Effective and Sustainable Utilization of Geothermal Resources

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ABSTRACT

Effective and sustainable utilization of geothermal energy attributes to scientific and reasonable production and reinjection strategy. Monitoring of pressure, temperature, fluid geochemistry and production rate of geothermal field can keep track of the dynamics of a geothermal field; hydrothermal relationship between production and reinjection wells and “cooling” potential of reservoir can be processed by reinjection experiment and tracer test before the operation of a large scale reinjection project; the response of geothermal field during different periods can be predicted effectively by lumped and distributed parameter model, the geothermal data base and management information system provide data information for efficient managing prospecting and geothermal field development.

1. INTRODUCTION

The Earth is a huge heat reservoir. The geothermal temperature inside the earth increases with increasing depth. Geothermal energy transmitting to the earth’s surface equals to 2.5 times of the energy consumed per day[1], and therefore geothermal is far greater than fossil fuel. Nowadays, the global climate change and environmental pollution push people to pay more attention to geothermal energy as it is clean energy. Valgardur[2] found that 0.2 TWe geothermal energy could be used to produce electricity and 4.4 TWe could be directly used in all verified geothermal resources in the world. Until 2010, there are 78 counties use geothermal resources directly in the world. [3]

The geothermal energy can be classified as a kind of renewable resource. When the discharge is considerably larger than the recharge, the current technology and economy cannot afford geothermal exploitation, and as a result, the benefit of geothermal exploitation reduces. To this end, scientific and reasonable exploitation and reinjection scheme are urged to proceed sustainable development and utilization of geothermal energy. [4] The optimal scheme should depend on the dynamic data of geothermal field, including the pressure, temperature, hydrochemistry, exploitation quantity and replenishment. In addition, a geothermal field monitoring system is required. The efficient geothermal reinjection guarantees the geothermal fluid to consume the lowest, and also increases the efficiency of geothermal exploitation. However, the geothermal reinjection is very complex, and thus the injection test and tracing test are necessary before the construction of a large-scale reinjection. Numerical simulation is a popular method to investigate the effects of responding to production and reinjection after the running of a geothermal field for a long time [5]. Geothermal information system provides reliable information for efficient geothermal exploration [6].

2. GEOTHERMAL FIELD MONITORING

2.1 Reservoir Pressure/Water Level Monitoring

The reservoir pressure determines the productivity of a geothermal well. With the consuming of geothermal fluid, the reservoir pressure drops if the makeup fluid is less than the loss, which then influences the productivity of a geothermal well. The reservoir pressure should be monitored in the high temperature geothermal field while the water level should be monitored in the meso-low temperature geothermal field. Based on the monitoring results, we can adjust the Production Program to keep the reservoir pressure at one level, to balance the exploitation against the replenishment, and to make a sustainable utilization of geothermal resource.

2.2 Reservoir Temperature Monitoring

When the geothermal well is exploited continuously, the thermal energy will be provided constantly by the deep reservoir, which keeps the geothermal temperature constant. However, instantly reinjection increases the geothermal energy consuming rate of shallow reservoir, which results in the decrease in geothermal temperature. Generally, the thermal transmission in the thermal reservoir is at a low level, and the temperature reduction is also at a low level. Temperature reduction of the reservoir, however, cannot be reversed, and thus the temperature drop happens instantly. Consequently, exploitation and reinjection scheme need to be adjusted immediately. Monitoring is an important method to record reservoir temperature changes and the changes are known through monitoring discharge temperature and regularly measuring temperature profile of a geothermal well.

2.3 Geothermal Fluid Hydro-chemical Monitoring

Geothermal fluid chemical components reflect reservoir’s water-rock reaction process. The components in the fluid is measured using geothermometer and the temperature in the deep of reservoir is then estimated; By monitoring the geothermal fluid in isotope change, we can judge whether the reservoir gets a new recharge; By monitoring the geothermal fluid in the proportion of special components, the mix degree of geothermal fluid at different depth and temperature in the geothermal reservoir can be estimated. In addition, by monitoring the changes in temperature and chemical components of the geothermal fluid, the temperature change and water-rock reaction process can be mutually authenticated in the reservoir. The monitoring of geothermal fluid water chemistry is carried out by gathering geothermal fluid samples regularly.
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2.4 Production/Discharge Monitoring
The flow quantity of geothermal field reflects its productivity. Generally, at the beginning of the exploitation, the pressure of geothermal reservoir is at a high level, and the flow quantity is large. After continuously exploitation, especially when the exploitation quantity is larger than the recharge quantity, there will be a decline in the geothermal reservoir pressure. At the same condition of water intake, the geothermal well capacity is reduced which means the productivity is decreased. Because the productivity of geothermal field determines the investor’s investments and incomes, the excessive exploitation in a short time results in the fact that the geothermal resource exhausts rapidly. Consequently, the economic loss will be serious. Unlike the solid mineral resource and petrochemical resource, the geothermal resource is renewable. This means the resource will be recharged in a short time. By monitoring the flow quantity and timely adjusting scheme, the geothermal resource can be used continuously in a long term. The flow quantity monitoring is carried out by setting up a flowmeter at the mouth of geothermal well.

3. GEOTHERMAL FIELD REINJECTION
3.1 Rejection Test
The geothermal recharge started in 70s of the last century, which was to recharge the used geothermal water to avoid the land and air pollution[7][8]. The complexity of geothermal rejection is realized by researchers. Rejection rate is limited by poor permeability in some types of reservoirs, and the injection capacity decreases drastically after a period of rejection. The rejection well can be even totally clogged. For a large-scale rejection, it causes rapid temperature drop in the reservoirs with fine permeability[9], and therefore the rejection site test is necessary confirm the permeability and injection capacity before the operation of a large-scale injection.

The recharge test usually starts with a low flow, and then increases the flow gradually to test the capacity of rejection. The recharge can be classified as non-pressured rejection and pressured rejection. The non-pressured rejection makes use of the gravity of injection water without wellhead pressure. This rejection mode saves the energy and makes a less impact to pore permeability of the thermal reservoir. The pressured rejection needs pressure at the wellhead to push the water back to the thermal reservoir. This mode consumes external energy, e.g., the electric energy is consumed by the pressure pump. Besides, if the pressure is overloaded, this mode affects the pore permeability of the thermal reservoir and causes a turbulent flow in the well, leading to the decrease in the injection capacity. Therefore, rejection test of different rejection capacities in different modes is required to provide information for large-scale geothermal reinjection.

3.2 Tracer Test
The thermal reservoir ability of recharge and its effect on thermal reservoir pressure can be obtained by recharge test, but the effect on thermal reservoir temperature cannot be obtained (this effect can’t be reversed even detected). Therefore, the test is required to forecast the effect on the thermal reservoir temperature. Tracing test estimates the influencing scope and degree of reservoir temperature which is affected by different schemes of exploitation and reinjection.

Tracer test injects the tracer into the injection well and accelerates the tracer flow by inducing flow field which is formed by recharging. The tracer can be classified as chemical tracer, environmental tracer, radioactive tracer. The principle of selecting a tracer is to use a minimum dosage to make sure the hydraulic connection between pore permeability and geothermal well. The chemical tracer has a low unit price but also has a low sensitivity and a large dosage. The environmental tracer is traced by chemical characteristics of geothermal fluid. This tracer is suitable for large-scale tracing test in geothermal field, in a small area, however, the concentration varies slightly and the sensitivity has a low level. The radioactive tracer has a high unit price, but it has very high sensitivity and small dosage. The control policy of radioactive source becomes stricter in many countries, and the tracking operation requires professional skills, and thus its field application is limited. To date, the popular tracer is the chemical tracer. Chemical tracer is classified as organic tracer and inorganic trace[10]. Amongst them, the organic tracer is widely used due to its high sensitivity and convenience.

Given the heterogeneity of the karst and the fracture development in the reservoir, especially in a karst thermal reservoir, the tracing test needs to be conducted repeatedly[11][12] to comprehensively analyze the permeability and fracture characteristics of the reservoir, and to estimate the movement rate of temperature frontal through the movement rate of tracer’s frontal.

3.3 Arrangement of Production and Rejection
The arrangement of reinjection is classified as decentralized distribution and centralized distribution. The effect of thermal reservoir pressure and temperature is different in different modes. The decentralized distribution is to alternately arrange the reinjection well and the production well in one zone. The centralized distribution is to arrange the reinjection well and the production well in different zones. For instance, the production well is drilled in the center of geothermal field while the reinjection well is drilled at the edge of the geothermal field; the production well is drilled in high temperature area of a reservoir while the reinjection well is drilled in low temperature area of the reservoir[13].

Because the distance between production well and reinjection well in the decentralized distribution is closer than the centralized distribution, once the recharging start, the reinjection water could keep the thermal reservoir pressure effective. The recharging makes the thermal reservoir cooled. This cooling happens in all of the distribution range and the range of thermal reservoir cooling will spread out gradually, resulting in temperature drops and affecting the production well’s productivity.

Under the centralized distribution mode, the production well and reinjection well are arranged in different zones. The hydraulic connection between them is weak, and the pressure of geothermal reservoir cannot be kept in a short time. The pressure in reinjection well zone increase, and decreases the production well zone. The impact on reservoir temperature is only in the recharge zone, which does not affect productivity of the exploiting zone. When the production and reinjection mode reach to a certain size, a generalized “EGS” could be formed between production area and reinjection area, and then the hydraulic connection increases and reinjection’s effect for maintaining reservoir pressure becomes obvious. In the medium and low temperature geothermal system,
when the production and reinjection quantity reach to a certain size, the centralized distribution mode can not only keep the pressure of thermal reservoir effective, but also have no impact on the productivity in production area, and therefore is advantageous over the decentralized distribution mode.

4. GEOTHERMAL MODEL

4.1 Lumped Parameter Model

Lumped parameter model represents the system’s characteristic and the dynamic which does not change with the space coordinate. Usually, the system is considered as a whole, the study of the fitted relationship between input and output, the process and the Mechanism internal is not enough. The model can be classified as the stable and unstable; Linear and nonlinear. At the beginning of the development of geothermal field, there was not enough monitoring data to build distributed parameter model. The lumped parameter model played a very important role. With a limited number of monitoring data, lumped parameter model is able to find out the relationship between total production of geothermal fluid and the changes in pressure and temperature in a reservoir, and thus the recharge and the discharge in the reservoir could be estimated. Besides, the effects of pressure and temperature, different exploitation scheme can be also evaluated[13].

At the beginning of the development of geothermal field, the geothermal reservoir method is used to calculate the static geothermal resources and to determine the potential of geothermal field. Because the thermal energy inside the geothermal field is mainly stored in the matrix, only a few of the thermal energy can be exploited.

Lumped parameter model studies the response relationship between the exploitation and the geothermal field as a whole system[14]. But lumped parameter model can’t express the change of pressure and temperature in everywhere of geothermal field, and the distributed parameter model is needed to calculate.

4.2 Distributed Parameter Model

Distributed parameter model represents the system’s characteristic and dynamics which change with the space coordinate. It is a mathematical model expressed by hydrodynamic differential equation in porous medium, and this equation is strictly relied on fluid mechanics. The equation can be solved on the basis of boundary and initial conditions to obtain the system’s feature, dynamic and the relation or arithmetic solution of coordinates and time variable. The models can be classified as stable and unstable; Linear and nonlinear. The distributed parameter model requires detailed data (e.g., geological conditions, temperature field and hydrogeological conditions of geothermal field) to construct conceptual model and numerical model, and then uses the continuous pressure and monitoring data of temperature to correct the model which is then used to predict the change of pressure and temperature in different geothermal fields.

Because the understanding of the geothermal field is progressive, the numerical model need to be updated and improved on the basis of survey results after the model is built up. The model expresses geothermal field accurately and stably when compared with groundwater numerical model. Geothermal numerical model has to consider migration of water and thermal for hydro-thermal coupling at the same time. The change in water density due to temperature change causes the change in volume, enthalpy, and phase of thermal water; therefore, programs using groundwater numerical simulation is not feasible in geothermal simulation. As a geothermal simulation program, TOUGH2[15-16] considering migration and conversion of heat and energy between liquid, gas and solid phases is wildly applied in geothermal study and is effective to instruct the exploitation of geothermal field.

5. GEOTHERMAL INFORMATION SYSTEM

5.1 Spatial Database

The spatial database of geothermal field includes basic database, production database, recharge database, management database and planning database. The basic database includes basic geological data, hydrogeological data and geothermal system data. The production database includes the position, depth and structure of producing well, the well log data, well test data, production history and production monitoring. Rejection database includes the position, depth and structure of recharge well, well log data, well test data, reinjection test data, tracing test data, reinjection history data and recharge monitoring data[60]. The management database includes the analysis data of producing well, reinjection well layout rationality, the result data of producing and recharge system running evaluation. The planning database includes suitability assessment of geothermal exploitation, several planning data, the scale and planning data of production, the layout data of producing well and reinjection well and the heating system planning data.

The spatial databases is on the basis of geothermal field management system, giving supports to formulate geothermal development planning, to adjust schemes of production and reinjection, to update geothermal numerical model, and to guarantee sustainable utilization of the geothermal fields.

5.2 Geothermal Field Management System

The construction of geothermal well field data acquisition system, the progressive realization of automatic data acquisition and remote wireless transmission are developed. Realizing the function of querying, gathering statistics and modifying the information of geothermal wells make the information mappable and the data visible. Information technology is the only way to achieve intensive management of geothermal fields. It can not only save manpower but also improve management efficiency. Geothermal field management system includes early exploration of geothermal field, geothermal reserves evaluation, geothermal well construction, operation of geothermal wells, maintaining geothermal wells, geothermal wells exploitation management and measuring the pressure and temperature of geothermal field. The geothermal field management system also includes a geothermal field numerical model, the management of development and utilization of geothermal fields and planning.

Meanwhile, with the development of geothermal field, geothermal field management system includes data submitted and receiving feedbacks and published information of geothermal field[17]. Geothermal field warning system is required as well. When the
exploitation of geothermal resources exceeds the benchmark, the system alarms warning and alerts the reinjection managers to adjust the planning time.

6. CONCLUSION
The sustainable development and utilization of geothermal field are mainly realized in efficient control of the production. A geothermal field monitoring system that can timely grasp the dynamics of geothermal field and provide information for formulating and adjusting the exploit scheme is discussed. The recharge test and the tracing test provide important and reliable reference for large-scale geothermal recharge. The numerical model can predict the response of geothermal field in different production and reinjection models, which provides information for formulating the production and reinjection plan. The geothermal field information system can manage the geothermal field development and plan timely by integrating geothermal field information.

REFERENCES