Maximum Flow-Rate of Steam-Water Wells

Aleksandr Shulyupin¹, Alla Chermoshentseva²

¹ Far Eastern Mining Institute of RAS, Turgenev str., 51, Khabarovsk, Russia
² Kamchatka State Technical University, Kljuchevskaja str., 35, Petropavlovsk-Kamchatsky, Russia

E-mail address, ans714@mail.ru, allachermoshentseva@mail.ru

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ABSTRACT
Existence of maximum flow-rates of steam-water wells is obtained by numerical modeling. These flow-rates are close to exploitation values. The obtained phenomenon is associated with the first stage of the critical flow. The maximum flow-rates are about half the values determined by the famous James’s formula, which meets the third stage of critical flow. Existence of maximum flow-rates should be taken into account in the forecast of well productivity when exploitation conditions change.

1. INTRODUCTION
Use of geothermal heat is one of the most successful developing directions of alternative energy (Bertani, 2010). The first Russian Pauzhetskaya geothermal station (Kamchatka) effectively operates since 1966. Receipt of the heat carrier on station is provided by development of the Pauzhetskoe geothermal field. Productive wells of the Pauzhetskoe field work in steam-lift mode. These wells are bring steam-water mixture to a surface.

Requirements of increased Pauzhetskaya geothermal station are increased in last time. Need of commissioning all reserve productive wells was appeared. Working with the maximum flow rates is reduced the amount of energy over time. The complex studies of system mining and transporting heat-transfer were conducted in the summer of 2013. Measures to stabilize and increase the production were defined. Those measures are included the use of reserve exploiting with more high pressure wells 103, 120, 122 and 131. It was assumed that lower wellhead pressure will increase rate of the extracted heat.

As a result was supposed to increase the flow-rates: well 103 up to 36 kg/s, well 120 - to 19 kg/s, well 122 - to 47 kg/s and well 131 - to 54 kg/s. In this paper it is shown that these optimistic forecasts may not come true. Flow-rate limits the occurrence of critical flow regime.

2. METHODS AND RESULTS OF CALCULATIONS
Diagrams of capacity of wells 122 and 131 were taken off in 1977 and 1979, respectively. Observations of current exploitation parameters show an essential change the capacity of these wells since the tests. Diagrams of capacity of wells 103 and 120 were taken off in the summer of 2013 by with use low accuracy methods of measurement. Besides, pressure estimated (2.5 bar) was out of the range of testing all wells and extrapolation for high rate has been actively used. Therefore it is advisable to find a method of calculation diagrams of capacity.

The dependence of the flow rate of steam-water wells from the wellhead pressure is determined by the hydrodynamic processes in the wellbore and in geothermal reservoir. The using a simple calculation of the flow in the wellbore and supposing pressure as constant can get a good coincidence experiment and calculation diagrams (James, 1970). This is the dominant factor is the processes in the wellbore. Numeric values of the flow rate exemplary to real exploitation rate are important to calculation diagrams of capacity for exploitation wells. Change of parameters in the geothermal reservoir is a slight and unable to have a significant impact on the result. Therefore, the following method of calculating diagrams of capacity is proposed:

- Pressure, flow rate and the enthalpy are defined to real exploitation of the well. Than the pressure and enthalpy in reservoir are fined by using mathematical simulation.

- Assuming that pressure and enthalpy in reservoir is unchanged. Wellhead pressures are fined by using mathematical simulation for various rates. Correlation for flow rate and wellhead pressure is fined.

In this article model WELL-4 (Shulyupin and Chermoshentseva, 2013) is used to calculate the flow in the wellbore. The model WELL-4 was used to reconstruction well A-2 on the Mutnovskoe field. The theoretical estimates were confirmed in practice (Chernev and Shulyupin, 2013). Reconstruction substitute building of a new well has allowed saving 5 million dollars.

The simulation describes pure water and steam-water flow. Equations of indissoluble, of movement and energy are basis of simulation:

\[ dG = 0, \]
\[ \rho^0 \varphi^0 d\gamma + \rho^1 (1 - \varphi)^1 d\gamma + \frac{(\gamma^0 - \gamma^1)}{\alpha R^2} dG^2 = -dp \frac{2\pi}{R} dz - \rho g dz, \]
\[ dh + de + gdz = dq, \]

where \( G \) and \( G' \) – mass flow rates of the mixture and steam, respectively; \( \rho' \) and \( \rho'' \) – densities of the steam and mixture, respectively; \( \varphi \) – true volume content of the steam; \( \nu'' \) and \( \nu' \) – velocity of the steam and water, respectively; \( z \) – directional up coordinate along the axis of the pipe; \( p \) – pressure; \( R \) – radius of the well; \( \tau \) – shear stress at the wall; \( g \) – acceleration of gravity; \( h \) – specific enthalpy of the mixture; \( e \) – specific kinetic energy; \( dq \) – differential of energy from the heat flow from the walls.

Wells 103, 120, 122 and 131 on the Pauzhetskoe field are exploited many years. Necessary to calculate data: inside diameter, the depth of upper boundary of inflow zone, wellhead parameters (summer of 2013) and the pressure at to set depth are presented in table 1. Calculation parameters are presented in Figure 1.

### Table 1: The original data and the calculated depth pressure.

<table>
<thead>
<tr>
<th>Well</th>
<th>Diameter, m</th>
<th>Depth, m</th>
<th>Wellhead pressure, bar</th>
<th>Flow-rate, kg/s</th>
<th>Enthalpy, kJ/kg</th>
<th>Depth pressure, bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>0.152</td>
<td>320</td>
<td>5.5</td>
<td>28.1</td>
<td>775</td>
<td>25.3</td>
</tr>
<tr>
<td>120</td>
<td>0.199</td>
<td>249</td>
<td>4.1</td>
<td>14.0</td>
<td>812</td>
<td>6.6</td>
</tr>
<tr>
<td>122</td>
<td>0.199</td>
<td>249</td>
<td>4.1</td>
<td>41.6</td>
<td>846</td>
<td>9.8</td>
</tr>
<tr>
<td>131</td>
<td>0.199</td>
<td>295</td>
<td>5.1</td>
<td>37.8</td>
<td>804</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Figure 1: Calculated according to wellhead pressure by flow rate of Pauzhetskoe field. 1 – well 120, 2 – well 103, 3 – well 122, 4 – well 131.

Diagram on Figure 1 illustrate existence the maximum wellhead pressure also maximum rate and corresponding wellhead pressure. The maximum rate and the wellhead pressure amounted: well 103 - 32.9 kg/s, 3.1 bar; well 120 - 28.8 kg/s, 1.7 bar; well 122 - 43.2 kg/s, 2.6 bar; well 131 - 45.9 kg/s, 2.6 bar. Calculation for rate more than the maximum is impossible because the pressure gradient have break off.

Break off pressure gradient (usually the output cross section channel) is a sign of critical flow. Critical flow is characterized by the jump in pressure and prevents the passage of disturbances from the pressure down the stream. For single-phase environments the criticality condition is identified by the flow of the speed of sound. This condition don’t use for two-phase environment. The steam-water mixture flow is three stages of criticality (experimental receive). These stages of criticality are connected with fall of back-pressure (pressure in the environment around flowing jet) (Theoretical principles, 1988). In the first stage rate becomes independent of back-pressure and the flowing pressure (in outlet cross section) is equal to the back-pressure. Then, the flowing pressure begins to exceed the back-pressure, but still fall after him. The third stage characterized by the complete independence of the back-pressure settings.

The formation of surface rupture pressure gradient occurs when the component of the pressure gradient acceleration associated with the change of pressure (that is caused by the presence of the pressure gradient) becomes equal to the gradient pressure. For steam-water flow acceleration mixture depends by compressibility environments, phase transition and the sliding velocity. Account acceleration in the mathematical model led to emergence of break, which can be associated with the achievement of the conditions for the first stage of criticality. For subsequent phases, you must use a special model, which takes into account the behavior of the phases under high pressure gradients (about 10 bar/m (Shulyupin, 2011)). Perhaps the success of the simulation of subsequent stages shall allow using evolutionary models for description development ordinary flow to a critical.
The maximum flow rates slightly above specific to the current exploitation (table 1) and for wells 103, 122 and 131 are below expectations. Expectations are based on extrapolation of the experimental diagrams of capacity. The model has assumptions, approximation, errors of data, etc. Diagrams of capacity do not claim to accuracy. Experiment at the moment use exact methods of measurement. However, incorrectness of extrapolating experimental of the diagrams of capacity is obvious. They was obtained for high flow rate and much earlier projected.

The first stage of critical flow allows a substantial reduction in pressure. In addition, practically measured wellhead pressure might not match the plane of critical flow. Reduction of wellhead pressure value bellow than corresponding to the maximum flow rate is possible. However, this reduction does not lead to an increase of flow rate, its only reduce the energy value of the heat-carrier. Therefore, lower wellhead pressure below than for the maximum flow rate is inappropriate.

3. CONCLUSION

The need of the forecast of flow rate in productive wells is regularly occurs in all geothermal fields, when the wellhead pressure changes. Such a forecast, for example, extensively was used in the planning of activities for reconstruction of heat transportation system in the Mutnovskoe field. Therefore, by the results obtained, in a complex of works on monitoring geothermal mining should include periodic testing of production wells to the experimental determination of the diagrams of capacity. The maximum flow rate and its corresponding wellhead pressure is necessary determine.

REFERENCES


