The computational web technologies for decision of oil problems

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Abstract - *In oil branch for the economic analysis of oil fields' development the high-performance computational technologies, based on modern mathematical methods and computing algorithms are widely used. In this paper, the software developed by authors, for the solution of production's problems on the analysis of oil stratums development's processes taking into account water forcing in wells' system is offered. The software is realized in the form of the web-solution and allows to model three-dimensional stratum processes at high level.*

Keywords *– software; high-performance computational technologies; mathematical model; numerical methods; algorithms; oil field*

I. INTRODUCTION

Today, in the conditions of oil branch's rapid development, with increase in quantity of low production's oil fields, with exhausted of oil stratums there is a question of qualitative analysis of oil objects development efficiency using the modern computational technologies and achievements of computer science for simulation of stratum processes in the oil production analysis. By mathematical and computer simulation of multiphase filtration liquid problems in development of oil and gas fields are reflected in the following works of scientists [1-27].

In turn methods of computer simulation of oil stratum processes require use more perfect computational technologies both on time of calculation and for the detail numerical analysis of three-dimensional hydrodynamic models. And computational technologies require use of high-performance computation and high-end powerful servers. Thanks to such technologies time of the analysis of development of oil reservoirs decreases, quality of their maintenance increases.

II. THE STATEMENT TO THE PROBLEM

In Kazakhstan oil fields are at a great distance from large metropolitan centers with developed scientific infrastructure. Therefore for oil experts development of web application which will represent as the remote computing server on simulation of oil stratum processes dynamics is urgent. Users can enter into this web system directly from the local offices, placed on fields "Figure 1".

Considering the aforesaid, authors developed software application for remote modeling of oil field exploration process in terms of injection of water by water wells to oil stratum. As the numerical solution of the problem on simulation of stratum processes dynamics takes a lot of machine time, designed computational algorithms were parallelized on MPI-technologies.

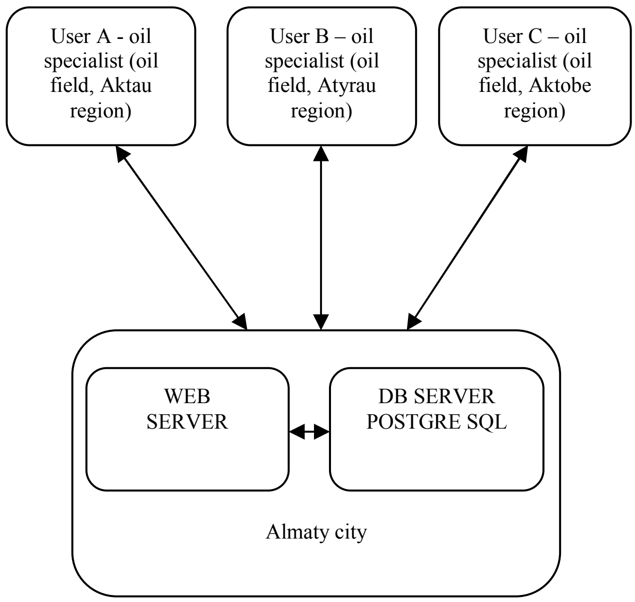

Figure 1. Scheme of WEB – computational application.

This web-application on dynamic modeling includes three-dimensional mathematical model. This mathematical model describes the impact of thermal method by injection of water to oil stratum for maintain of reservoir's pressure in terms of arbitrary location of water and oil wells and is based on nonisothermal two-phase filtration of liquid in view of inter-phase capillary forces.

The mathematical model has the following form in a domain $G \times (0, T]$:

$$m\frac{\partial(\rho_w s_w)}{\partial t} + div(\rho_w w_w) = \sum_{i=1}^{N_1} Q_{w,i}^{in}\delta(x - x_{w,i}, y - y_{w,i}, z - z_{w,i}) -$$
$$- \sum_{i=1}^{N_2} Q_{w,i}^{out}\delta(x - x_{o,i}, y - y_{o,i}, z - z_{o,i}), \quad (1)$$

$$m\frac{\partial(\rho_o s_o)}{\partial t} + div(\rho_o w_o) = \sum_{i=1}^{N_2} Q_{o,i}^{out}\delta(x - x_{oi}, y - y_{oi}, z - z_{oi}), \quad (2)$$

$$w_w = -k\frac{f_w}{\mu_w}(\nabla p_w - \rho_w g \nabla z), \quad (3)$$

$$w_o = -k\frac{f_o}{\mu_o}(\nabla p_o - \rho_o g \nabla z),$$

$$p_o - p_w = p_{cap}(s_w, T), \quad (4)$$

$$s_w + s_o = 1, \quad (5)$$

$$\frac{\partial}{\partial t}((ms_w c_w \rho_w + ms_o c_o \rho_o + (1-m)c_r \rho_r)T) + $$
$$+div((\rho_w c_w w_w + \rho_o c_o w_o)T) = div(m(s_w \lambda_w + s_o \lambda_o) + $$
$$+(1-m)s_w \lambda_r)\nabla T) + \sum_{i=1}^{N_1} Q_{heat,i}^{in} \delta(x - x_{w,i}, y - y_{w,i}, z - z_{w,i}) - $$
$$-\sum_{i=1}^{N_2} Q_{heat,i}^{out} \delta(x - x_{o,i}, y - y_{o,i}, z - z_{o,i}). \quad (6)$$

Here s_w, s_o - saturation of water, oil respectively; p_w, p_o - pressure of water, oil respectively; T - temperature; p_{cap} - capillary pressure between oil and water phases; k - absolute permeability; m- porosity; ρ_w, ρ_o, ρ_r - density of water, oil and rock respectively; c_w, c_o, c_r - heat capacity of water, oil and rock respectively; $\lambda_w, \lambda_o, \lambda_r$ - heat conductivity of water, oil and rock respectively; g - gravity; N_1, N_2 - quantity of input (water) and output (oil) wells respectively; $(x_{w,i}, y_{w,i}, z_{w,i})$, $(x_{o,i}, y_{o,i}, z_{o,i})$ - coordinates of i-input and i-output well respectively; $Q_{w,i}^{in}, Q_{w,i}^{out}, Q_{o,i}^{out}$ - injection rate of water on i-input well, production rate of additional recoverable water and oil on i-output well respectively; $Q_{heat,i}^{in}, Q_{heat,i}^{out}$ - rate of heat injection on i-input well and heat recovery on i-output well respectively and so on.

The initial and boundary conditions of this problem are given on wide data span.

III. The Solving of the Problem

Considering that the mathematical model is non-linear and three-dimensional with many parameters, the main difficulty in creation of this software consisted in development of effective computational algorithm which is a kernel in this software.

Let's provide the scheme of the solution of this problem:

1. Building of the discrete model of the initial mathematical problem.
2. Development of effective computational algorithm for the solution of the discrete model.
3. Testing of the developed computational algorithm on real oil field's data.
4. On the basis of the created algorithm software is created.

The pressure, temperature, water and oil saturations are defined by iteration implicit schemes.

For high-speed performance of computing calculation concurrency methods of these implicit schemas taking into account MPI - technologies are used.

The pressure is defined by implicit schema of iteration method of splitting on local variables. Implicit scheme for pressure has a following form:

$$\alpha_p \frac{p_{o,ijk}^{n+1/3} - p_{o,ijk}^{n}}{\tau} = \beta_{p,x}\Lambda_{xx} p_{o,ijk}^{n+1/3} + f_{p,ijk}^{n}, \quad (7)$$

$$\alpha_p \frac{p_{o,ijk}^{n+2/3} - p_{o,ijk}^{n+1/3}}{\tau} = \beta_{p,y}\Lambda_{yy} p_{o,ijk}^{n+2/3} + f_{p,ijk}^{n}, \quad (8)$$

$$\alpha_p \frac{p_{o,ijk}^{n+1} - p_{o,ijk}^{n+2/3}}{\tau} = \beta_{p,z}\Lambda_{zz} p_{o,ijk}^{n+1} + f_{p,ijk}^{n}. \quad (9)$$

Similarly implicit schemes for water saturation and temperature of oil stratum are given respectively.

$$\alpha_s \frac{s_{w,ijk}^{n+1/3} - s_{w,ijk}^{n}}{\tau} = \beta_{s,x}\Lambda_{xx} s_{w,ijk}^{n+1/3} + f_{s,ijk}^{n}, \quad (10)$$

$$\alpha_s \frac{s_{w,ijk}^{n+2/3} - s_{w,ijk}^{n+1/3}}{\tau} = \beta_{s,y}\Lambda_{yy} s_{w,ijk}^{n+2/3} + f_{s,ijk}^{n}, \quad (11)$$

$$\alpha_s \frac{s_{w,ijk}^{n+1} - s_{w,ijk}^{n+2/3}}{\tau} = \beta_{s,z}\Lambda_{zz} s_{w,ijk}^{n+1} + f_{s,ijk}^{n}, \quad (12)$$

$$\alpha_T \frac{T_{ijk}^{n+1/3} - T_{ijk}^{n}}{\tau} = \beta_{T,x}\Lambda_{xx} T_{ijk}^{n+1/3} + f_{T,ijk}^{n}, \quad (13)$$

$$\alpha_T \frac{T_{ijk}^{n+2/3} - T_{ijk}^{n+1/3}}{\tau} = \beta_{T,y}\Lambda_{yy} T_{ijk}^{n+2/3} + f_{T,ijk}^{n}, \quad (14)$$

$$\alpha_T \frac{T_{ijk}^{n+1} - T_{ijk}^{n+2/3}}{\tau} = \beta_{T,z}\Lambda_{zz} T_{ijk}^{n+1} + f_{T,ijk}^{n}. \quad (15)$$

Here τ - step on time. On each time step the following variables $p_{o,ijk}^{n+1}$, $s_{w,ijk}^{n+1}$, T_{ijk}^{n+1}, $s_{o,ijk}^{n+1}$ are defined.

Then, on calculated pressure, temperature, saturation of water, oil and their densities the integral indexes of oil field's development are defined: oil recovery, water cutting, stored oil production and other indexes on a set time point of development.

IV. The Computational Algorithm

The computational schemes for determination of pressure, water saturation and temperature represent a structure of three-diagonal system of the linear algebraic equations. The three-diagonal system of the linear equations has the following form:

$$Dy = e. \quad (16)$$

Here D - three-diagonal matrix; y – decision vector; e – vector of free elements.

For parallelization, divide the matrix D, the decision vector y and the vector of free elements e into k - processors.

In parallelization of algorithm for separation of data the three-dimensional decomposition is used. As the computational algorithm is applied to each area x, y, z respectively, it will be necessary to create MPI communicators on these areas, as shown in “Figure 2”, “Figure 3”, “Figure 4”.

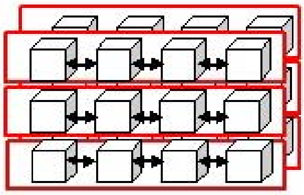

Figure 2. MPI communicator on x - direction.

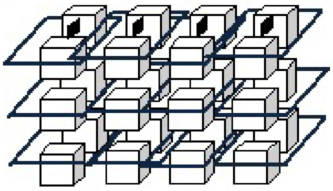

Figure 3. MPI communicator on y - direction.

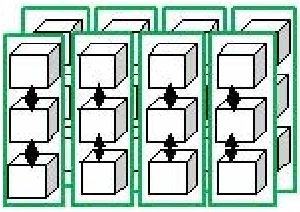

Figure 4. MPI communicator on z - direction.

All computing data are distributed on all processors. Each process determines parameters of the upper and lower bound respectively. Then there is an assembly of these parameters on the main process of each communicator. The main process by means of the computational method determines boundary conditions of the required decision.

After that finding boundary conditions are sent to each process. In turn each process finds internal values of the required solution of given task.

V. THE DESCRIPTION OF SOFTWARE

The list of input data for this software on thermal method of impact to stratum in a well’s system includes of the following data:

1. Oil field’s contour’s and schema’s base points.
2. Coordinates of injection and oil wells.
3. Pressure on injection and oil wells.
4. Temperature of pumped water on injection wells.
5. Thickness of oil stratum.
6. Permeability of oil stratum.
7. Porosity of oil stratum.
8. Pressure of water, oil.
9. Temperature of oil stratum.
10. Density of water, oil, rock.
11. Coefficient of compressibility for water.
12. Coefficient of compressibility for oil.
13. Coefficient of thermal expansion for water.
14. Coefficient of thermal expansion for oil.
15. Heat capacity of water, oil, rock.
16. Heat conductivity of water, oil, rock.

The software is realized on programming languages C#, Java, Java-script with using of database management system PostgreSQL 8.4. The client part of this software does not require installation, as it is done in Web-site form and is opened in any of browsers: MS Internet Explorer, Mozilla Firefox, Opera. So this software is a thin client. It allows user to be in any of city and in any of country, and to do necessary computations by Internet on high-performance Web-server. At request of oil company’s specialists the interface of this software was done in Russian language for ease work at it.

As a Web-server Microsoft IIS 7.0 is used. Mathematical computations are executed on the Web-server. With the help of java-script, java and Ajax –technologies the output of diagrams is performed by the client machine.

Data on wells, parameters of oil stratum, constants are stored in database of PostgreSQL 8.4. It allows several users to work at the same time and to store data separately.

Input of oil field’s contour

On the page “Oil field’s contour” of this software the user of oil company sets coordinates of oil field’s contour in the form of reference points’ sequence with coordinates (X, Y) clockwise “Figure 5”, or they can be loaded from the file “Figure 6”.

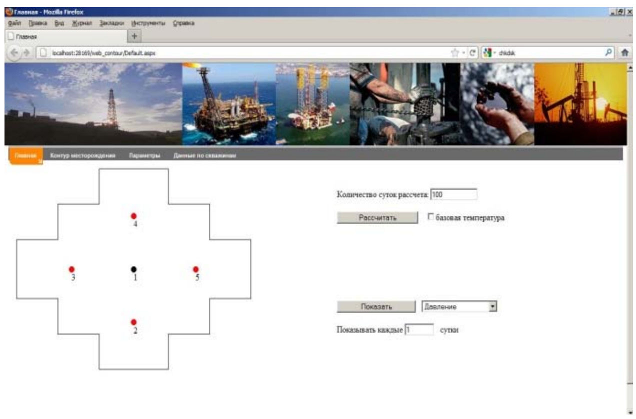

Figure 5. Input of oil field’s contour.

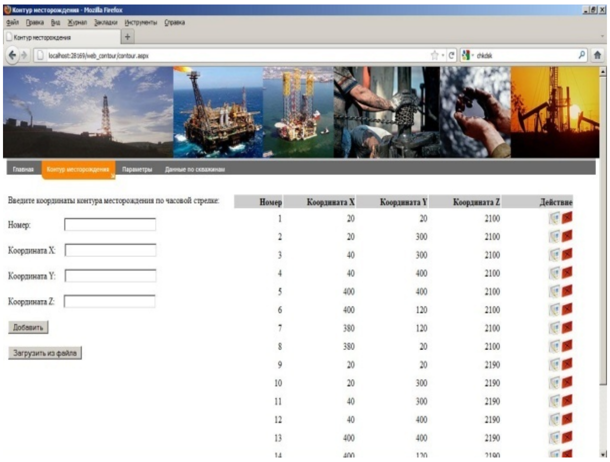

Figure 6. Input of oil field's contour from file.

Input of wells' data

On the page "Data of wells" of this software the user sets number, type, coordinates of well; measured values of oil stratum's thickness, porosity, permeability, pressure, temperature by well "Figure 7".

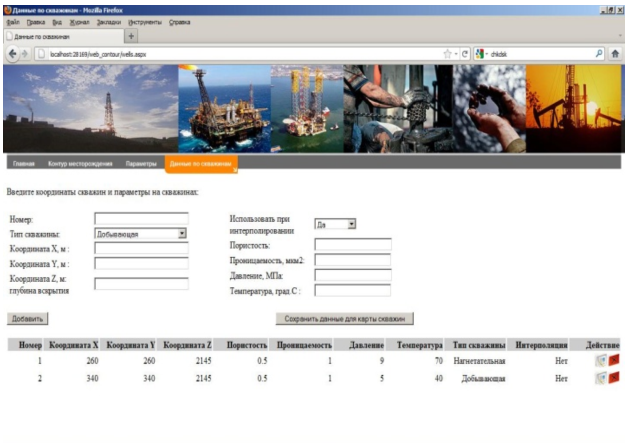

Figure 7. Input of wells' data.

Input of oil field's parameters

On the page "Oil field's parameters" the user sets parameters of oil stratum: pressure and temperature of stratum; saturation of oil and water; density and heat capacity of water, oil and rock; heat conductivity of water, oil and rock "Figure 8".

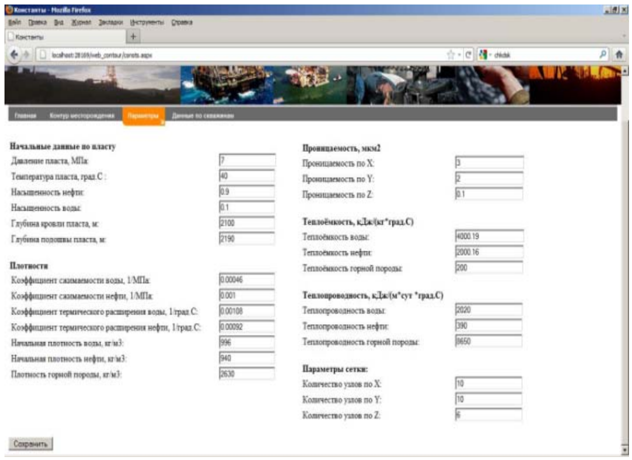

Figure 8. Input of oil field's parameters.

Execution of computations

Let's provide one of computation's variants. In this variant the one oil well and the one water injected well are given. Further 3D - graphics of oil pressure and water saturation, finding for fifteenth days of computations, are shown "Figure 9", "Figure 10".

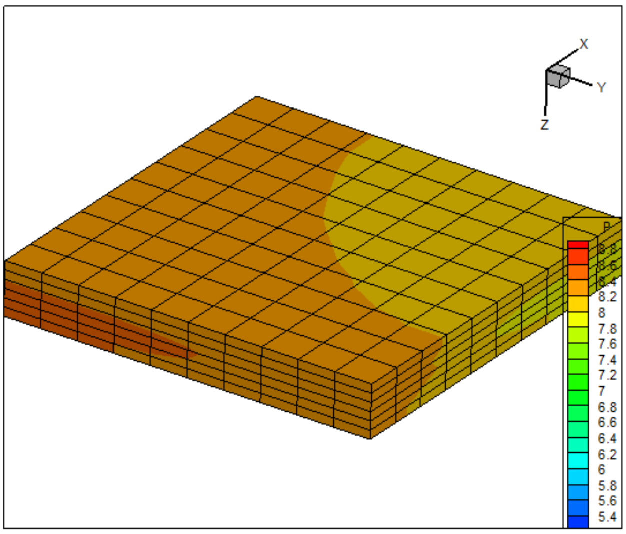

Figure 9. 3D-graphic of oil pressure in the initial stage of oil field development.

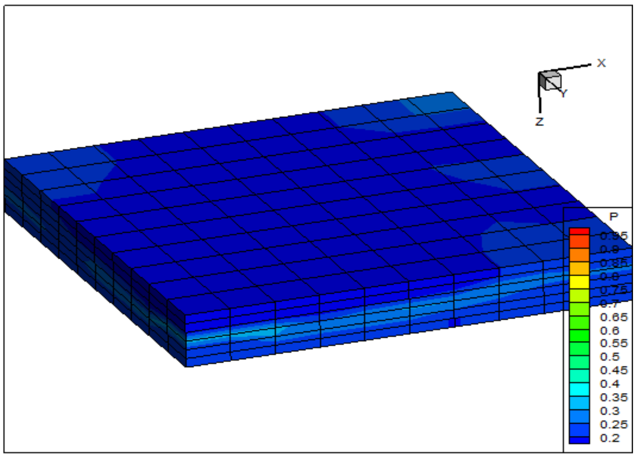

Figure 10. 3D-graphic of water saturation in the initial stage of oil field development.

The software consists of the following subsystems:

- Subsystem of collection and analysis of oil field's development geological data.
- Subsystem of information's input about operation of wells, analysis of wells' operation, an assessment of interaction of injected water wells and oil operation wells.
- Subsystem of automated collection and information storage on wells, monthly updating of a database, visualization of wells' status and formation of diagrams of development, technological mode of wells, sampling logs on wells, analysis of wells' fund, indexes of oil field's development, regulated reporting, determination of technological indexes of oil field's development.
- Subsystem of dynamic simulation of oil field development processes by secondary method as injected water on wells.

VI. Conclusions

The developed software by means of the functional capabilities can use other automated systems on monitoring of application-oriented tasks of oil fields' exploration. This software was approved on real data of oil fields of Republic of Kazakhstan.

Thanks to this software oil industry specialists can select effective ways of oil fields' development, do authentic forecasts on oil production and analyze a current status of oil objects' exploration.

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