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BASIC MACRONONEQUILIBRIUM EQUATIONS OF MULTIPHASE FILTRATION OF MULTICOMPONENT MIXTURES IN DEFORMABLE POROUS MEDIA

Abstract

The conservation equations and boundary conditions of fluid and rigid space being in local equilibrium state in macrosystem are reduced to macrononequilibrium equations. Physical sense of each term arising in the obtained equations is investigated, and they are estimated in some cases.

Consider the basic equations of multiphase filtration of multicomponent mixtures in deformable porous media by using local averaging method on macrovolume of equations of conservation laws of continuum mechanics and balance relations on interfacial areas. In general cases in the deduced equations the average parameters do not satisfy the conditions of thermodynamic equilibrium and therefore the obtained system of equations will describe the process of macrononequilibrium filtration. Thermodynamic disequilibrium arises by movement of multiphase systems in connection with their inhomogeneity, multicomponent property of composition of each phase, phase transfers, adsorption, movements in a large domain and so on [1-3].

The series of papers [3-6] which will be the basic instrument in the further investigations is devoted to the volume-averaging methods of law of continuum mechanics.

1. Volume averaging of conservation equation of mechanics of multiphase mediums. Let us select elementary macrovolume $\Delta V = \Delta X_1 \Delta X_2 \Delta X_3$ and macrovolume $dv = dx_1 dx_2 dx_3$ and corresponding scales ($dX_i \sim \Lambda$) and $x_i (dx_i \sim \lambda \ll \Lambda)$ in porous medium. Let macrononequilibrium process occurs in linear scale L and local thermodynamic equilibrium characterized by linear scale of movement in l is satisfied on microlevel.

The quantity L is external scale of the considered movement (dimension of seam, radius of tube) and l is scale of internal movement (state), (dimension of pore channel, macromolecule in polymer solution). Then in assumption $L \gg \Lambda \gg \lambda$ we may accept that the volumes $\Delta V \sim \Lambda^3$ and $dv \sim \lambda^3$ are differential in corresponding scales L and l . This approach is used for the determination of motion equation of continuum in macroscale X_i on known equation in scale x_i . We describe the last ones as balance equations which we can conveniently represent in the common form

$$\frac{\partial}{\partial t} \rho_l e_l + \nabla \cdot \rho_l e_l \underline{W}_l = \nabla \cdot \Omega_l^e + \theta_l^e \quad l = \overline{1, M} \quad (1.1)$$

for volume phases,

$$\underline{n}_{lm} \cdot \left[\rho^e \left(\underline{W} - \underline{W} \underline{\Sigma} \right) - \Omega^e \right]_l^m = \theta_{lm}^l, \quad l \neq m \quad (1.2)$$

for interfacial areas $\underline{\Sigma}_{lm}$ with the normal \underline{n}_{lm} .

The parameters entering to (1.1) and (1.2) characterize the specific values e of densities of flows Ω^e and local production θ^e . We represent conservation of mass of individual components in phase, masses of phases, momentum and quantity of energy on the table in the following form:

$$e : \omega^k, 1; \underline{W}, E + 0, 5W^2, \quad \Omega^e, -j^k, 0, \Pi, \Pi \cdot \underline{W} - q - \sum_k \hbar^k \underline{j}^k \quad (1.3)$$

$$\theta^e, R^k, 0, \rho \underline{g}, \rho \underline{g} \underline{W}$$

where $\rho, \underline{W}, \omega, j, \Pi, \rho g, E, q, h$ correspond to weight density, local speed, weight fraction, density of diffusion flux, microstress tensor, gravity, internal energy, heat flow, enthalpy; R^k is change of mass of k -th component of phase in unit time per unit volume due to chemical reaction of ionization, M is number of phases each of which consists of the same N components ($k = \overline{1, N}$). $[\Omega]_l^m = \Omega_{lm} - \Omega_{ml}$, pair index lm denotes limit values of the corresponding quantity in phase l on the boundary with the phase m , \sum is an interfacial area which will be assumed as non-material, upper index "e" denotes a balanced quantity, line below denotes vector quantities.

Besides, the system of equations (1.1) and (1.2) is completed by state equations

$$\rho_1 = \rho_1(\Pi_1, T_1, \omega_l^k), \quad E_l = E_l(\Pi_1, T_1, \omega_l^k), \quad (1.4)$$

and by conditions of conservation of mass of all mixture for chemical reactions and equality to unit of total concentrations, T is absolute temperature

$$\sum_{k=1}^N R_1^k = 0, \quad \sum_{k=1}^N \omega_1^k = 1. \quad (1.5)$$

From equations for mass of components in phase, only $N - 1$ ones are linear independent since, by the definition of ω_1^k the second one from the relations (1.5) must be satisfied.

The conditions of local thermodynamics equilibrium on phase boundaries, the expressions obtained from analysis, for dissipative function on boundary of phase have the form [3,4]

$$[T]_l^m = 0, \quad [\mu^k]_l^m = 0, \quad n_{lm} \cdot \left[\left(\tau - 0, 5\rho \left| \underline{W} - \underline{W}^\Sigma \right|^2 \right) \left(\underline{W} - \underline{W}^\Sigma \right) \right]_l^m = 0 \quad (1.6)$$

where μ^k is chemical potential of component, $\Pi_1 = -P_1 E + \tau_1$, P_1 is ball pressure, τ_1 is deviator tensor. If we take trace of the both parts $tr \tau_1 = 0$, $tr \Pi_1 = -3P$.

We average out the equation (1.1) and (1.2) by the volume ΔV under continuity condition of field of variables. After application of the Ostrogradsky-Gauss theorem we obtain

$$\begin{aligned} & \frac{\partial \epsilon_l \rho_l^e e_l^e}{\partial t} + \nabla \cdot \epsilon_l \rho_l^e e_l^e \underline{W}_l^e + \nabla \cdot \epsilon_l \left(\tilde{\rho}_l \tilde{e}_l \tilde{W}_l \right) = \\ & = \nabla \cdot \epsilon_l \Omega_l^{el} - \sum_m a_{lm} \left(n_{lm} \cdot \left(\rho_{lm} e_{lm} \left(\underline{W}_{lm} - \underline{W}_{lm}^\Sigma \right) - \Omega_{lm}^e \right) \right)^{lm} + \epsilon_l \rho_l^e \theta_l^{el}, \end{aligned} \quad (1.7)$$

$$a_{em} \left(\left[\rho e \left(w^n - w^{\Sigma_n} \right) - \Omega^{en} \right]_l^m - \theta_{lm}^e \right)^{lm} = 0, \quad (1.8)$$

where we denote

$$\nabla \cdot \underline{j} = \text{div} \underline{j}, \quad W^n = \underline{n} \cdot \underline{W}; \quad n_{lm} \cdot \Omega^e = \Omega^{en}$$

by scalar product of vectors,

$$\underline{n}_{lm} \cdot \Pi_{lm} = \Pi_{lm}^n, \quad \epsilon_l = \Delta V_l / \Delta V, \quad a_{lm} = \Sigma_{lm} / \Delta V, \quad \rho_l^l = \frac{1}{\Delta V_l} \int \rho_l dV,$$

$$e_l^l = \frac{1}{\Delta V_l} \int e_l dV, \quad \rho_{lm}^{lm} = \frac{1}{\Sigma_{lm}} \int \rho_{lm} dV,$$

$$\int_{\Delta V_l} \frac{\partial}{\partial t} e_l \rho_l dV = \frac{\partial}{\partial t} \int_{\Delta V_l} \rho_l^l e_l^l dV - \sum_m \int \underline{n}_{lm} \rho_{lm} e_{lm} \underline{W}_{lm}^{\Sigma} d\Sigma,$$

$$\rho_l = \rho_l^l + \tilde{\rho}_l, \quad W_l = \underline{W}_l^l + \tilde{W}_l, \quad (\tilde{\rho}_l)^l = 0, \quad (\tilde{W}_l)^l = 0,$$

$$\frac{1}{\Delta V} \int_{\Delta V_l} \rho_l \underline{W}_l dV = \epsilon_l \rho_l^l \underline{W}_l^l + \epsilon_l \left(\tilde{\rho}_l \tilde{W}_l \right)^l,$$

$$\frac{1}{\Delta V} \int_{\Delta V_l} \rho_l e_l \underline{W}_l dV = \epsilon_l e_l^l \rho_l^l \underline{W}_l^l + \epsilon_l \left(\tilde{\rho}_l e_l \tilde{W}_l \right)^l.$$

Here $\tilde{W}_l, \tilde{\rho}_l$ is pulsation of speed, density and so on.

We denote mean volume quantities arising on phase and interfacial surface only by upper indices l, m and m, l .

Using the table (1.3) we rewrite the averaged equations (1.7) and (1.8) in expanded form

$$\begin{aligned} \frac{\partial \epsilon_l \rho_l^l \omega_l^{kl}}{\partial t} + \nabla \cdot \epsilon_l \rho_l^l \omega_l^{kl} \underline{W}_l^l + \nabla \cdot \epsilon_l \left(\tilde{\rho}_l^l \omega_l^l \tilde{W}_l^l \right)^l + \nabla \cdot \epsilon_l \underline{j}_l^{kl} + \\ + \sum_m a_{lm} \zeta_{lm}^{klm} - \epsilon_l \cdot R_l^{kl} = 0, \end{aligned} \quad (1.9)$$

$$\left[\zeta^k \right]_l^m = 0 \quad (1.10)$$

for mass of component ,

$$\frac{\partial \epsilon_l \rho_l^l}{\partial t} + \nabla \cdot \epsilon_l \rho_l^l \underline{W}_l^l + \nabla \cdot \epsilon_l \left(\tilde{\rho}_l^l \tilde{W}_l^l \right)^l + \sum_m a_{lm} \zeta_{lm}^{klm} = 0, \quad [\zeta]_l^m = 0 \quad (1.11)$$

for mass of phase,

$$\begin{aligned} \frac{\partial \epsilon_l \rho_l^l W_l^l}{\partial t} + \nabla \cdot \epsilon_l \rho_l^l (D_1)_l^l + \nabla \cdot \epsilon_l \left(\tilde{D}_2 \right)_l^l + \nabla \cdot \epsilon_l \Pi_l^l - \\ - \sum_m a_{lm} \left(\underline{n}_{lm} \cdot \Pi_{lm} \right)^{lm} + \sum_m a_{lm} \zeta_{lm}^{klm} - \epsilon_l \cdot \rho_l^l g = 0, \end{aligned}$$

$$\left(\left[\rho \underline{W} \left(W^n - W^{\Sigma_n} \right) - \Pi^n \right]_l^m - \rho_{lm} g \right)^{lm} = 0 \quad (1.12)$$

for momentum,

$$\begin{aligned} & \frac{\partial \epsilon_l \rho_l^i h_l^i}{\partial t} + \nabla \cdot \epsilon_l \rho_l^i h_l^i \underline{W}_l^l + \nabla \cdot \epsilon_l \left(\tilde{\rho}_l^i h_l^i \tilde{W}_l^l \right)^l + \nabla \cdot \epsilon_l \sum_k \left(h_l^k j_l^k \right)^l + \nabla \cdot \epsilon_l q_l^l - \\ & - \nabla \cdot \epsilon_l \left(\Pi_l \cdot \underline{W}_l \right)^l - \sum_m a_{lm} \left(\underline{n}_{lm} \cdot \Pi_{lm} \cdot \underline{W}_{lm} \right)^{lm} - \epsilon_l \rho_l^i g \cdot \underline{W}_l^l + \sum_m a_{lm} Q_{lm}^{lm} = 0 \\ & a_{lm} \left([Q]_l^m \right) = a_{lm} \left([\Pi^n \cdot \underline{W}]_e^m + \rho_{lm} g \cdot \underline{W}_{lm} \right)^{lm} \end{aligned}$$

for energy balance. Here D_1 and D_2 are second-rank tensors by dyad components

$$\begin{aligned} & \underline{W}_l \cdot \underline{W}_l, \quad W_i \cdot W_j \quad \text{and} \quad \rho \tilde{W}_i \cdot \tilde{W}_j \\ & \zeta_{lm}^{klm} = \rho_{lm}^{lm} \omega_{lm}^{klm} \left(W_{lm}^n - W_{lm}^{\Sigma_n} \right)^{lm} + j_{lm}^{knlm} - R_{lm}^{klm}, \\ & \zeta_{lm}^{lm} = \rho_{lm}^{lm} \left(W_{lm}^n - W_{lm}^{\Sigma_n} \right)^{lm}, \quad \zeta_{lm} = \left(\rho_{lm}^{lm} \underline{W}_{lm} \left(W_{lm}^n - W_{lm}^{\Sigma_n} \right) \right)^{lm}, \\ & Q_{lm}^{lm} = \rho_{lm}^{lm} h_{lm}^{lm} \left(W_{lm}^n - W_{lm}^{\Sigma_n} \right)^{lm} + q_{lm}^{nlm} + \sum_k h_{lm}^{klm} j_{lm}^{kml}. \end{aligned}$$

2. Multiphase filtration of Newtonian fluid. Let each of phase of fluid obey the linear law of flow in saturated porous mediums and surface tension [3,4] arises on interfacial area

$$\Pi_l = -P_l E + \tau_l, \quad \Pi_{lm} = t_\alpha^i a_{lm}^{\alpha\beta} \cdot \sigma_{lm} \quad (2.1)$$

where $l = M - 1$, $l = M$ corresponds to solid phase, P_1 is pore pressure, τ_l is a coefficient of dynamic viscosity, t_α^i is hybrid tensor, $a_{lm}^{\alpha\beta}$ is metric tensor of interfacial area, σ_{lm} is surface stress. By Onzager principle the rates are diffuse and and heat flows on interfacial surface are directly proportional by thermodynamic forces evoking them, where the matrix of proportionality coefficients has the symmetric property

$$\begin{aligned} & W_{lm}^{nlm} = K_{lm}^* \left(P_l^l - P_{lm}^{lm} \right), \quad J_{lm}^{knlm} = D_{lm}^{k*} \left(\mu_l^{kl} - \mu_{lm}^{klm} \right); \\ & q_{lm}^{nlm} = C_{lm}^* \left(T_l^l - T_{lm}^{lm} \right). \end{aligned} \quad (2.2)$$

Averaged conditions of thermodynamic equilibrium (1.6) on boundaries will have the form

$$T_{lm}^{lm} = T_{ml}^{ml}, \quad \mu_{lm}^{klm} = \mu_{ml}^{kml}, \quad (2.3)$$

$$K_{lm}^* = K_{lm} / \eta_l L_l, \quad D_{lm}^{k*} = D_{lm}^k / L_l; \quad C_{lm}^* = C_{lm} / L_l$$

where K_{lm} is a permeability index, D_{lm}^k is a heat-conductivity coefficient, L_l is characteristic linear dimension of phase.

In the equation (1.9) the sum of two addends

$$\nabla \cdot \epsilon_l \left(\rho_l^l \omega_l^l \underline{W}_l^l \right) + \nabla \cdot \epsilon_l j_l^{kl} \equiv \nabla \cdot \epsilon_{ll} \underline{J}_l^k \quad (2.4)$$

gives dispersion of component in flow. Using the known principle of thermodynamics of irreversible processes of general theory of dimension as well as taking into account that the quantity \underline{J}_l^k must not depend on reference system and cannot be accepted to be an implicit state function, according to [1-4] we represent \underline{J}_l^k in the following form

$$\underline{J}_l^k = \sum_{r=1}^{N-1} D_{l\omega}^r \cdot \nabla \omega_l^{rl} + D_{l\omega} \underline{W}_l^l + D_{lr} \cdot \nabla T_l^l, \quad (2.5)$$

where $D_{l\omega}^r$, $D_{l\omega}$, D_{lr} are tensors of second rank effective diffusion. With the help of (1.10) and (2.2), (2.3) we have

$$\zeta_{lm}^{klm} = \left(D_{lm}^{k*} D_{ml}^{k*} / D_{lm}^* + D_{lm}^{k*} \right) \left(\mu_l^{kl} - \mu_m^{km} \right) + \delta \zeta_{lm}^{klm}. \quad (2.6)$$

We may write the equation (1.9) allowing for (2.5) and (2.6) in the following form

$$\frac{\partial}{\partial t} \epsilon_l \rho_l^l \omega_l^{kl} + \nabla \cdot \epsilon_l \rho_l^l \omega_l^{kl} \underline{W}_l^l + \nabla \cdot \epsilon_l^l \underline{J}_l^k + \sum_m a_{lm} \zeta_{lm}^{klm} = 0. \quad (2.7)$$

The equation being a result of summation (2.7) on all the components will be continuity equation of mass balance of phase

$$\frac{\partial}{\partial t} \epsilon_l \rho_l^l + \nabla \cdot \epsilon_l \rho_l^l \omega_l^{kl} \underline{W}_l^l + \nabla \cdot \epsilon_l^l \sum_k \underline{J}_l^k + \sum_m a_{lm} \zeta_{lm}^{klm} = 0. \quad (2.8)$$

Here $\sum_k \underline{J}_l^k \neq 0$, since \underline{W}_l^l is determined for menavolume rate but not for barycentric one. At slow motions of phase in equations we disregard momentum and energy, squares of rates and higher orders. Then the equation (1.3) and boundary condition (1.14) subject to (2.1) and (2.8) get the form

$$\begin{aligned} & \epsilon_l \rho_l^l \frac{\partial \underline{W}_l^l}{\partial t} + \epsilon_l \nabla \cdot P_l^l + P_l^l \nabla \epsilon_l - \nabla \cdot \epsilon_l \tau_l^l + \\ & + \sum_m a_{lm} (\underline{n}_{lm} \cdot P_{lm})^{lm} - \sum_m a_{lm} \underline{n}_{lm} \cdot \tau_{lm}^{lm} - \nabla \cdot \epsilon_l \rho_l^l \underline{g} = 0, \end{aligned} \quad (2.9)$$

$$([P]_l^m) \equiv P_{lm}^l = 2H_{lm} \sigma_{lm}, \quad \nabla P_l^l E = \nabla P_l^l = \text{grad} P. \quad (2.10)$$

Using the first relation of (2.2) and (2.10) we represent the expression

$$P_l^l - P_{lm}^{lm} = \delta \mathfrak{R}_{lm} = \frac{[(K_{lm}^* \cdot K_{ml}^* / K_{lm}^* + K_{ml}^*)]}{K_{lm}^*} \cdot (P_l^l - P_n^m + P_{lm}^l) + \delta P_{lm}. \quad (2.11)$$

Further

$$\nabla \epsilon_l = -\frac{1}{V} \sum_m \int \underline{n}_{lm} d \sum = - \sum_m a_{lm} \underline{n}_{lm}, \quad a_{lm}^n \approx - \epsilon_m \nabla \epsilon_l. \quad (2.12)$$

Substituting (2.11) and (2.12) in (2.9) instead of two addends and discarding the pulsation of pressure P_{lm} we obtain

$$\begin{aligned} P_l^l \nabla \in_l + \sum_m a_{lm} (\underline{n}_{lm} \cdot P_{lm})^{lm} = \\ = \sum_m \in_m \left(P_l^l - P_{lm}^{lm} \right) \nabla \in_l = \sum_m \in_m \delta \mathfrak{R}_{lm} \nabla \in_l. \end{aligned} \quad (2.13)$$

Disregards of force viscous components on the surface ΔS_2 of macrovolume are completely checked out in comparison with viscous forces on set of initial interfacial areas

$$|\nabla \cdot \tau_l^l| \ll \left| \sum_m a_{lm} \underline{n}_{lm} \cdot \tau_{lm}^{lm} \right|.$$

In [6] by Onzager's principle

$$\sum_m a_{lm} \underline{n}_{lm} \cdot \tau_{lm}^{lm} = - \sum_m \left(\underline{W}_l^l - \underline{W}_m^m \right) f_{lm} \left(\left| \underline{W}_l^l - \underline{W}_m^m \right| \right)$$

is determined.

If we use the method of [6], we obtain the relation

$$\sum_m a_{lm} \underline{n}_{lm} \cdot \tau_{lm}^{lm} = \sum_m r_{lm} \cdot \left(\underline{W}_l^l - \underline{W}_m^m \right) \quad (2.14)$$

where r_{lm} are coefficients of interfacial interaction, which subject to term $r_{lm} = r_{ml}$ having the known mechanical sense [4-6].

Allowing for (2.13) and (2.14) in (2.9) we obtain result balance equation of impulse (law of motion of multiphase fluid)

$$\begin{aligned} \in_l \rho_l^l \frac{\partial W_l^l}{\partial t} + \in_l \nabla P_l^l + \sum_m r_{lm} \left(\underline{W}_l^l - \underline{W}_m^m \right) + \\ + \sum_m \in_m \cdot \delta \mathfrak{R}_{lm} \nabla \cdot \in_l - \in_l \rho_l^l \underline{g} = 0. \end{aligned} \quad (2.15a)$$

Summing the equations (2.9) over the phases including solid one we obtain

$$\begin{aligned} \sum_{l=1}^M \in_l \rho_l^l \frac{\partial W_l^l}{\partial t} - \nabla \cdot \left(\in_M \Pi_M^M - \sum_{l=1}^M \in_l P_l^l E \right) - \\ - \sum_{l=1}^{m-1} \mathfrak{R}_{lm}^c - \sum_{l=1}^{m-1} \in_l \rho_l^l \underline{g} = 0, \quad m = 1, M = 1 \end{aligned} \quad (2.15b)$$

where $\nabla \cdot \in_l \Pi_l^l \approx -\nabla \cdot \in_l P_l^l$, $\mathfrak{R}_{lm}^c \approx \mathfrak{R}_{lm}^c \frac{1}{\nabla V} \int_{\Sigma_{lm}} \underline{n}_{lm} d\Sigma$.

We sum (2.15a) over the index $l = 1, M = 1$ and subtract the resulting equation from (2.15b) we shall have

$$\in_M \rho_M^M \frac{\partial W_M^M}{\partial t} - \nabla \cdot \in_M \Pi_M^M + \sum_{l=1}^{M-1} r_{lm} \left(\underline{W}_l^l - \underline{W}_M^M \right) +$$

$$+ \sum_m P_{lM}^M \underline{g} \nabla \in_l - \in_M \rho_M^M \underline{g} = 0. \quad (2.15c)$$

If we scalarwise multiply the equilibrium microequations (1.1) (momentum equation without inertial term) by \underline{W}_l and use an element of tensor analysis we have

$$\nabla \cdot (\Pi_l^l \cdot \underline{W}_l) - \Pi_l^l : \nabla \underline{W}_l + \rho_l \underline{g} \cdot \underline{W}_l = 0.$$

Hence after averaging we obtain

$$\begin{aligned} \nabla \cdot \in_l (\Pi_l^l \cdot \underline{W}_l)^l + \sum_m a_{lm} (\underline{n}_{lm} \cdot \Pi_{lm} \cdot \underline{W}_{lm})^{lm} + \in_l P_l \underline{g} \cdot \underline{W}_l = \\ = \frac{1}{V} \int (\Pi_l : \nabla \underline{W}_l) dV = - \in \left(\frac{d\mathfrak{R}_l}{dt} \right)^l + \in_l (\tau_1 : \nabla \underline{W}_l)^l \end{aligned} \quad (2.16)$$

where $\tau_1 : \nabla \underline{W}_l = \tau_{li} \frac{\partial W_{li}}{\partial X_i}$; $\left(\frac{d\mathfrak{R}_l}{dt} \right)^l = \frac{1}{V} \int_{\Delta V_1} (P_l \nabla \cdot \underline{W}_l) dV$.

The summation is taken over nonrepeatable index $i = \overline{1, 3}$. Substitution (2.16) in (1.15) reduces it to the form

$$\begin{aligned} \frac{\partial}{\partial t} \in_l \rho_l^l h_l^l + \nabla \cdot \in_l \rho_l^l h_l^l \underline{W}_l^l + \nabla \cdot (\in_l \tilde{\rho}_l h_i \tilde{W}_l) + \nabla \cdot \in_l \sum_k (h_i^k j_i^k)^l + \\ + \nabla \cdot \in_l q_l^l + \in_l \left(\frac{d\mathfrak{R}_l}{dt} \right)^l - \in_l (\tau_1 : \nabla \underline{W}_l)^l + \sum_m a_{lm} Q_{lm}^{lm} = 0. \end{aligned} \quad (2.17)$$

The first two terms in the equation (2.17) characterize enthalpy of volume of phase for time unit. The third member reflects heat transport in consequence of pulsation of speed. The fourth and fifth member reflects heat transport in consequence of pulsation of speed. The fourth and fifth members characterize energy inflow due to molecular diffusion and heat conductivity, respectively. The sixth and seventh members characterize energy inflow in consequence of works of pressing force and viscosity. Finally, the last member in (2.17) describes transition of energy through interfacial area. Analogously to (2.4) and (2.5) we denote

$$\left(\tilde{\rho}_l h_i \tilde{W}_l \right) + \sum_k \left(h_i^k j_i^k k \right)^l + \underline{q}_l^l = \underline{J}_{ql} \quad (2.18)$$

and represent

$$\underline{J}_{ql} = \Lambda_{lT} \cdot \nabla T_l^l + \Lambda_{lW} \cdot \underline{W}_l^l + \sum_k \Lambda_{l\omega}^k \cdot \nabla \omega_l^{kl} \quad (2.19)$$

where Λ_{lT} , $\Lambda_{l\omega}$, Λ_{lW} are tensors of effective heat conductivity.

If we take into account (2.19) in (2.17) the energy balance equation is represented in the form

$$\begin{aligned} \frac{\partial}{\partial t} \in_l \rho_l^l E_l^l + \nabla \cdot \in_l \rho_l^l E_l^l \underline{W}_l^l + \nabla \cdot \in_l \underline{J}q + \in_l \left(\frac{d\mathfrak{R}_l}{dt} \right)^l - \\ - \in_l (\tau_1 : \nabla \underline{W}_l)^l + \sum_m Q_{lm}^{lm} = 0. \end{aligned} \quad (2.19a)$$

We represent the boundary condition (1.16) in the form

$$a_{lm} ([Q]_l^m)^{lm} = \sigma_{lm} \frac{d}{dt} a_{lm}. \quad (2.19b)$$

The obtained system of equations and boundary conditions (2.7)-(2.10), (2.15a), (2.18), (2.19) describe macronequilibrium filtration of multicomponent fluids in porous medium. The additional addends δP_{lm}^{klm} , $\delta \mathcal{R}_{lm}^{klm}$, Q_{lm}^{klm} arising here characterize macronequilibrium and reflect effects of interfacial interaction. These functionals and unknown coefficients must be determined as a result of processing of special laboratory and field experiments [1-6].

References

- [1]. Nikolaevsky V.N., Bondarev E.A., Mirkin M.I. and others. *Movement of hydrocarbon mixture in porous medium*. M.: "Nedra", 1968, 192p. (Russian)
- [2]. Rozenberg M.D., Kundin S.A., Kurbanov A.K. and others. *Filtration of fluid and the other multicomponent mixtures in oil strata*. M.: "Nedra", 1969, 456p. (Russian)
- [3]. Sletteri J.S. *Theory of transfer of impulse, energy and mass in continuums*. M.: Energy, 1978, 448p. (Russian)
- [4]. Tsiubulsky G.P. *Equation of nonequilibrium twophase filtration*. In book: *Numerical solution of filtering problem of multiphase incompressible fluid*. Novosibirsk, 1977, pp.203-213. (Russian)
- [5]. Khaaze R. *Thermodynamics of nonreversible processes*. M. Mir, 1967, 544p. (Russian)
- [6]. Nikolaevsky V.N. *Geomechanics and fluid-dynamics*. M.: "Nedra", 1996, 447p. (Russian)

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