Effect of convective transport in porous media on the conditions of organic matter maturation and generation of hydrocarbons in trap rocks complexes

Yurie Khachay*, Mansur Mindubaev*

*Institute of geophysics Ural Branch of Russian Academy of science, Amundsen str. 100, Ekaterinburg 620016, Russian Federation

Abstract

By analyze of catalysis processes of hydrocarbons and oil in the medium with the oil source rocks usually it is used the approximation about homogeneous medium and homogeneous PT- conditions in it. But the oil source rocks are porous medium, the slow flows in which are influenced by convection, which leads to significant heterogeneities of the structure of PT-conditions of oil source matter ripening. These structures can be either stationary or no stationary. In that paper we developed results of numerical modeling of convection in homogeneous medium and in the medium that contains heterogeneous for permeability 2D and 3D inclusions for detection and quantitative estimation the convection influence on the volume oil source rocks estimation in which the oil catalysis conditions are realized. It is showed that the amount of oil forming significantly depends from the convection intensity.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Oil deposit, convection in the porous medium, stationary state.

1. Introduction

By investigation of the oil deposit the most interest is the oil volume and oil quality. The oil quality depends from the content of oil source rocks and conditions of the thermal influence on its matter maturation. The last features

* Yurie Khachay. Tel.: +7-912-603-6903; fax: +7-343-267-8872.
E-mail address: yu-khachay@yandex.ru
depend from the distribution of the heat sources and conditions of the heat-mass transfer of the oil source matter inside the porous rock. Therefore it is very important to consider new effects and new models for analyze and estimating the process of oil forming and saturating inside the oil source porous medium.

2. Model and equations

For receiving the simplest qualitative estimations of oil resources usually it is used the one dimensional medium model [1]. In that case the process of heat transfer is described by one heat transfer equation and it allows for the forms of the oil layers use the horizontal layered structures. However such model cannot be used for the porous medium after a free convection of viscous fluid occurring which is the oil component in the porous medium [2]. This model becomes not only rough, but yet it becomes incorrect. First of all from that follows that the induced as the result of convection the flows structure does not stay constant and one dimensional. By convection occurring there are forming 2D or 3D flows of viscous fluids [2 3] and this means that by constant one dimensional distributions of thermal conductivity values of the rocks and oil matter for describing the process of heat transfer inside the viscous porous medium it is needed to use a system of equations for the impulse and temperature. If the velocity of the flow inside the porous medium can be considered as a sufficiently small value, usually it is used the approximation of Darcy and the convective movement of a viscous incompressible one component fluid inside the porous medium can be described by a system equations as follows [2,3]:

\[
\begin{align*}
\mathbf{u} &= \frac{K}{\nu} \left( -\nabla p + g \alpha T \mathbf{e}_z \right) \\
\frac{\partial T}{\partial t} + (pc_p)_e \frac{\partial T}{\partial t} + (pc_p)_b \mathbf{u} \cdot \nabla T &= \lambda e \nabla^2 T \\
\nabla \cdot \mathbf{u} &= 0
\end{align*}
\]

(1)

where \( \mathbf{u} = \eta \mathbf{v} \) – velocity Darcy for filtration inside the porous medium, \( \eta \) – porosity of the medium, \( \mathbf{v} \) – average velocity of the fluid inside the pores, \( p \) – pressure, \( g \) – acceleration of gravity, \( \nu \) – kinematic viscosity of the fluid, \( K \) – permeability, \( T \) – temperature, \( \lambda_e \) – thermal conductivity, \((pc_p)_e\) – heat capacity of the fluid saturated medium, \((pc_p)_b\) – heat capacity of the fluid.

For numerical modeling of that problem we shall formulate the system (1) in dimensionless form. Let us take as units: for the length – the thickness of the permeable layer \( H \); for filtration velocity – \( \kappa_{ef}/H \); time – \( bH^2/\kappa_{ef} \); pressure – \( \rho_0 \kappa_\alpha/\kappa_{ef} \), where \( \kappa_{ef}=\lambda_\alpha/(pc_p)_b \) – effective coefficient of thermal conductivity of the medium, \( b=(pc_p)_f/(pc_p)_b \) – ratio of thermal capacities of the medium and fluid. The system of dimensionless free thermal convection in the porous medium inside the permeable area is as follows:

\[
\begin{align*}
\frac{\partial \theta}{\partial t} + \mathbf{u} \cdot \nabla \theta &= \nabla^2 \theta \\
\nabla \cdot \mathbf{u} &= 0
\end{align*}
\]

(2)

where \( \theta=(T-T_0)/\Delta T_H \) – dimensionless temperature, \( T_0 \) – temperature at the upper cold boundary of the layer, \( \Delta T_H \) – vertical difference of temperatures inside the layer with a thickness \( H \); \( \alpha \) – coefficient of thermal fluid expansion. The dimensionless temperature \( \theta \) changes from \( \theta_i=0 \) at the upper boundary up to \( \theta_i=c=\Delta T/\Delta T_H \) at the lower, where \( \Delta T \) – difference of temperatures between the isothermal horizontal boundaries of the including area. The values of the parameter \( c \) are fitted in each case related to the angle of incline of the permeable layer. The convection intensity is determined by the number of Raleigh-Darcy [2,3]:

\[
Rd = \frac{\alpha g H \Delta T_H K}{\nu \kappa_{ef}}
\]

(3)
Let us suppose that in the area without the permeable area the flow does not exist. The corresponding equation of thermal distribution in it will be written as follows:

\[
\frac{\partial T}{\partial t} = \nabla^2 T
\]  

(4)

Let us suppose that the lower and upper boundaries of the layer are isothermal:

\[ T=2 \quad z=-2; \quad T=0 \quad z=0. \]

At the side boundaries we take for the temperature such boundary conditions:

\[ \frac{\partial T}{\partial x} = 0, \quad x=0 \text{ и } x=\lambda_{0x}, \]
\[ \frac{\partial T}{\partial y} = 0, \quad y=0 \text{ и } y=\lambda_{0y}. \]

For 2D case for the vector potential of the velocity \( \tilde{\psi} \) we take the usual ratio:

\[ \tilde{u} = \nabla \times \tilde{\psi} \]

(5)

Then the equation of continuity (the last from the system (2)) will be automatically confirmed.

For the components of the vector potential of the velocity \( \psi \) on the boundaries of the interior anomaly area according to [5] there are taken following conditions:

\[
\frac{\partial \psi_x}{\partial x} = \psi_y = \psi_z = 0 \quad x = 1, \quad \lambda_{0x} = 1
\]

\[
\frac{\partial \psi_y}{\partial y} = \psi_x = \psi_z = 0 \quad y = 1, \quad \lambda_{0y} = 1
\]

\[
\frac{\partial \psi_z}{\partial z} = \psi_x = \psi_y = 0 \quad z = 1, \quad 2
\]

(6)

Let us apply to the first equation of the system (2) the rot operation and taken into account the boundary conditions (6), we obtain for the whole porous area the \( z \) component of the vector potential \( \psi_z \) is equal to zero. Finally the system of equations of the free thermal convection in the interior area with the viscous fluid using the variables \( (\psi_x, \psi_y, T) \) can be written as follows:

\[
\nabla^2 \psi_x = -Rd \frac{\partial T}{\partial y},
\]

(7)

\[
\nabla^2 \psi_y = Rd \frac{\partial T}{\partial x},
\]

(8)

\[
\frac{\partial T}{\partial t} + u_x \frac{\partial T}{\partial x} + u_y \frac{\partial T}{\partial y} + u_z \frac{\partial T}{\partial z} = \nabla^2 T
\]

(9)

The components of the velocity in 2D case are presented through \( (\psi_x, \psi_y) \) according to (5). For numerical solution of equations (2) with the boundary conditions (6), we used the approach [4]; for numerical solution of equations (7-9) we used the method of subsequent upper relaxation [4,5]. The space discretization step for dimensionless variables in 2D and 3D cases had been taken as 1/30. There are presented the distributions of the temperature inside the permeable area for the number Darcy Rd 150 on the figure 1; on the figure 2 – the isolines of temperature for Rd 300.
Figure 1. Isolines of temperature inside the porous medium for the Darcy number $R_d = 150$.

Figure 2. Isolines of temperature inside the porous medium for the Darcy number $R_d = 300$.

Figure 3. Isolines of fluid velocity vertical component: the light colored - the matter rising structures; the dark - the matter top down structures.
3. Results and conclusions

The numerical modeling of convection for 2D and 3D cases inside the porous medium showed the possibility of a stationary state. That means that the structures, formed by convection, keep during the characteristic time of the considered problem. In contrast to the 1D case these structures have a complicate form, for instance fig.3. Comparably only not large part of the porous medium, filled by the oil source rocks, can undergo the stage of catalysis. For estimation of the oil source rocks volume, that had been underwent the catalysis, and for estimation of the formed oil the character of convection inside the porous medium has the significant meaning. More over from that result we can conclude that we can forecast the conditions of exploitation for each structure of oil deposit that at least partially recover the reserves of it.

References


Acknowledgements

This work is partly supported by the grant N15-18-5-32 UB RAS