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SOME ASPECTS OF STEAM-WATER FLOW SIMULATION IN GEOTHERMAL WELLS

Alexander N. Shulyupin

Physics Department of PKVMU
Kluchevskaya Str., 35
Petropavlovsk-Kamchatsky, Russia, 683003

ABSTRACT

Actual aspects of steam-water simulation in geothermal wells are considered: necessary quality of a simulator, flow regimes, mass conservation equation, momentum conservation equation, energy conservation equation and condition equations. Shortcomings of traditional hydraulic approach are noted. Main questions of simulator development by the hydraulic approach are considered. New possibilities of a simulation with the structure approach employment are noted.

INTRODUCTION

A steam-water flow simulation has two main practical problems: determination of bottomhole parameters by wellhead measurements and determination of wellhead parameters when bottomhole parameters are known by a geothermal reservoir simulation. Solution of the first problem is useful for exploration of the geothermal reservoir when the bottomhole measurements are difficult. Solution of the second problem is a part of general problem of technological prediction for geothermal reservoir exploitation.

Considering the practical importance of the steam-water well flow simulation the interest to this question remains valid. Constantly new paper about simulation appears in press. However some crisis exists in this question in present. Existent simulators are based on hydraulic approach. This approach considers the balance equations for elementary pipe length. Simulators employ the average parameters in pipe cross-section. The average parameters' determinations are executed with the empirical correlations (equations) use. In result the simulator adequacy is determined by adequacy of conditions for experimental investigations.

Complex experimental investigation in productive well is very difficult. In better case the some total parameters are measured, for example, the total pressure loss (even such measurements are rare), but accuracy of the correlation for separate terms of total pressure loss is doubtful.

The present paper considers main aspects of hydraulic approach of steam-water well simulation. Also principles of structure approach are considered. Employment of structure approach may decrease number of empirical correlations in simulator.

NECESSARY QUALITY OF A SIMULATOR

Two factors determine the necessary quality of a simulator. First factor is the error of the determination of initial date for calculation. Second factor is the permissible error of calculated parameters. We have maximum precision of initial data if a simulation is used for determination of bottomhole parameters. Also we have the intention to obtain the bottomhole parameters with maximum precession. Therefore in this case the requirements for simulator quality are maximum.

Quality of a simulator is less important if a simulation is used for determination of wellhead parameters. This is connected with essential errors of initial data determination. Simple methods (James,1970, Nathenson,1974) may employ in order to calculate wellhead parameters.

Moreover the using of simulator WELL (Shulyupin,1991) discovers the different stability for different problems. For example variations 0.1 bar of wellhead pressure result in the variations of bottomhole pressure about 1.0 bar, but variations 0.1 bar of bottomhole pressure result in the variations of wellhead pressure about 0.01 bar.

FLOW REGIMES

Mixture parameters have a wide range of values along well length. Change of flow conditions requires to employ the different empirical correlations. As a rule, changes of used empirical correlations are connected with changes of steam-water flow regimes. Gould (1974) and Tachimori (1982) considered three flow regimes and Palacio (1990) considered four flow regimes.

Experimental investigations of flow regimes' changes are related to slim pipes. Existence of similar flow regimes is the controversial question for pipes with large diameters (such as geothermal wells). Increase of number of flow regimes is connected with increase of number of empirical correlations and it increases the probability for employment of unsuitable empirical correlations.

Bubble and slug flow regimes are characterized by small steam fraction. Simple calculations show that steam phase dominates in mixture volume above of ten metres from water flash point. It follows that well part with these regimes is small (Tolivia,1972). Therefore bubble and slug regimes may consider as one regime with small steam fraction.

Annular-mist and transition (when flow velocity is small for stable existence of water film) regimes are important for steam-water wells. The simulator must take into consideration the existence of these regimes.

MASS CONSERVATION EQUATION

Excepting some specific cases (Miller Constance,1981) the mass conservation is described as follows

$$Q_m = (1 - x)Q_l + xQ_g \qquad (1)$$

where Q_m- mass flow-rate, Q_g and Q_l - gas and liquid flow-rates, x - mass discharge gas fraction.

MOMENTUM CONSERVATION EQUATION

Total pressure gradient is the sum of three terms: gravitational gradient, friction gradient and acceleration gradient

$$\frac{dP}{dz} = \left(\frac{dP}{dz}\right)_g + \left(\frac{dP}{dz}\right)_f + \left(\frac{dP}{dz}\right)_a \qquad (2)$$

The gravitational term in Eq. 2 is given as follows

$$\left(\frac{dP}{dz}\right)_g = \pm\left[\rho_l(1-\varphi) + \rho_g\varphi\right]g \qquad (3)$$

where ρ_g and ρ_l - gas and liquid densities, φ- volume gas fraction, g - gravitational acceleration.

Volume gas fraction is determined by empirical correlations for every flow regime. Friction pressure loss is important in total pressure loss only for annular-mist flow. Therefore one empirical correlation for pressure gradient may employ for all flow regimes. This correlation must correspond to annular-mist flow.

Thachimori (1982) noted the importance of the acceleration term. This is true in principal. However, there is difficulty of acceleration term definition in hydraulic approach. In order to define the acceleration term we must know the real distributions of phase velocities in pipe cross-section. Hydraulic approach must not define the parameter distribution in cross-section. This approach uses the empirical correlations for definitions of terms in Eq. 2.

Experimental data about values of separate terms in Eq. 2 for steam-water well conditions are absent. Probably the experimental data about values of acceleration term are absent in general (for any conditions). Therefore the definition of acceleration term is very difficult problem.

Friction and acceleration terms are proportional to flow-rate in second power. Usually the acceleration term is neglected when the suitable correlation for friction term is determined by experimental values of total pressure gradient. Therefore the chosen correlation takes into consideration the acceleration too. In this case the acceleration term may by absent in simulator's momentum conservation equation.

ENERGY CONSERVATION EQUATION

Some simulators neglect the change of flow enthalpy. In general case the enthalpy flow change is determined by energy conservation equation

$$di_m = dq - de_c - de_p \qquad (4)$$

where i_m- specific enthalpy of mixture, q - heat flux in rock, e_c and e_p -specific kinetic energy and specific potential energy.

Calculation of the potential energy change does not have difficulties. Calculation of the kinetic energy change has methodical difficulty. However, this term has small influence on the total results of simulator calculations. Therefore a rough calculation of kinetic energy change is satisfactory in practice.

Palacio (1990) noted the importance of the heat flux in rock. In present there are a lot of recommendations for calculation of the heat flux term in energy equation. The bond of enthalpy loss, mass flow rate and time is shown in Figure 1. Calculations are produced by simulator WELL (Shulyupin,1991) for well with depth 1500 m and bottomhole temperature 200° C. Simple equation for heat flux is used in this simulator

$$dq = \frac{\Delta T 2\pi\lambda dz}{Q_m \, ln\left(1-\sqrt{\frac{\pi a \tau}{R^2}}\right)} \qquad (5)$$

where ΔT - difference of initial and flowing temperatures, λ- coefficient of heat conductivity, a-coefficient of temperature conductivity, R -well radius, τ- time of well operation.

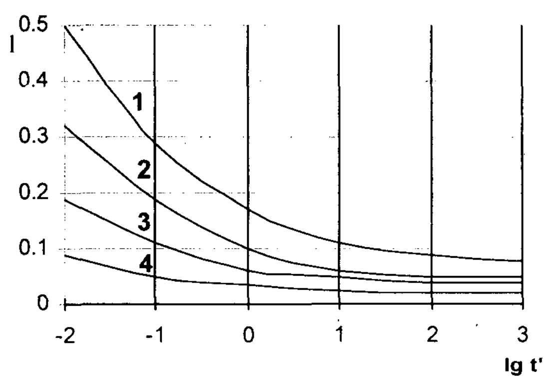

Figure 1. Enthalpy losses from bottomhole to wellhead. $I = (i_b - i_w)/i_b$, i_b - bottomhole enthalpy, i_w - wellhead enthalpy, t' - time of wellhead operation in day (τ_d= 3600*24*τ). Mass flow rates: 1 - 5 kg/s, 2 - 10 kg/s, 3 - 20 kg/s, 4 - 50 kg/s.

CONDITION EQUATIONS

Usually the assumption about thermodynamic equilibrium of phases is used. Special investigations with employment of a various condition equations (Zabarny and Shulyupin,1988, Shulyupin,1988) showed that possible deflection from thermodynamic equilibrium had small influence on the total results of simulator calculations.

One factor exists which may have essential influence on simulator results. This is the existence of gas (CO_2,H_2S etc.) in mixture (Barelli et al.,1994, Upton,1995, Antics,1995). Consideration of this factor requires the information about concrete mixture composition.

STRUCTURE APPROACH OF STEAM-WATER FLOW SIMULATION

New possibilities of steam-water flow simulation are connected with employment of the structure approach. Conservation equations are considered for concrete flow structure (flow regime) in this approach. For example, momentum conservation is described by two equations for annular-mist flow (for liquid film and mist central flow).

Wide employment absence of structure approach in present is connected with insufficient knowledge of physical mechanism of flow structure forming. Progress of structure approach employment is connected with progress of steam-water flow theory. Absence of satisfactory theory demands the employment of empirical correlations. Thus result of structure approach employment is the same as for hydraulic approach.

Development of critical flow theory may develop the steam-water flow theory. Critical flow condition is determined as follows

$$\upsilon^2 = \frac{dP}{d\rho} \qquad (6)$$

where ρ - density, υ - velocity.

Density and velocity for steam-water mixture are defined as follows

$$\rho_m = \rho_l(1-\varphi) + \rho_g\varphi \qquad (7)$$

$$\upsilon_m = \upsilon_l(1-x) + \upsilon_g x \qquad (8)$$

where υ_l and υ_g -water and steam velocities.

Critical flow condition in steam-water flow is realized in local part of cross-section. For example, critical velocity of boiling water is determined by formula (Shulyupin,1994)

$$v_c = \left[\frac{d\rho_l}{dP} + \frac{(\rho_l - \rho_g)}{(i_g - i_l)} \frac{\rho_l}{\rho_g} \left(\frac{di_l}{dP} - \frac{1}{\rho_l} \right) \right]^{-0.5} \quad (9)$$

where i_l and i_g - specific enthalpies of water and steam.

Results of calculations by formula (9) are shown in Figure 2. Existence of local critical flows has influence on flow structure. Such as the water velocity in boundary film-mist (annular-mist flow) must not exceed the value calculated by formula (9). Employment of this formula for velocity in pointed boundary decreases number of empirical correlations in simulator.

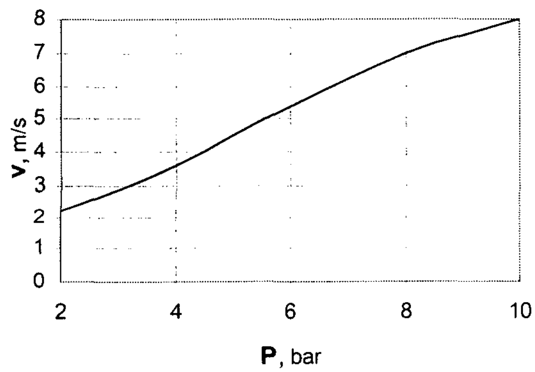

Figure 2. Critical velocity of boiling water.

CONCLUSION

Elaboration of steam-water flow simulator in geothermal wells must take into consideration the possibilities of used approach and the deficit of experimental data in corresponding conditions. Increase of empirical correlations number increases the possibility for employment of unsuitable correlations.

Employment of structure approach discovers new possibilities of steam-water flow simulation. Theoretical basis of this approach is the effect of local critical flows.

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