

Software for Determining Residual Oil Reserves in Oil Deposit Development

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Abstract. The problem of calculating residual oil reserves and predicting wells flow rates is considered in the paper. A mathematical model for calculating this problem is given. A computational algorithm and a program for the mathematical model are created. Using the developed program the flow rate was predicted and the residual reserves were calculated on the example of a well of the Umid field. The convenience of the problem solution with a developed program is shown.

1. Introduction

The geological and hydrodynamic model of the reservoir is a mathematical description of the processes occurring in it, under conditions as close as possible to the actual ones. A closed system of partial differential equations is formed on the basis of mass conservation law and Darcy's law; the pressure distribution and the filtration rate field are calculated. The development of algorithms and principles, software packages for geological and hydrodynamic 3D modeling, has been the subject of a large number of studies [1,2].

The studies in [3] deal with a mathematical problem statement of unsteady fluid flow in a heterogeneous porous medium with various hydrogeological characteristics. To solve the problem the authors of that paper developed an approximate analytical method. The method allows to reduce the multidimensional differential equation in partial derivatives describing the process of fluid filtration in layered porous medium to the one-dimensional differential equation. A calculation formula was obtained for determining the process of mass transfer between the layers, depending on the operating modes of production wells and hydrogeological parameters of filtration layers. The model and the algorithm can be used as a mathematical tool in the processes of oil and gas fields development.

Using geological and hydrodynamic models, it is possible not only to predict the behavior of the reservoir during various processes occurring in it (geological and technical measures, water flooding, etc.), but also to solve many other, no less important, applied problems, such as: refining the structure and properties of the formation when adapting the model to the development history, comparing the model and laboratory studies on the core samples to clarify the phase permeability, various studies (cone formation, hydraulic fractures propagation of layer), etc.

Similar to the calculation of the balance reserves, the determination of the final coefficients of oil recovery and recoverable reserves should be linked with the stages of exploration and deposits development, i.e., with the amount of available information, with the features of the deposits geological structure.



Depending on the quality and quantity of initial information at different stages, the oil recovery coefficient can be estimated and recoverable reserves can be calculated based on its value, or recoverable reserves can be determined and the oil recovery coefficient can be calculated based on their value.

At the stages of prospecting and evaluating fields in the process of exploration, with a minimum of information about the structure and geological-physical characteristics of the productive formations, a preliminary assessment of the oil recovery coefficients is carried out. The calculation of recovery factors is based on multivariate statistical models.

At the stage of development preparation and the beginning of the field development, oil and gas reserves are calculated, a feasibility study for the oil recovery coefficient is compiled, the State Commission for Reserves approves balance and recoverable reserves, and a development flow chart is drawn up. In the feasibility study of the oil recovery coefficient the choice of the best option for the development system is substantiated based on the results of the feasibility studies of several options, including the version of the natural development system. For each option, the recovery ratio and other development indices are calculated. The extraction coefficient of the option that is most rational taking into account the closing costs is accepted [1, 4, 5, 6].

Oil recovery ratios at medium, large and unique deposits are calculated by hydrodynamic methods with one-dimensional filtration models - at the stage of exploration completion, and with two-dimensional models identified with real reservoir conditions - at the stages of development. For small deposits, oil recovery ratios are determined using the displacement efficiency, displacement coverage, and waterflood displacement efficiency. For oil and gas deposits developed using water flooding and other methods of formation stimulating, as well as those developed under natural conditions, a unified approach to the substantiation of the final oil recovery ratio is provided. For deposits with balance reserves of more than 30 million tons, recoverable reserves and oil recovery ratios are determined separately for oil, water-oil, gas-oil, and water-gas-oil zones [4].

To determine recoverable reserves at a late stage of development, while maintaining the current location chart and density spacing pattern, exploitation data are used for the period of work preceding the date of reserves calculation [5]. In this case, the approved oil recovery factor is refined following the calculated recoverable reserves and is taken equal to the ratio of their value to the initial balance reserves.

After commissioning of wells and reaching their maximum productivity, a decrease in the flow rate of wells begins at a certain intensity, but with a pronounced exponential trend. Based on this property, the probabilistic-statistical method can be used to estimate the current drained oil reserves. A similar method (method of V. D. Lysenko) was used to estimate the residual oil reserves of the Umid field individually for each well [1, 2, 7].

One of the principal methods for determining residual oil reserves by sweepout characteristics is the Lysenko method. The essence of this method is given below.

1.1. Statement of the problem. Let it be required to calculate the residual oil reserves and determine the forecast of production rates for wells [7-10].

This problem is calculated using the following mathematical model.

The mathematical model of this problem proposed by Lysenko is based on the law of reducing oil production rate and is described as an exponential function [1, 2, 11]:

$$q = q_0 \cdot e^{-\frac{q_a \cdot t}{Q_0}} \quad (1)$$

where q is the oil flow rate of the producing well at time t ; q_0 is the annual oil production for the first year of the period under consideration; q_a is the amplitude (initial) oil production rate; Q_0 is initial recoverable reserves per well.

This model is calculated for ideal conditions when a field is developed under fixed conditions, i.e., when in operating wells there are no transfers of perforation intervals, drained reserves do not change

due to the changes in the density of spacing patterns, the ratio of injection and production wells remains unchanged. Since these conditions are in most cases not feasible, it is necessary to make corrections based on a priori information and expert assessment.

In the beginning, a sampling of representative data for the well is performed. Consider this stage on the example of the analysis of the dynamics of the well flow rate (Fig. 1).

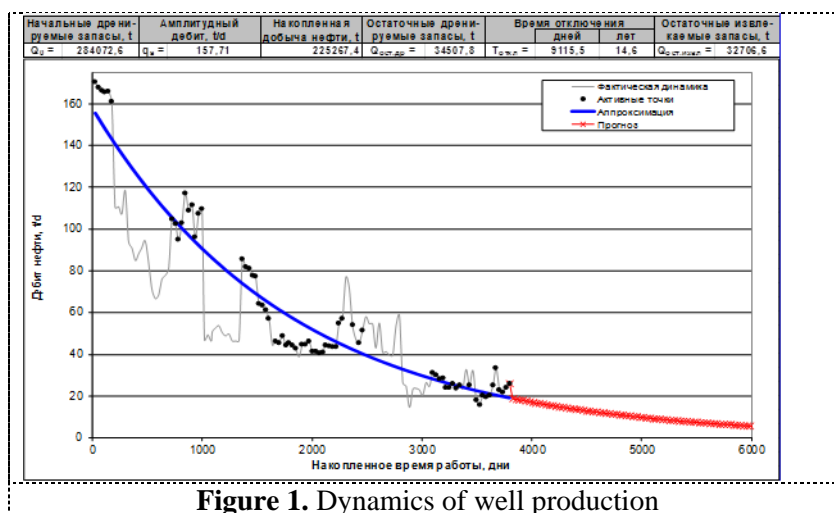


Figure 1. Dynamics of well production

The first 6 points in the figure marked by black dots show high flow rates at the beginning of the well operation. Further, seventeen actual values of the flow rates were rejected, since the flow rates that they indicate are very different from the values of neighboring points, which makes it possible to doubt their reliability.

One of the basic parameters determined by the Lysenko method is the determination of the forecast flow rate. The forecast flow rate is given using the example of wells No. 19 and 75 of the Umid field (Figures 2, 3).

First of all, the points that correspond to the periods of temporary decrease and increase in production, respectively, were rejected; followed by flow rate return to the main trend line, which is clearly seen from the figure.

The second stage is to determine the amplitude production rate (q_a) and recoverable oil reserves (Q_0) of the well, which are found by the approximation of selected data according to a mathematical model by the least-squares method.

Next, based on the obtained values of q_a and Q_0 a forecast of oil production is conducted: to obtain oil production for the next month of development, we introduce into the model calculated q_a and Q_0 and accumulated time in days by increasing the previous value by a corresponding number of days in the month under consideration.

2. Methods

The residual oil reserves based on the Lysenko method are calculated as:

$$Q_{OCT} = \int_{T_{TEK}}^{\infty} q_a e^{-\frac{q_a t}{Q_0}} dt = Q_0 \left(e^{-\frac{q_a T_{TEK}}{Q_0}} - e^{-\frac{q_a T_{KON}}{Q_0}} \right) \tag{2}$$

$$Q_{OCT.P-R} = \int_{T_{TEK}}^{T_{KON}} q_a e^{-\frac{q_a t}{Q_0}} dt = Q_0 \left(e^{-\frac{q_a T_{TEK}}{Q_0}} - e^{-\frac{q_a T_{KON}}{Q_0}} \right) \tag{3}$$

where Q_{OCT} are the residual oil reserves; $Q_{OCT.P-R}$ are residual recoverable reserves while limiting to extremely profitable oil production; TTEK is current accumulated time, T_{KON} is final accumulated time, determined by setting the maximum profitable flow rate: $q_{P-R} = 0.3t / d$

$$T_{KON} = -\frac{Q_0}{q_a} \ln\left(\frac{q_{P-R}}{q_a}\right) \quad (4)$$

The amplitude flow rate is found by the formula:

$$q_a = e^{\left(\frac{\sum \ln q_i - \frac{\sum (t_i \cdot \ln q_i) - \sum t_i \sum \ln q_i}{\sum t_i^2 - (\sum t_i)^2} \cdot \sum t_i}{\sum t_i}\right)} \quad (5)$$

Here q_i is the current rate, t_i are working days

The initial drained reserves are calculated by the formula:

$$Q_0 = \frac{q_a}{\left(\sum (t_i \cdot \ln q_i) \div (\sum t_i^2 - (\sum t_i)^2)\right)} \quad (6)$$

and accumulated production:

$$\sum (q_i \cdot t_i) \quad (7)$$

Residual drained reserves are calculated by

$$Q_{oct.dr.} = Q_0 \cdot e^{-\frac{q_a}{Q_0 \cdot \sum t_i}} \quad (8)$$

and residual recoverable reserves are calculated by

$$Q_{oct.izv.} = Q_{oct.dr.} - Q_0 \cdot e^{-\frac{q_a}{Q_0 \cdot t_{ok.}}} \quad (9)$$

Using this method, the residual oil reserves in the Umid field were estimated individually for each well [12].

Using the Lysenko method when calculating in an excel file, the following disadvantages can be noted.

It takes a lot of time to enter the source data for the wells, select active points, plot the graphs, add the source data to an existing file. There is also a risk of distortion of the entered formulas, as they are entered into the table cells and are available to the user.

To solve this problem, an advanced computational algorithm and a program for the calculation by the Lysenko method have been created; it eliminates these shortcomings.

There are several differences between the created computational algorithm and the program from the Excel file [11, 13, 15, 16]:

- determination of active points using the set conditions;
- using the conditions to cancel selected active points, to select active points from the graph;
- the calculated values for all considered wells are stored in separate files for each well;
- the calculated values in all considered wells are stored in one file;
- using the graph, the results at an arbitrary time interval can be viewed.

Therefore, the advanced algorithm program had the following advantages:

1. Reduces time expenses:
 - a. Entering the initial data on wells, which is of great importance if there are many wells in the field;
 - b. Selecting active points using the specified conditions:
 - Determination of average point change;
 - The given interval is divided into small pieces, and point values are determined on these pieces;
 - Points close to the found values are called active, distant ones - inactive;

• If the debit values are changed to be greater than allowed, these points are considered active if less than allowed - inactive.

c. When plotting the graph, it possible to correct the interval of accumulated operating time, to manually adjust the number of active points;

d. Conducting calculations adding data to an existing file;

2. The possibility of teaching the improved program, due to detailed instructions;

3. Excludes the possibility of accidentally ruining formulas because they are embedded in the program and are not accessible to the user.

3. Results and Discussion

Figures 2, 3, and 4 show calculated graphs in MS Excel and the advanced program [11, 12].



Figure 2. Dynamics of flow rate of well No. 19 of the Umid field (graph built in MS Excel)

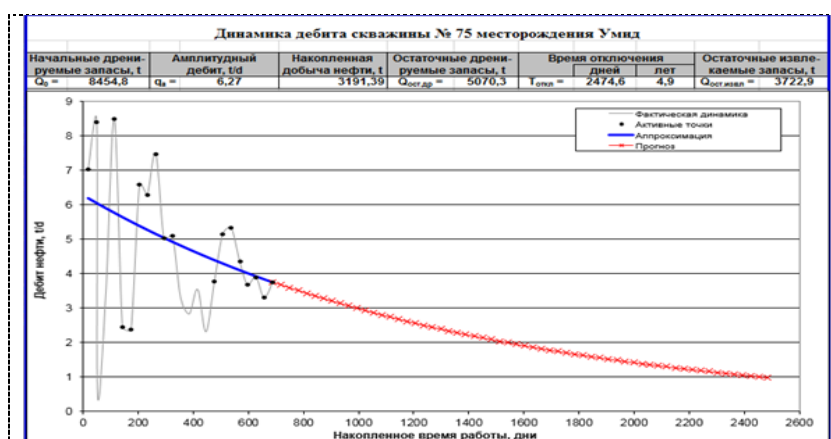


Figure 3. Dynamics of flow rate of well No. 75 of the Umid field (graph built in MS Excel)

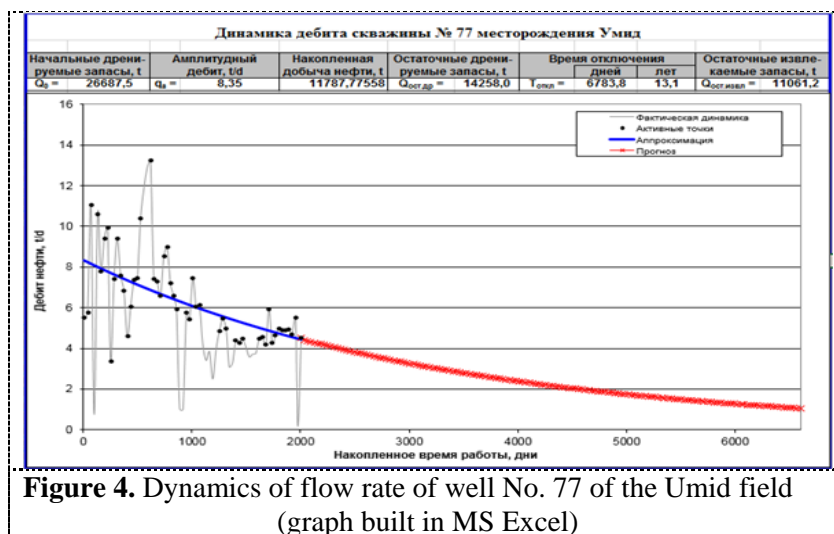


Figure 4. Dynamics of flow rate of well No. 77 of the Umid field (graph built in MS Excel)

Table 1

Field name:	Umid	
Well number	19	75
Initial drained reserves, <i>t</i>	14658.55	8461.34
Amplitude flow rate, <i>t/d</i>	37.11	6.27
Accumulated oil production, <i>t</i>	9773.47	3190.68
Residual drained reserves, <i>t</i>	986.51	5077.75
Disconnection time	Days	1427.54
	Years	0.99
Residual recoverable reserves, <i>t</i>	591.49	3728.46

Table 2

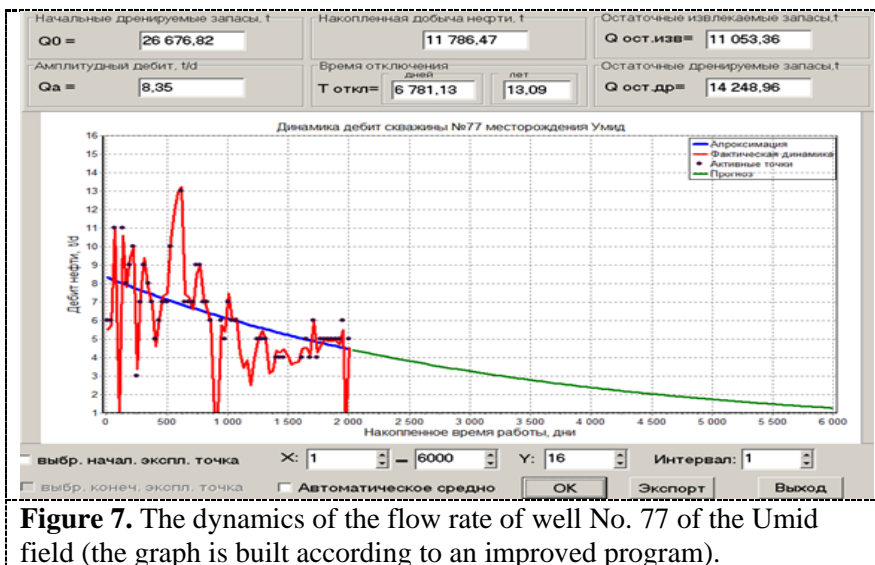
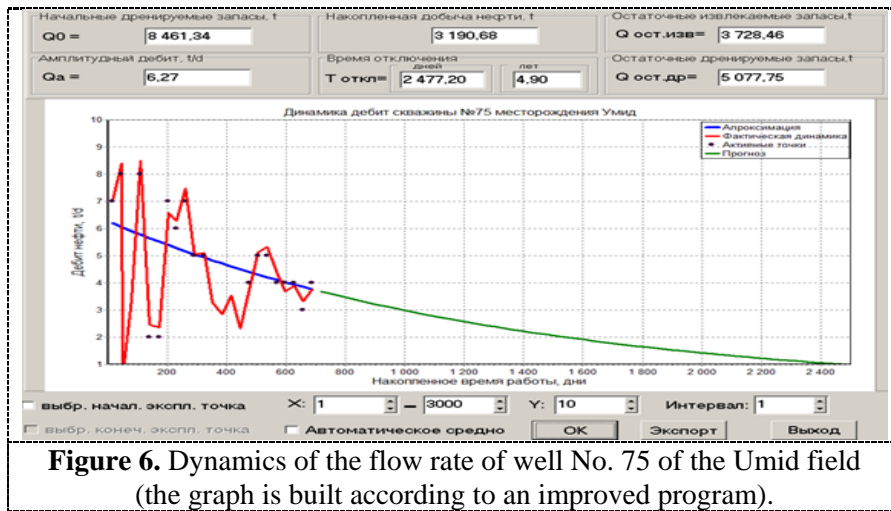
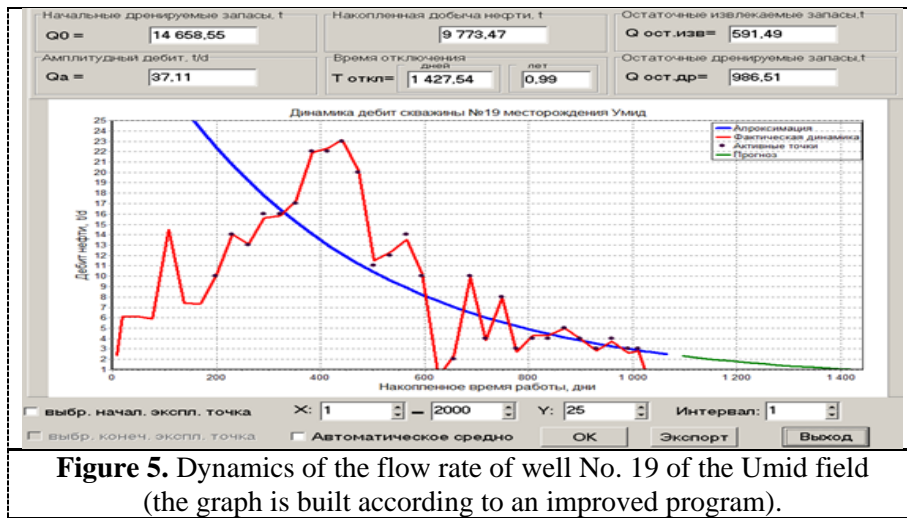
Field Name: Umid

Well number	75	
Initial drained reserves, <i>t</i>	8461.34	
Amplitude flow rate, <i>t/d</i>	6.27	
Accumulated oil production, <i>t</i>	3190.68	
Residual drained reserves, <i>t</i>	5077.75	
Disconnection time	Days	2477.2
	Years	4.90
Residual recoverable reserves, <i>t</i>	3728.46	

Table 3

Field Name: Umid

Well number	77	
Initial drained reserves, <i>t</i>	26676.82	
Amplitude flow rate, <i>t/d</i>	8.35	
Accumulated oil production, <i>t</i>	11786.47	
Residual drained reserves, <i>t</i>	14248.96	
Disconnection time	Days	6781.13
	Years	13.09
Residual recoverable reserves, <i>t</i>	11053.36	



There are several differences between the estimation of residual recoverable oil reserves by the V.D.Lysenko method excel according to an improved program [11, 12, 14].

4. Conclusions

Table 4. Comparison of MS Excel and advanced program for estimating the residual recoverable oil reserves by the V.D.Lysenko method [12].

Operation	MS Excel	Advanced Program
Entering initial data for wells	Data is entered into one file, for each well a separate sheet	Data is entered into one file; one sheet after another, which eliminates the need to switch to different sheets
Selection of active points	Selection is done manually by entering 1 and 0 into the corresponding cell.	Done automatically according to the built-in algorithm (manual correction of the graph is possible)
Plotting the dynamics of the well flow rate.	Built manually or copied from another field, then adjusted for each well separately (Figures 2, 3, 4)	Built automatically (the name of the field is entered when loading data) (Figures 5, 6, 7)
Calculation results	They are part of Fig. with a graph of the dynamics of the well flow rate (top row)	Saved in a separate file and a common file for all the wells.
Calculation formulas	Introduced in the cells as formulas that can be edited, it is necessary to extend the range of cells when adding data.	Built into the program as an algorithm without the possibility of making changes by the user, which eliminates accidental changes in the formulas and invalid calculations. When adding data, just upload the updated file.

As seen from Table 4, the advanced program has several advantages compared to Excel calculations.

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