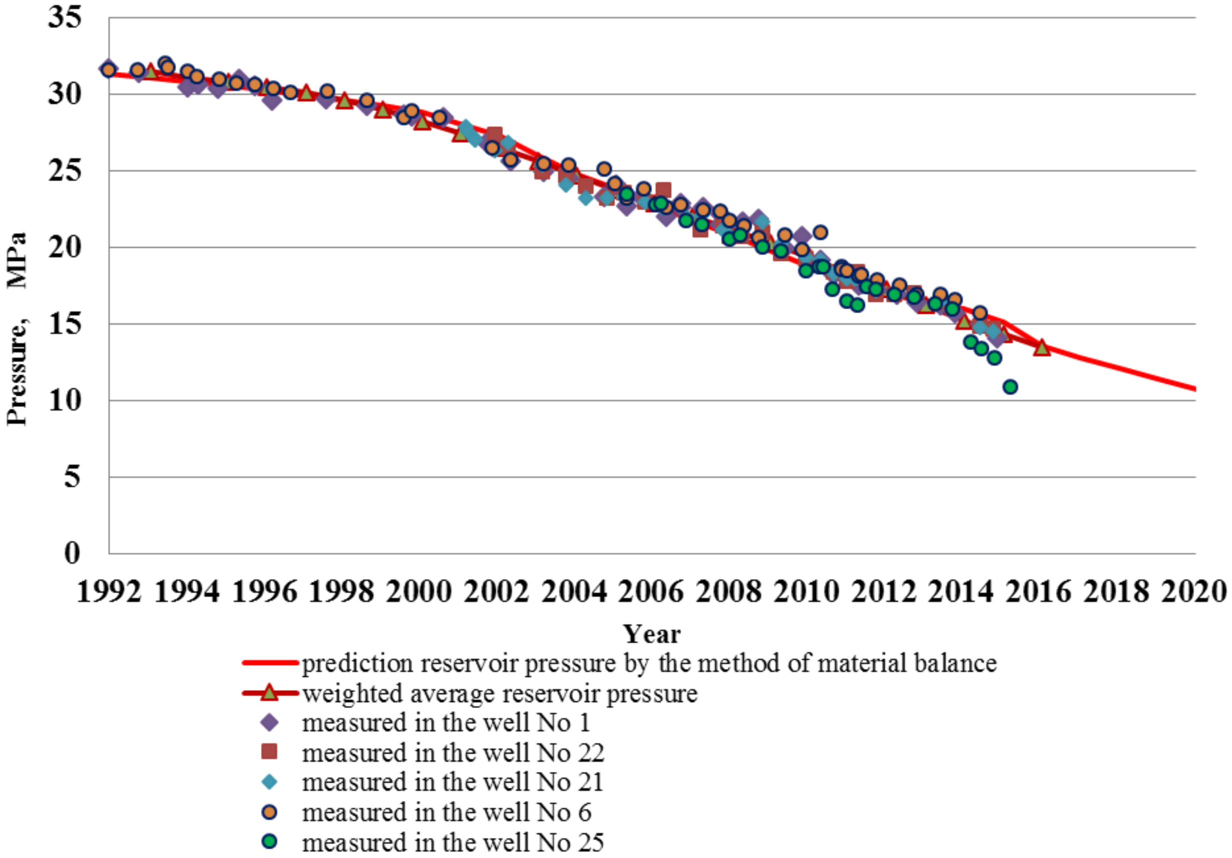

Fig. 5. Changes in reservoir pressure in wells of the 1st object of the Vishnevsky field and results of its forecast by the method of material balance

The dynamics of formation pressures measured in the wells of the second object are not typical (Fig. 6). The facility was put into development in 1993 with two production wells – No. 3 and No. 7. In 2008, low-rated flow well No. 23bis was put into operation. By 2005, the projected formation pressure corresponds to the actual selections and is in good agreement with the measured at an initial reservoir pressure of 31.7 MPa and drained reserves of 818 million m^3 of gas. In the period from 2005 to 2011, gas recovery for technological needs are sharply reduced. It is obvious that the consequence of this is the growth in the period of 2006-2009 formation pressure in wells and thus the growth of the calculated weighted average formation pressure. The long period of pressure increase indicates that the physics of this phenomenon is probably related to the influence of the aquifer. With its small size, water influx is not noticeable against the background of a rapid decrease in formation pressure at high rates of gas extraction. However, with a decrease in the rate of recovery, the influence of water movement from the aquifer becomes noticeable in the dynamics of formation pressure.

Considering water influx from the aquifer in the system of material balance equations by the Fetkovich method provides a satisfactory coincidence of the calculated dynamics with its actual measurements in wells. According to the criterion of minimum total standard deviation for 1993-2015, the best approximation is provided by the initial gas reserves of at 822 million m^3 with formation pressure of 32 MPa, the volume of the aquifer domain of 4.67 million m^3 and the index of the flow of water of 2.4 thousand m^3/ (MPa·month).

Summary

Given the existing uncertainties in the assessment of drained reserves by the material balance method, the key is the correct matching and adaptation to the actual data of the main parameters. In particular, the accuracy of determining the mode of

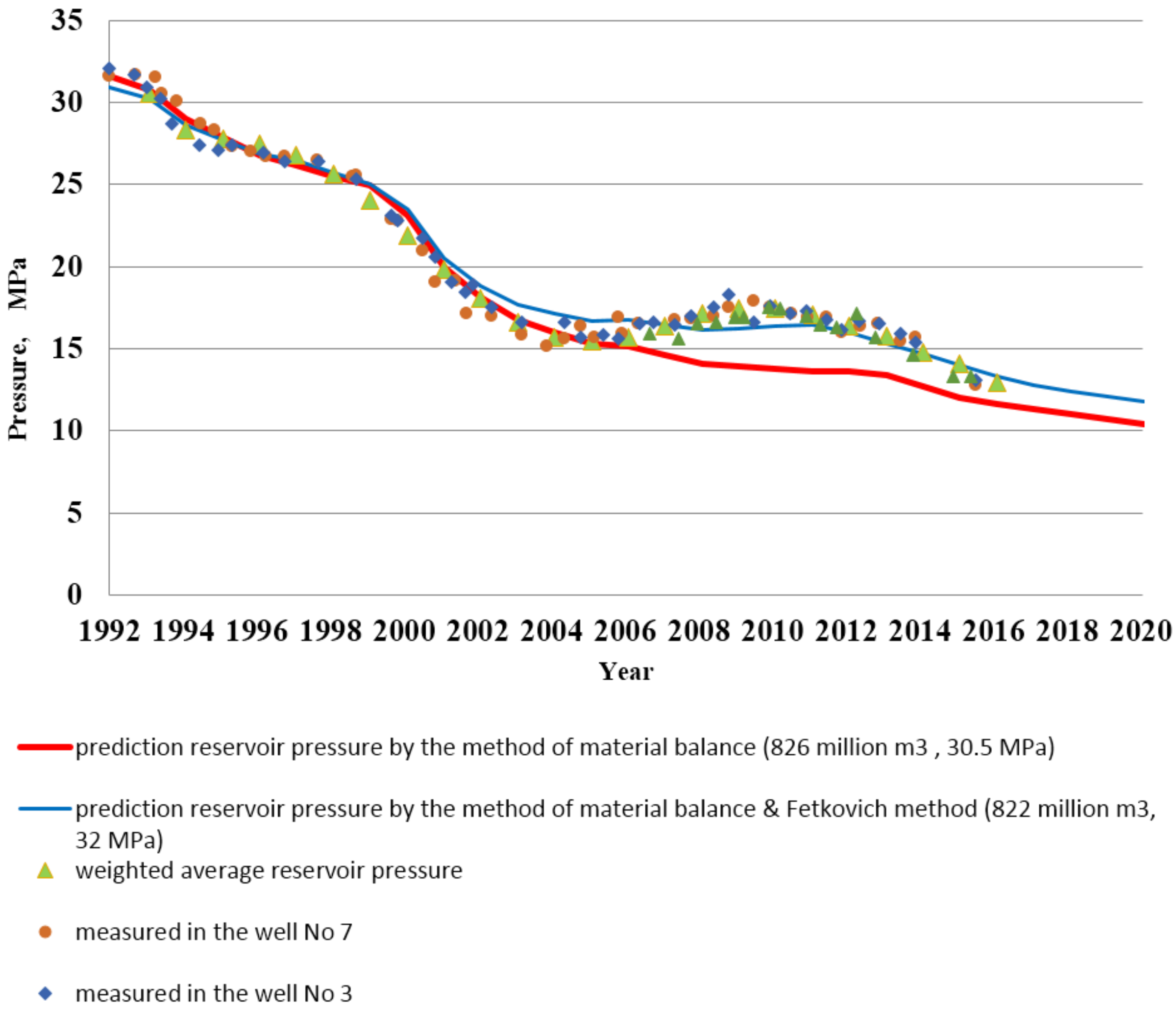

Fig. 6. Changes in reservoir pressure in wells of the 2nd object of Vishnevsky field and results of its forecast by the method of material balance

operation of the deposit, the rate and volume of water influx, the initial and current formation pressure as well. Based on the results of the examples of the development of gas condensate fields of the Dnieper-Donets basin that were took according to the changes in the basic parameters and by adaptation of real data, the realistic values of drained gas reserves were obtained. The adaptation results are most clearly reflected on the example of the Shebelinske gas field in the presence of formation pressure large data massif, which ensures almost complete coincidence of the forecast method of material balance to the average pressure with its weighted average before sampling value used for calculating reserves.

Therefore, the best way to determine or refine the input data is to adapt the material balance model to the previous history of reservoir development with a sufficient sampling of the correct information on formation pressure measurements, which will serve as a reliable basis for making the right engineering and financial decisions.

References

1. Akulschin A.I. 1988. Oil Field Forecasting. M. *Nedra*. 240 p. (In Russian)
2. Fetkovich M.J. 1971. A simplified Approach to Water Influx Calculation-Finite Aquifer System. JPT. July. P. 814-828.
3. Instructions for comprehensive research of gas and gas condensate wells. Part II. Joint Stock Company «*Gazprom*». 2011. M. 319 p. (In Russian)
4. Kanevskaya R.D. 2003. Mathematical modeling of hydrodynamic processes of hydrocarbon field development. M. Institute for Computer Research. 140 p. (In Russian)
5. Rules of development of oil and gas fields. Order No. 118 of the Ministry of Ecology of Ukraine issued 15.03.17. (In Ukrainian)
6. Zarubin Yu.A.*, Gunda M.V., Nikolaychuk V.V., Lastovetska A.V. 2017. Risks of gas production forecasting, using material balance equations. Journal of Hydrocarbon Power Engineering. Vol. 4. Issue 1. P. 8-17.
7. Zheltov Yu.P. 1986. Oil field development: university texbook. M. *Nedra*. 332 p. (In Russian)