PROCEEDINGS, 44th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 11-13, 2019
SGP-TR-214

Calculation of Characteristics of a Feeding Aquifer of a Steam-Water Well by Wellhead Measurements

Alexander Shulyupin[1] and Alla Chermoshentseva[2]

[1]Institute of Mining, Far Eastern Branch, Russian Academy of Sciences, Khabarovsk, Russia

ans714@mail.ru

[2]Kamchatka State Technical University, Petropavlovsk-Kamchatsky, Russia

allachermoshentseva@mail.ru

Keywords: Steam-water mixture flow, geothermal wells, mathematical models, wellhead measurements

ABSTRACT

Actual problems and prospects of practical development of geothermal fields are noted in the present work. The problems of substantiating the reality of the dependence of the results of testing wells on the conditions of flow down the stream from the wellhead. The substantiations are given by the complex of author's mathematical models of steam-water mixture flow in geothermal wells (WELL-4).

1. INTRODUCTION

Currently, the involvement of geothermal resources in the global energy sector is growing steadily. Intensively developing geothermal energy requires improving the efficiency of the use of available resources and equipment [Bertani R. (2015), Armenta M.F., Montes M.R. and Alcala L.M. (2015), Gudmundsdottir H. and Jonsson M.T. (2015), Fathaddin M.T., Jibriela H.A. and Azmi I.M. (2015)]. The prospects for the development of geothermal fields for electricity generation are obvious.

Now in Russia, five geo-power Stations with a total installed capacity of 81.2 MW are operated, three of which are located in Kamchatka (74 MW).

Unsolved problems constrain the development of geothermal fields and the advancement of this area as a whole. Most of these problems are related to the system of extraction and transportation of heat-carrier.

Prospects for the practical development of geothermal deposits are associated with deposits, the heat-carrier of which is a mixture of water and steam. Of particular importance is the need to develop reliable methods for calculating steam-water flows [Dobrohotov V.I. and Povarov O.A. (2003), Chermoshentseva A.A. and Shulyupin A.N. (2011)].

These measurements of flow parameters of steam-water wells are used to calculate the reserves of the field, its development and ground equipment are designed. The problems relate lies in the need to measure two independent parameters characterizing the steam-water mixture. Traditional single-phase hydraulic methods are not acceptable, a combination of methods or special approaches is required.

The calculation of the flow of steam-water mixture in the development of geothermal fields is important points. In the production wells necessary to determine the parameters in the reservoir by wellhead parameters for the calculation of reserves and reverse calculation for the design of field development.

The complexity of the processes of dynamics of the steam-water mixture, which are interrelated with thermodynamic processes, often does not allow obtaining simple solutions to the problems. Mathematical modeling of these processes helps significantly [Shulyupin A.N. and Chernev I.I. (2012)].

The development of modern science is impossible without mathematical modeling and computational experiment, which in some cases can reduce the number of field experiments or completely replace them. A qualitative mathematical model is usually more accessible and convenient for research than a real object. The model allows learning how to manage the object by testing different options. Mathematical modeling of steam-water flows is widely used in the development of geothermal fields for the calculation of flows in wells.

2. METHOD OF CALCULATION

An important issue that determines the possibility of stable operation of wells is to obtain the practical characteristics of the feed aquifer, which is a dependence of the flow rate of the produced heat-carrier from the bottom-hole pressure. It is difficult to obtain such characteristics for steam-water geothermal wells. In contrast to typical water wells, the measured pressure at the wellhead does not have a single-valued relationship with the bottom-hole pressure. Direct measurement at the bottom-hole is a complex technical problem, often causing questions of methodological correction.

The accuracy of the bottom-hole pressure calculation from the measurements at the wellhead is affected by the error in the calculation method used and the error in determining the initial data. It is very difficult, and probably impossible, to fully assess the errors of such a definition. It was noted in [Shulyupin A.N. (1991)] that for wells with a single-phase fluid, in determining the total error of the calculation, the most important role is played by the error in measuring the enthalpy at the mouth, which is used as the initial value. We will evaluate the effect of this error on the results of determining the pressure on the bottom-hole.

The separation method described in [Mubarok M.H., Cahyono Y.D., Patangke S. and Siahaan E.E. (2015), Wormald C.N. (1984)] is the most accurate method for measuring the flow and enthalpy of a steam-water mixture. For its realization, there is a wide range of separators. Based on the experience of work at the Kamchatskenergo stand [Shulyupin A.N. (2004)], taking into account the metrological examination of the stand, while observing the maximum requirements for the accuracy of measurements of individual species, the maximum error for measuring the enthalpy by the separation method is 3%.

Consider an average well, from currently operating, the Pauzhetsky field. For the accepted enthalpy of 800 kJ / kg, the pressure at the level of the beginning of steam-formation of water calculated for thermodynamic properties on the saturation line [Rivkin S.L. and Alexandrov A.A. (1980)] is 12.1 bar, and the density of water (for single-phase flow) is 878 kg/m^3. Taking into account the error of 3%, the spread in the determination of enthalpy is 776 824 kJ/kg (i.e. ± 24 kJ/kg). The pressure at the level of the beginning of steam-formation gives values of 10.7-13.6 bar, the water filter value is 884-873 kg/m^3.

The bottom-hole pressure deviation is the sum of the pressures at the level of the beginning of steam-formation and the hydrostatic pressure of water in the single-phase flow:

$$\delta p_b = \delta p_0 + (\rho + \delta\rho) g \delta L + \delta\rho g L \tag{1}$$

where δp_b – deviation from actual bottom-hole pressure, δp_0 – deviation from the actual value of the pressure at the level of the beginning of steam-formation, ρ – actual density of water, δρ – deviation from the actual value of the water density, g – acceleration of gravity (module), L – the length of the single-phase flow (the height of the column of water above the strata), δL – deviation from the actual value L.

In formula (1) the last term on the right-hand side is neglected, which is justified for small sections of single-phase flow. At the maximum enthalpy deviation in the lower side δp_0 = - 140 kPa, δρ = 6 kg/m^3, δL = 56 m, and for the pressure deviation on the bottom-hole 3.5 bar. Similarly, for the enthalpy deviation in the greater direction δp_0 = 150 kPa, δρ = - 5 kg/m^3, δL = - 58 m, pressure - 3.5 bar. That is, the range of the bottom-hole pressure variation calculated by the corresponding variation of enthalpy within the measurement error gives 7.0 bar. In addition, in case of the last member of the right part (1) this value will increase.

Stationary inflow into a well with a single-phase fluid is described by the Dupui formula [Klimentov P.P. and Kononov V.M. (1973)]:

$$G = \frac{2\pi k m \Delta p}{g \ln(R_д / R)} \tag{2}$$

where km – water-conductivity of the strata, Δp – reduction bottom-hole pressure, $R_д$ – The radius of the depression funnel (the radius of influence of release from the well).

The water-conductivity of the strata is:

$$km = \frac{G \cdot g \cdot \ln(R_д / R)}{2\pi \cdot \Delta p}\,. \tag{3}$$

For production wells of the Pauzhetsky field, take the following typical values R = 0.095 m, $R_д$ = 1000 m and mass flow rate (maximum) G = 50 kg/s. The pressure decrease will be considered equal to its variation, calculated taking into account the error in determining the enthalpy. Calculating from (3), we get the limiting value of water-conductivity $1.04 \cdot 10^{-3}$ м^2/с (90 м^2/day). In this case, the change in bottom-hole pressure during the release process will correspond to the error of its determination. With a higher water conductivity, the decrease in bottom-hole pressure during discharge will be less than the error in its determination caused by the error in measuring the enthalpy. For Pauzhetsky geothermal field the feeding aquifer has a water-conductivity 190-450 m^2/day. [Asaulova N.P., Vorozheykina L.A., Manuhin Yu.F. and Obora N.V. (2009)]. For wells of this field with a single-phase feed fluid should not be calculated aquifer characteristics according to measurements at the wellhead.

The work [Droznin V.A. (1980)] contains characteristics of wells drilled at the stage of field exploration. By their parameters, including the enthalpy of the heat-carrier, they are significantly inferior to the wells currently in operation. Variations of the pressure on the bottom-hole is dependent on base values of the enthalpy. For enthalpy 600 kJ/kg calculated by the pressure at the level of the beginning of steam-formation is 3.9 bar, the water density is 923 kg/m^3. When the enthalpy changes within 3% of the initial value, its variation is 582-618 kJ/kg, the pressure at the level of the beginning of steam-formation gives a spread of 3.45-4.35 bar, and the water density is 927-920 kg/m^3.

The average pressure gradient in the steam-water section for wells with the accepted enthalpy [Bjornsson G. (1987)] is 3800 Pa/m, the maximum pressure deviation gives a change in the length of the steam-water flow section by 24 m (a decrease of 12 m with a decrease in pressure and 12 m increase with an increase in pressure).

The formula (1) gives 0.6 bar in lower and higher sides. Accordingly, the range of pressure changes at the bottom-hole is 1.2 bar. The limit estimation of the value of water-conductivity according to the formula (3), with other identical values, gives $6.05 \cdot 10^{-3}$ m^2/s (523 м^2/day). This covers the range of actual values at the field. That is, for wells with low enthalpy, the use of this method is justified.

It is expected that with the increase in the values of the well enthalpy, the possibility of calculating the aquifer characteristics will decrease. Thus, for the wells of the Mutnovsky field appropriating to the enthalpy value of 1100 kJ/kg, calculated by pressure at the level of the beginning of steam-formation is 41.8 bar, the water density is 795 kg/m^3. Changes within 3% give the enthalpy spread 1067-1133 kJ/kg. In this case, the change in the pressure values at the level of the beginning of steam-formation is 37.2-46.6 bar, and the density of water is 805-785 kg/m^3.

Similarly, with an average pressure gradient at the steam-water section of 2500 Pa / m, the pressure deflection to the lower side will result in a reduction in the length of the steam-water flow section by 184 m, and in the higher side it will increase by 192 m.

Formula (1) with a variation of the enthalpy to the lower side gives a pressure of 9.9 bar, in a higher - 10.0 bar. Then, the pressure variation at the bottom-hole is 19.9 bar. With other equal values, a similar estimate of the limiting value of water-conductivity calculated by formula (3) gives a value of $3.65 \cdot 10^{-4}$ m^2/s (32 m^2/day).

The feeding aquifer of Mutnovsky and Pauzhetsky fields are similar in their structure and have similar values of water-conductivity. The calculated value is an order of magnitude less than real. Then, for Mutnovsky field wells, fed with a single-phase heat-carrier, the calculated determination of the aquifer characteristics according to wellhead measurements is unacceptable.

Wells that feed on two-phase fluid there are on Mutnovsky and Pauzhetsky fields. This is confirmed by calculations and field experiments [Bjornsson G. (1987), Shulyupin. A.N. and Chermoshentseva A.A. (2015)]. The dependence of flow and pressure at the upper and lower boundary of the well feeding area may differ significantly. The concept of aquifer characteristics for wells with a two-phase fluid is specified. The well feeding area may consist of sections of two-phase and single-phase flow, or be purely two-phase. Consider the simplest option: take the main, for the characteristics of the aquifer, the pressure at the upper boundary of the well feeding area, which in the calculation of the well will be as bottom-hole pressure. Then, as a characteristic of the aquifer will be the dependence of the pressure at the specified boundary of the flow rate.

Obtaining experimental data to determine the aquifer characteristics for such wells is a very difficult task. The real possibility to estimate the error of the calculation of the pressure on the bottom-hole is to analyze the calculation method. The technique used to develop a mathematical model, which is implemented in the computer program WELL-4 [Shulyupin. A.N. and Chermoshentseva A.A. (2015), (2017), Chermoshentseva A.A. and Shulyupin. A.N. (2018)] will consider.

In [Bjornsson G. (1987)] it is indicated that the average error in the calculations for determining the mean pressure gradient at the steam-water section is 8%. The maximum error in the estimated determination of the mean pressure gradient in the steam-water section will be considered to be twice as large, i.e. 16%. Then, the deviation of the calculated values from the bottom-hole to the wellhead will be 32% of the differential pressure. If, as result of the calculated determination of the bottom-hole pressure for various wellhead flow parameters obtained as result of well testing, the range of its change will not significantly exceed the specified value, then the calculated determination of the aquifer characteristics will be impossible [Shulyupin A.N., Chermoshentseva A.A. and Konstantinov A.V. (2016)].

The calculation of bottom-hole pressure data for exploitation well testing Pauzhetsky and Mutnovsky fields showed corresponding to condition only data of the well 106 to Pauzhetka geothermal field (test 1977). To a depth of 198 m, this well has a casing with an internal diameter of 0.199 m, below (to a depth of 811 m) an open hole with a diameter of 0.19 m. The feeding zone is located at a depth of 198 to 760 m. the Wellhead parameters and the calculated bottom-hole pressure are shown in table 1.

Table 1

Well 106 of the Pauzhetsky field

Wellhead pressure, bar	Flow rate, kg/s	Mix enthalpy, KJ/kg	Bottom-hole pressure, Bar
4,9	33,8	846	8,2
5,9	30,4	846	8,9
6,4	25,0	846	9,5
6,8	13,8	846	11,6

Thus, the calculations indicate that the possibility of a calculated determination of the characteristics of aquifer of a steam-water well according to wellhead measurements is extremely limited. With an increase in the enthalpy of the carrier and the water-conductivity of the aquifer, the calculation of its characteristics becomes unacceptable. In particular, for the current operation wells of the Pauzhetsky and Mutnovsky geothermal fields, such a calculation method is unacceptable

3. CONCLUNION

In the present work, existing problems, approaches and methods used in modeling steam-water flow in geothermal wells are investigated. Particular attention is paid for calculating the flow of heat-carrier in wells at geothermal field in Kamchatka. Researches and calculations show, that the determination the calculation characteristics of the feeding aquifer of the steam-water well by wellhead parameters for the operating production wells of Pauzhetsky and Mutnovsky is unacceptable.

REFERENCES

Armenta M.F., Montes M.R. and Alcala L.M.: Wellbore modeling of production well H-1D using WellSim, Los Humeros geothermal field, Mexico, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia (2015).

Asaulova N.P., Vorozheykina L.A., Manuhin Yu.F. and Obora N.V.: Results of long-term exploitation of Pauzhetka geothermal field, *Mountain messenger of Kamchatka*, **№ 2(8)**, (2009), 47–56.

Bertani R.: Geothermal power generation in the World 2010–2014. Update report, *Proceedings*, World Geothermal Congress 2015, Melbourne, Australia (2015).

Bjornsson G.: A multy-feedzone geothermal wellbore simulator, *Report* LBL-23546. Lowrence Berkeley Laboratory, (1987).

Chermoshentseva A.A. and Shulyupin A.N.: *Mathematical modeling of steam-water flows in the elements of geothermal equipment*, (Kamchatka St. Tech. Univ., 2011), 144.

Chermoshentseva A. and Shulyupin A.: The collection of mathematical models of Well-4 for the calculation of flows in steam-water geothermal wells, *E3S Web of Conferences*, **56**, (2018).

Dobrohotov V.I. and Povarov O.A.: Use of geothermal resources in the Russian energy, *Thermal power engineering*, **№ 1**, (2003), 2-11.

Droznin V.A.: *A physical model of the volcanic process*, (Science, 1980).

Fathaddin M.T., Jibriela H.A. and Azmi I.M. Geothermal two phase flow correlation in vertical hihes using dimensional analyses, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia (2015).

Gudmundsdottir H. and Jonsson M.T. The wellbore simulator FloWell – model enhancement and verification, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia (2015).

Klimentov P.P. and Kononov V.M.: *Groundwater dynamics*, (Higher school, 1973).

Mubarok M.H., Cahyono Y.D., Patangke S. and Siahaan E.E.: The geothermal two-phase orifice plate, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia (2015).

Rivkin S.L. and Alexandrov A.A.: *Thermophysical properties of water and steam,* (Energy, 1980).

Shulyupin A.N.: Flows in a geothermal well: model and experiment, *Volcanology and seismology*, **№ 4**, (1991), 25-31.

Shulyupin A.N.: *Steam-water flow in geothermal fields*, (Kamchatka St. Tech. Univ., 2004).

Shulyupin A.N. and Chernev I.I.: Problems and prospects of development of geothermal resources of Kamchatka, *GEOresources*, № 1(43), (2012), 19-21.

Shulyupin. A.N. and Chermoshentseva A.A.: Steam-water flow in a geothermal well, *Thermophysics and Aeromechanics*, **T. 22, № 4**, (2015), 493–499.

Shulyupin A.N., Chermoshentseva A.A. and Konstantinov A.V.: About calculating the characteristics of the feed water-steam reservoir wells according to the measurements at the well-head, *Mining inf. and analytical Bulletin*, **№ 5**, (2016), 360-368.

Shulyupin A.N. and Chermoshentseva A.A.: The collection of mathematical models of Well-4 for the calculation of flows in steam-water geothermal wells, *Mathematical Models and Computer Simulations*, **V 9, N 1**, (2017), 127–132.

Wormald C.N.: Two phase flow measurement, *Measurement and instrum. control,* GB, (1984), 61-72.