Research on Multi-layer combined Mining of EGS based on Downhole Decoder Technology

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Abstract: EGS system is a single-layer heat exchanger system. Because of its output requirements, the temperature drop of the heat exchanger layer is very significant in the expected production stage. At the same time, due to the uncontrollable conditions of the storage tank, the generation of calorific value can not be accurately controlled, so the optimization of the existing EGS heat transfer research is not comprehensive. The solution to this problem is to design a three-tube and six-control EGS technology, which is based on the structure of multi-layer heat exchangers. This technology can control the stratified flow, ensure the medium production, avoid the problem of large temperature gradient in the heat exchanger layer caused by large single layer flow, and provide some reference for conventional and unconventional oil and gas co-production technology.

1. Introduction
Enhanced geothermal system (EGS) technology is the main research technology of using geothermal energy for power generation at the present stage. The principle of this technology is as follows: through the cyclic operation of "injection-extraction-heat exchange-re-injection" of the heat exchanger, the extraction and utilization of the calorific value of the target geothermal layer can be realized[1].

For the research of key technologies of EGS, many corresponding achievements have been made at home and abroad. HouZ et al of the Energy Research Center of Lower Saxony in Goslar, Germany, established a traditional double-well layout model through the multi-objective CFD code finite element framework for simulation and analysis, and gave the changing trend of the heat transfer coefficient of the working fluid under different flow rates[2-6]. It is pointed out that the greater the flow rate, the faster the heat transfer coefficient decreases. ChenY et al. carried out simulation analysis by three dimensional unified pipe-network method, and concluded that under a certain production time, the temperature decline gradient of the heat exchanger layer will increase with the increase of working fluid flow[7]. Therefore, if the total output of refrigerant production can be kept unchanged and the working fluid flow
between heat exchangers can be reduced, the calorific value recovery of EGS development can be effectively improved.

For this reason, combined with the co-production technology in conventional oil and gas under the same pressure system, it is proposed that based on the shunt working fluid of multi-heat transfer layer and using downhole decoder to control wellbore flow pressure, several low-flow heat transfer reservoir systems are constructed to form EGS co-production heat transfer development technology[8-9].

2. Downhole Decoder Technology based on EGS

The downhole decoder technology is that the hydraulic pressure is injected into the downhole decoder from the ground through the hydraulic pipeline, and after the corresponding hydraulic sliding sleeve switch is controlled, the hydraulic control sleeve displacement is used to adjust the inflow area of the working fluid into the tubing, so as to control the pressure of each heat exchange layer into the tubing, which can meet the compatibility of the pressure system in the whole tubing and avoid interference in production.

EGS geothermal wells are usually deep and the downhole space is limited, so as to avoid the phenomena of pipeline winding and blockage caused by too many pipelines, the downhole decoder technology with three lines and six layers is used to carry out EGS co-production operation. At present, the technical process of downhole decoder with three-line control and six-layer control is mostly complicated. According to the requirements of EGS co-production, this paper designs a set of relatively simple decoder operation process, and attaches the relevant hydraulic circuit. The pipeline principle is as follows:

2.1. Model assumptions

According to the above analysis, the premise that the decoder technology is suitable for EGS co-mining operation is to ensure the controllability of the downhole pressure system. In order to accurately control the change of downhole pressure parameters caused by sliding sleeve displacement, it is necessary to establish a corresponding model of the wellbore pressure system. The following assumptions have been made while establishing the pressure model of EGS multi-layer decoder co-mining system.

1. The working fluid is an incompressible single-phase fluid.
2. The circulating flow of working fluid in the reservoir follows the percolation law and Darcy's law.
3. The thermal insulation material is used in the tubing, the temperature loss of the working medium in the tubing is not considered, and the temperature has little effect on the viscosity of the working fluid.
4. The tubing opening controlled by each layer of sliding sleeve is uniform up and down.

2.2. Parameter Analysis of pressure system Model

The EGS heat exchange cycle system is pressurized by the injection well to the underground thermal reservoir, and then exploited by the production wells of six horizons. Because the supply pressure is stable, the reservoir pressure of the six layers can be regarded as a fixed value, and the relevant pressure model can be established by calculating the pressure gradient in the tubing. According to the relationship of the downhole layer, a node is established in the wellbore, and the pressure gradient in the wellbore is calculated by stages from the end of the wellhead to the bottom of the wellbore. The wellhead position, the first layer, the second layer, the third layer, the fourth layer, the fifth layer and the sixth layer are taken as the nodes in the wellbore respectively, which are represented by the number 0-6 respectively.

Figure 1 Hydraulic lines for three-channel control six-layer
In the model, the Beggs-Brill gradient model is used to iteratively calculate the pressure gradient in the co-production pipe, and the expression is formula (1), which characterizes the variation of the pressure in the pipeline with the potential difference of the working fluid, the flow friction loss and the acceleration of the working fluid flow.

\[
\frac{dp}{dZ} = \rho g \sin \theta + \frac{\rho}{2} \frac{dE}{dZ} + \rho \frac{dV}{dZ}
\]  

(1)

Combined with the established wellbore node pressure model, the expression of pressure drop in wellbore can be expressed by equation (2). The specific calculation process is calculated by Beggs-Brill gradient method in A Study of Two-phase Flow in Inclined Pipes.

\[
\frac{dp_i}{dh} = \frac{\rho_i g \sin \theta + \frac{\rho_i dV_i}{2d_i A_p}}{1 - \frac{\rho_i g v_i^2}{\rho_i p_i}}
\]

(2)

h is the well depth, \(m\); \(\rho\) is the working medium density, \(kg/m^3\); \(\theta\) is the wellbore slopel, \(^\circ\); \(q_i\) is the current wellbore working fluid flow rate, \(m^3/d\); \(v_i\) is the current wellbore working fluid velocity, \(m/s\); \(d_p\) is the wellbore tubing inner diameter, \(m\); \(A_p\) is the tubing cross-sectional area, \(m^2\); \(p_i\) is the current wellbore pressure, MPa.

The flow rate of the working fluid flowing into the casing annulus from the reservoir should be equal to that flowing into the tubing in the replacement annulus, and it should be obtained according to the corresponding parameters of the node.

\[
q_i = \frac{2\pi h_i (p_{sw} - p_{rw}) k_i}{\ln \left( \frac{r_e}{r_w} \right)} = C_q A_{hp} \left( \frac{2}{\sqrt{\rho_i}} \frac{p_{sw} - p_i}{p_i} \right)
\]

(3)

\(q_i\) represents the average reservoir pressure of horizon i, \(m^3/d\); \(p_{sw}\) represents the average reservoir pressure of horizon i, MPa; \(p_{rw}\) represents the flow pressure of the working medium of horizon i, MPa; \(p_i\) represents the tubing pressure of horizon i, MPa; \(k_i\) represents the reservoir permeability of horizon i, \(m^2\); \(h_i\) represents the effective reservoir thickness of horizon i, \(m\); \(r_e\) represents the radius of oil supply of horizon i, \(m\); \(r_w\) is the wellbore radius of wellbore, \(m\); \(s_i\) is the skin factor of horizon i, dimensionless; \(\mu\) represents the viscosity of the working fluid, Pa·s; \(A\) represents the conversion coefficient of different units; \(A_{hp}\) represents the cross-sectional area of the orifice of the tubing under the action of the sliding sleeve of layer i, \(m^2\); \(C_q\) represents the coefficient of the orifice of the tubing under the action of the sliding sleeve, dimensionless, and \(C_q\) is expressed as:

\[
C_q = 0.964Re^{-0.05}
\]

(4)

Re stands for Reynolds number.

According to the mass continuity equation, it is known that the real total refrigerant \(q_0\) should be the sum of the total refrigerant output of the six layers.

\[
q_0 = \sum q_i (i = 1, 2...6)
\]

(5)

3. Case analysis of EGS combined mining

The production parameters of the formation draw lessons from the well condition parameters of geothermal wells such as China's Yangyi ZK212 well and South Korea's PX-1 well\(^{10-11}\), and the formation parameters of six layers in the wellbore are established as shown in Table 1.

| Table 1 | Formatting sections, subsections and subsubsections. |
|---------|-----------------------------------------------|
|         | First level | Second level | Third level | Fourth level | Fifth level | Sixth level |
| Depth / m | 1000       | 1200        | 1500       | 1800        | 2200       | 2700        |
| Permeability rate / \(10^{12}m^2\) | 0.03       | 0.025       | 0.04       | 0.018       | 0.038       | 0.021       |
| Formation pore effective thickness / m | 8          | 7           | 9          | 8           | 7           | 6           |
| Reservoir pressure / MPa | 11.76      | 13.56       | 17.16      | 20.64       | 25.8        | 31.92       |

The model adopts 51/2in casing with an inner diameter of 122mm and a diameter of 122mm. The inner diameter of the tubing is 48mm. The set discharge radius is 10m, the working fluid parameters are conventional launching and CO₂ density, viscosity, dissolved gas-liquid ratio, etc., 1.2MPa is used as...
wellhead pressure, and the initial working fluid flow rate $p_0$ is set to 1500 m$^3$/d. Choose to have the maximum displacement. 103.1 mm slide sleeve structure with 7-stage sliding control displacement.

During the period, according to the influence of sliding of different layer sliding sleeves, the pressure gradient changes at different stages of the wellbore under each layer sliding sleeve operation can be obtained.

![Figure 2 Influence that sliding sleeve closing displacement to wellbore pressure gradient.](image)

It can be seen in Figure 3 that the degree of pressure gradient of each stage in the wellbore is different when each layer sliding sleeve is operated separately. Among them, pressure gradient change between the third layer and the second layer is the most significant, and the change between the first layer and the wellhead is the most gradual. In addition, during the displacement process from the first layer sliding sleeve to the sixth layer sliding sleeve, the trend that pressure gradient change increasing in sequence for the six stages of the wellbore is presented. Slope of pressure gradient changes in the six stages in wellbore is relatively gentle when the first layer sliding sleeve is operated, and the position of the intersection between the curves is relatively right. However, when the sliding operation in the sixth layer is performed, pressure gradient change in the wellbore is significant as the layer position of the working sliding sleeve changes, and the intersection between the curves also moves to the left.

In the process of pressure control and EGS co-mining operation of the decoder wellbore, the sliding sleeve operation of the lower layer will make the change of the pressure gradient in the wellbore more significant, so that the changing speed of the pressure gradient in the wellbore can be effectively controlled and the production can be effectively controlled.
Figure 3 Relationship between sliding sleeve displacement and media production of each layer

Figure 4 above shows the relationship between the output of the working fluid in different layers under the sliding sleeve operation of different horizons, and it can be seen that the output of the original working fluid is related to the corresponding production parameters of the horizon. The production parameters of the third layer in this model make the output of the working medium in this layer reach the highest in the case of no interference from the sliding sleeve pressure regulating operation. Under the influence of sliding sleeve, the working fluid output of each layer will be significantly affected by the sliding sleeve operation of each layer. According to the calculated data, it can be seen that although the operation of sliding sleeve in each layer reduces the output of working fluid in this layer, the output of other layers will show a certain increasing trend. According to the relationship between the displacement of sliding sleeve and the output of working fluid in each layer, the relationship between the displacement of sliding sleeve and the total output of working medium in the EGS co-mining model is obtained.

Figure 4 Relationship between sliding sleeve displacement and total production.

As can be seen in Figure 5, it is not that the larger the sliding sleeve closure displacement, the lower the output. When the closing displacement occurs in the second level sliding sleeve, the total output of the wellbore shows an upward trend; when the third level sliding sleeve is operated, the total output decreases gradually with the increase of the sliding sleeve closing displacement; in the first level sliding sleeve operation, the total output does not change significantly, and the output tends to be stable.

4. Conclusion

According to the working boundary of heat exchange formation and the pressure and flow control principle of downhole decoder, several independent low production heat transfer reservoirs are constructed to form the EGS development technology of downhole multi-layer heat transfer and co-production, combined with three pipelines to control six layers of downhole decoder intelligent completion technology, which can meet the control of working fluid production on each layer.

For the working fluid production, in addition to the controlled wellbore pressure and wellhead pressure, the output is also related to the original formation conditions, and the working diameter of the
The sliding sleeve affects the output of the working fluid in the corresponding heat transfer layer. The working fluid output of other layers shows a slight upward trend. The total output of the system is not a decline in the operation of a slide jacket in a layer of slide, but to combine the production floor parameters, bring into the above-described mixing model for analysis.

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