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ANNULAR-MIST FLOWS OF STEAM-WATER GEOTHERMAL MIXTURE

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ABSTRACT

Engineering problems with annular-mist flows of steam-water geothermal mixture are considered. The flows take place in wells, pipelines and special equipments. Recommendations for solution of considered problems are presented. The features of flow in vertical and horizontal tubes are reviewed. The structural approach is used for the description of the annular-mist flow. It uses the differential method of the description of flow in the film and integral method of the description of flow in the core.

INTRODUCTION

The using of the geothermal fluids is a perspective direction in power engineering and in the geotechnological industry. This fact is confirmed by steady increase of the established power of geothermal power stations (Huttrer G.W., 2000) and by increase of an amount of the consumption of thermal waters in direct using (Lund J.W. and Freestin D.H., 2000). It is known that the cost of chemical elements and combinations dissolved in the fluids are surpasses cost heat-power of the fluid. The genesis of many fields of useful minerals is tied with hydrothermal activity. Therefore geothermal fluids should was considered as direct raw material for geotechnological industry

Hight-temperature fields are more interesting as from point of view of heat- power and as raw material with valuable chemical composition. The geothermal fields with overheated steam (as heat-carrier) were well studied, as a rule. Therefore steam-hydrothermal fields where heat-carrier represented mixture of steam and water are having a good perspective. The experience of development steam-hydrothermal fields indicates a broad spectrum of problems of dynamics of a steam-water mixture. The decision of these problems has of principle meaning for successful studying. These problems are related to geothermal equipment (well, means for measuring of parameters of the mixture, pipelines for transport of the mixture).

The success of the description of the flow in the well depends on successful description of the annular-mist regime. Annular-mist regime is necessary for elements of ground equipment for avoidance of pressure pulsations.

Take in to consideration the importance of this regime for development of geothermal fields this work is devoted to research of annular-mist flow of a steam-water mixture in horizontal and vertical pipes. In this work are given the practical recommendations at the calculation of parameters of the annular-mist flow in development of fields.

FLOW IN A HORIZONTAL TUBE

The structure of the annular-mist flow is stable enough. Therefore structural approach is used for description of this regime. Separate analysis of dynamics of a film and a core is the main of structure approach. Velocity and tangential stress on the border between a film and a core are equals. However at construction of closed mathematical simulator arose the difficulties. The formed influence of effect of local criticality can do profit.

The systems of the transport of the steam water mixture are characterized by high velocity of flow and by low pressures (usually no more than 10 bars). The velocity of the steam is recommended to support above than 30 m\s for decrease a level of pulsation. But critical velocity of a flow of the saturated water does not surpass 10 m\s (for the indicated pressure) (Chermoshentseva A.A., 1998). Therefore velocity of a steam-phase predominating in the core surpasses the critical velocity of the flow of saturated water. The velocity of the water on the film-core border is not attains meanings exceeding critical velocity of the flow of saturated water. Factors hindering the phase-change are absent. Attempts of increase of the velocity will lead to originating local expanding flows and actual runaway of the water in the core. The low velocities of the water in the film and (as a result) the low velocities of lowering of the pressure (in driving water volumes) should promote the process of the phase-change near to a line of saturation. Thus the velocities on the film-core border are receiving the equal to critical velocity of moving of the saturated water. It is condition of coupling of equations for the film and the core (Shulyupin A.N., 1996).

$$v_c = \left(\frac{d\rho'}{dp} + \frac{(\rho' - \rho'')\rho'}{\rho'' r} \left(\frac{di'}{dp} - \frac{1}{\rho'} \right) \right)^{-0.5} , \qquad (1)$$

where v_c – critical velocity of motion of saturated water; ρ' and ρ'' – density of water and steam; i' – specific enthalpy of water; r – specific heat of phase-change.

The mathematical simulator uses the differential method of the description of flow in the film and integral method of the description of flow in the core. The film is having the small depth, the low velocity of motion and the absence of projections of forces of gravitation on a direction of motion. Therefore the forces of the friction were determining the motion of a film. Thus the analysis of dynamics of a film was based on equation for tangential stress inside a film.

$$\tau = \mu' \frac{\partial v}{\partial y} + \tau_{tang} , \qquad (2)$$

where τ – tangential stress in a film, μ' – factor of dynamic viscosity of water, y – coordinate on a normal to the wall, τ_{tang} – turbulent component of tangential stress.

The tangential stress on film-core border is determined as the sum of flows of impulse passed from the core to single of surface of the film what is explained by diffusion of molecules of the steam τ_s and diffusion of drips of the water τ_d.

$$\tau_b = \tau_s + \tau_d . \qquad (3)$$

The homogeneous model was used for the core of the flow. The change of mass rate in the core takes place at the expense of the film. It was used as an equation of continuity

$$dG_c = -dG_f \qquad (4)$$

where G_c - mass flow the core, G'_f - mass flow of water in the film.

The equation of motion of the core has condition

$$\rho_c v_c \frac{dv_c}{dz} + \frac{2\tau_b}{R_c} + \frac{v_c - v_b}{\pi R_c^2} \cdot \frac{dG_c}{dz} = -\frac{dp}{dz} , \qquad (5)$$

where ρ_c – density of the mixture in the core; v_c – velocity of the core; R_c radius of the core; v_b – velocity on the film-core border by the formula (1); G_c – mass flow of the mixture in the core.

The change of an enthalpy of the mixture takes place at the expense of change of the kinetic energy. As an equation of energy was used

$$\frac{1}{2} d\left(\frac{G_c}{G} v_c^{\,2} \right) = -di , \qquad (6)$$

where G – mass flow of the mixture in a tube; i –- specific enthalpy of the mixture.

FLOW IN A VERTICAL TUBE

The simulation of annular-mist flow in horizontal tubes and in vertical tubes is analogous. To use is structural approach (separate analysis of dynamics of the film and of the core). The velocity on the film-core border is equal to critical velocity of motion of saturated water. But the count of forces of the gravitation is principled difference from horizontal channels. It is the necessity for low velocity. It stipulates the mechanism of “flooding” of the film resulting in to change mode of flow.

The typical conditions of realization of the annular-mist regime of the flow in steam-water geothermal wells are: the vertical tube of large diameter (casings with a inside diameter more than 0.1 м) that allows to neglect of the forces surface tension on macroscopic (in sizes of the channel) between-phase border; the low pressure (< 20 bars); considerable length of casings (up to 2 km and more) that allows to neglect influencing of conditions of a going into a channel on the flow parameters; a broad range mass quality of steam (from 0.1 up to 1.0).

The friction force on the film-core border, the friction force on the wall of a tube and the gravitation force have meaning for description of the dynamics of the fluid film. Other forces make the essential influencing on dynamics of mixture on the whole, but for the film have a higher order of smallness. For example, it is force of the pressure. For annular-mist flow the gradient of the pressure (about 1000Pa/m (Tachimori M., 1982) has the maiden order of smallness in relation to gravitation force of the film. The gravitation force is much less than friction force on the film-core border (as the film goes to top, except “flooding”).

The equation of motion of the core accounts the slip of the phases. It is key equation of this simulator.

$$\rho''\varphi_c v''\frac{dv''}{dz}+\rho'(1-\varphi_c)v_d\frac{dv_d}{dz}+\frac{2\tau_b}{R_c}+\frac{v''-v_d}{\pi R_c^2}\cdot\frac{dG''}{dz}+\frac{v_к-v_г}{\pi R_c^2}\cdot\frac{dG_c}{dz}=-\frac{dp}{dz}, \tag{7}$$

where φ_c – void fraction in the core; v" – velocity of the steam; v_d – velocity of the water (drips) in the core; G" – mass rate of the steam.

Accounting the influencing of the gravitation and difference of velocity of the phases is received the equation of the energy (by analogy with (6))

$$gdz+\frac{1}{2}d\left(\frac{G'_c}{G}v_d{}^2+\frac{G''}{G}v''^2\right)=-di\ . \tag{8}$$

The slip of the phases in the core is accounted by the introducing of relative velocity of motion of the drips in the steam flow. The evaluation calculations have shown if the flow over of the drip is turbulent, then the slip has the essential role. Therefore for calculation of relative velocity of motion of the drip the formula of turbulent flow over is recommended by (Grigoriev V.A., Zorin V.M., 1988),.

$$v_{slip}=2.5\sqrt{ag(\rho'-\rho'')/\rho''}\ , \tag{9}$$

where v_{slip} – the slip of phases in the core, and a – radius of the drips (calculated)

DISCUSSION

The numerical researches of the simulator of the flow in the horizontal channel is showed (in the conditions of the transport of the steam-water geothermal heat-carrier):

- the rate in the film is smaller than the rate of the water in the core;
- the pressure is determined by friction on the film-core border;
- the friction coefficient is about 0.02;
- the changes of the enthalpy of the mixture are small.

These conditions allows to account the flow homogeneous, to use the formulas of the single-phase fluid flow with account motions of the friction surface with velocity v_b. The acceleration has small influence on change of the pressure. The density of the mixture is also small. Therefore for hydraulic calculation of the transport systems of the geothermal steam-water mixture the formula is recommended

$$-\frac{dp}{dz}=\frac{0.02\rho_m(v_m-v_b)^2}{4R}\ , \tag{10}$$

where ρ_m and v_m – density and velocity of the mixtures (homogeneous model).

The simulator of the annular-mist flow can be used for research of the high-velocity flows (for the elucidation of the conformities of the critical expiration regime used for measurement of the parameters in the geothermal mixture). The annular-mist flow is preceding to critical expiration regime. The adequate simulator of the “usual” flow at maximum velocity should describe the critical flow. If the flows are high-velocity, then should be accounted the force of the inertias, force of the pressure and force of the friction. The forces of the gravitation may to neglect. Therefore for researches is used more simple model of the flow in a horizontal channel.

The deviation from thermodynamic balance of the phases has important part in the high-velocity flows. This fact is ascertained by the numeral researches of the simulator in the horizontal channel with high velocity (when module of the pressure gradient aims at perpetuity (critical flow)). In particular the overheating of the water relatively the pressure of the saturation in the carried phase is caused by the surface tensions influencing increasing the pressure in the drips and suppresses the phase-change. The comparison to calculation the experimental data indicates on the necessity of availability of overheating of the steam. It is caused by the heat-exchange with drips of the water. At first view this thesis seem improbable (usually the heat-rejection demands more time). In our case the hydrodynamics determine intensive change of thermodynamic parameters. But the estimation area of the drips surface (contact with 1 kg of the steam) convince of a converse. For example, for the drips with radius 10^{-5} m and mass friction 0.2 – 0.6 the area is estimated by the order 10^3 $м^2$ on 1 kg of the steam. Therefore the overheating of the steam is possible but it calculation demands the additional researches of the process of the heat-change between drips and steam.

Thus at simulation of the critical expiration of the steam-water mixture the agreement with the experimental data is possible only at count the overheating of the liquid and of the steam. The parameters of the expiration will depend on conditions of the inter-phase heat-change (upstream from exit section). The parameters of the expiration for lengthy tubes, nozzles and diaphragms differ. It connects with features of the inter-phase heat-change and different values of the overheating of the phases. The simulator of the annular-mist flow in a vertical tube was elaborated for application in general model of the steam-water flow in well. The change of the simulator of the annular-mist flow on the single formulas is purposeless (in any case the simulator of the well uses the computer for calculation). The simulator of the annular-mist flow in a vertical tube is founded on introduced principles can be used without simplifications in the general simulator of the well. In the simulator of the well the regime of the flow is important to ascertain (not only calculation of parameters of the flow regime). The elaborated simulator allows theoretically to determine the condition of the existence of the annular-mist flow (considering that it is possible if reflexive flows in the film ("flooding") is absent.

CONCLUSIONS

The using of the formula (1) for calculation of the velocity on the film-core border gives good chances for description of the structural approach for annular-mist flow.

The hydraulic calculation of systems of the transport of the geothermal steam-water mixture can be executed by the formula (10).

The critical steam-water flow characterizes by availability the overheating of the water and of the steam.

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