Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 260–269

Journal of Rock Mechanics and Geotechnical Engineering

Journal online: www.rockgeotech.org

Prospect of HDR geothermal energy exploitation in Yangbajing, Tibet, China, and experimental investigation of granite under high temperature and high pressure

Yangsheng Zhao[1*], Zijun Feng[1], Baoping Xi[1], Jinchang Zhao[1], Zhijun Wan[2], Anchao Zhou[1]

[1] *College of Mining Engineering, Taiyuan University of Technology, Taiyuan, 030024, China*

[2] *School of Mines, China University of Mining and Technology, Xuzhou, 221008, China*

Received 14 February 2011; accepted in revised form 19 July 2011; accepted 25 July 2011

Abstract: Hot dry rock (HDR) geothermal energy, almost inexhaustible green energy, was first put forward in the 1970s. The development and testing of HDR geothermal energy are well reported in USA, Japan, UK, France and other countries or regions. In this paper, the geological characters of Yangbajing basin were first analyzed, including the continental dynamic environments to form HDR geothermal fields in Tibet, the tectonic characteristics of south slope of Nyainqêntanglha and Dangxiong-Yangbajing basin, and the in-situ stresses based on the investigations conducted, and then the site-specific mining scheme of HDR geothermal resources was proposed. For the potential development of HDR geothermal energy, a series of experiments were conducted on large-scale granite samples, 200 mm in diameter and 400 mm in length, at high temperature and high triaxial pressure for cutting fragmentation and borehole stability. For the borehole stability test, a hole of 40 mm in diameter and 400 mm in length was aforehand drilled in the prepared intact granite sample. The results indicate that the cutting velocity obviously increases with temperature when bit pressure is over a certain value, while the unit rock-breaking energy consumption decreases and the rock-breaking efficiency increases with temperature at the triaxial pressure of 100 MPa. The critical temperature and pressure that can result in intensive damage to granite are 400–500 °C and 100–125 MPa, respectively.

Key words: hot dry rock (HDR); geothermal energy exploitation; high temperature and high pressure; cutting fragmentation; borehole stability

1 Introduction

The geothermal resources reserved in rocks with temperature over 200 °C are basically deemed as high-temperature rock geothermal resources, which are also named as hot dry rock (HDR) geothermal energy by the scientists from Los Alamos National Laboratory, USA. The total HDR geothermal reserve within the depth of 10 km in earth’s crust is (40–400) × 10^6 quads (1 quad = 1.055×10^{18} J), which is equal to 100–1 000 times of the total fossil energy [1–3]. As reported, there are abundant HDR geothermal resources in China. The abnormal geothermal zones of HDR have been formed in Qinghai-Tibet Plateau due to the subduction zone of Indian Ocean Plate to continent of Europe in Southwest China, such as the typical abnormal geothermal zones in Yangbajing basin in Tibet and Tengchong in Yunnan Province. In Southeast China, the high geothermal gradient zones are concentrated in Taiwan, Hainan provinces and southeast coastal area along the tectonism of Philippine Plate. And there also exist dormant volcanoes or vulcanian eruption zones, such as Changbai Mountain, Wudalianchi, etc., and high geothermal gradient zones, such as Tianjin, Beijing, and Shandong Province [4], etc.

The natural hot water resources in the Yangbajing zone in Tibet, China, have been obviously reduced for the last 20 years’ exploitation. The temperature, pressure and flow rate of production wells in this zone have declined to some extent. As expected, the geothermal resources in the Yangbajing zone can provide energy for a 16-MW geothermal power station at full load operation.

Geophysical exploration indicates that there exists a liquation magma chamber, outer temperature of which is about 500 °C at the depth of 5–15 km in the Yangbajing geothermal field. The geothermal gradient is about 45 °C/km. The reservoir is mainly composed of granite layer and it is high-gradient HDR geothermal resources. The current exploitation of

Doi: 10.3724/SP.J.1235.2011.00260

*Corresponding author. Tel: +86-351-6018893; E-mail: y-s-zhao@263.net

resources is basically using shallow hot water, which is only a small proportion of geothermal reserves in the Yangbajing geothermal field. Therefore, exploitation and use of HDR geothermal resources in the deep Yangbajing geothermal field are a preferred choice for replacement of shallow hot water and it can increase the electrical capacity of Yangbajing geothermal power station.

However, the fist problem encountered in the HDR thermal energy exploration is to drill rocks in geothermal reserves area at high temperature and high pressure (HTHP). Polycrystalline diamond compact (PDC) coring bit developed for HDR exploitation by Japanese scientists in the 1990s could drill the stratum at 250 °C at a depth of 1 900 m [5, 6]. Zhao et al. [7] studied the cutting effects of granite under coupled dynamic-static loads. Yet, the tests were conducted only at normal temperature and pressure, but not at HTHP.

Problems of borehole necking and collapse, resulting from drastic decline in intensity and rheology of rock mass at HTHP, are extremely serious during drilling. And the costs for drilling and preserving borehole stability will largely be increased. So the investigations on borehole stability are urgently needed. But recent reports on borehole stability were basically focused on developing diverse models at normal temperature and pressure [8–11], or discussing the micromechanisms of borehole instability based on drilling experiments conducted on a variety of granites, limestones and sandstones at room temperature [12].

In this paper, the HDR geothermal reserves are first estimated, and the technical schemes for HDR geothermal energy exploitation are presented based on temperature distribution in the Yangbajing geothermal field and the character of tectonic stress. Then experiments are conducted on granite samples with 200 mm in diameter and 400 mm in length at HTHP for rock breaking and borehole stability, using 600 °C 20 MN servo-controlled triaxial rock testing machine.

2 Technical schemes for HDR geothermal energy exploitation

2.1 Temperature distribution and geothermal resources evaluation

Dangxiong-Yangbajing basin is a long and narrow downfaulted basin and its orientation is NE. It is located in the southeast of Nyainqêntanglha and connected with Brahmaputra seam in the south. This area can be divided into two parts by China-Nepal road. In the south, the superficial formation is Quaternary alluvium. And it is moraine deposit, accompanied by weathered granite with different thickness [13]. There are a number of extensional faults, which control the strike of the basin.

Results obtained by using artificial seismic wave method show that a low-velocity layer, which is possible underground magma, exists in the depth of 22 km in the Yangbajing geothermal field. Based on the results of magneto-electrotelluric exploration (METE), there is a low-resistance (5 Ω·m) layer, which is referred as melt mass after high temperature cooling (Fig.1), at the depth of around 5 km in the north of the Yangbajing geothermal field. According to the data of deep seismic reflection exploration, there is a local liquating rock mass at the depth of 13–22 km of the supracrust in the north of Yangbajing geothermal field [14]. So it is confirmed that a heat producer induced by the high-temperature liquating magma exists in the deep layer of the Yangbajing geothermal field.

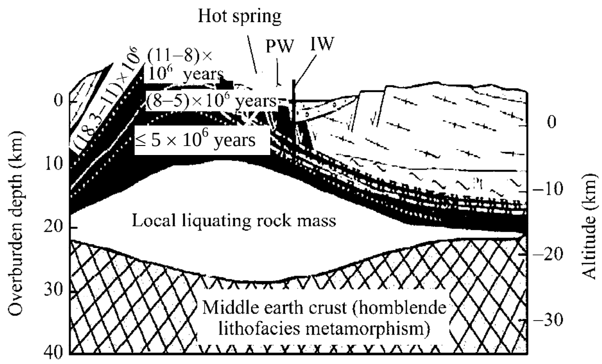

Fig.1 Crustal structure and tectonic model of Dangxiong-Yangbajing basin (PW represents production well, and IW injection well).

According to isotope analysis of hydrogen and oxygen from the thermal groundwater, the general replenishing height of the hot water, which consists of modern atmospheric precipitation and surface water infiltration, is 4 860 m, just equal to the elevation of local snowline and original distribution of surface water system. Large amount of snow-melting water from Nyainqêntanglha range and atmospheric precipitation permeates underground along the fault belts, and deep water-bearing stratum can get sustainable water replenishment continually. It will absorb the rock’s heat by heat exchange with the hot rocks in the cycle. Meanwhile, the density difference of hot and cool water can produce natural upwelling, making the flow move upward along the faults. So a high-temperature thermal storage can be formed in a