Experiments on thermal fracture in rocks

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Abstract The thermally induced fracturing appeared in the boundaries of mineral grains of rocks due to the different thermal expansion of different minerals while heating the rocks. When the microscopic fracturing connected like a network, the macroscopic permeability and the fluid transport properties of the rock changed remarkably. The implication of thermal fracturing to petroleum industry, earthquake process and transport modeling have been discussed.

Keywords: thermal fracturing, permeability, fracture system.

ROCK fracture and fluid transport are important subjects of rock physics, which deal with the following problems: How can fracture be located, identified, and characterized? How do flow and transport occur in the fracture system? And how can changes in fracture systems be predicted and controlled? Wong and Brace found that the thermal expansion of rocks is typically irreversible under high pressure[1]. Chen and Wang detected thermally induced acoustic emission from heated rocks[2], and proved such acoustic emission is caused by the microcracks in rocks. Later, most studies concentrated on the granular rocks because granular materials are very important for reservoir geophysics. Thermal properties of pore, rather than crack, were investigated in detail[3—5]. In this note, the experimental results of thermal fracturing of rocks are presented and the implications of thermal fracturing to petroleum industry are discussed briefly.

1 Acoustic emission during heating rocks

Westerly granite was chosen as the test material because most of its properties are known[2]. Six test samples were drilled from a single block of rock and signed as G14, G12, G3, G4, G7 and G2-1 respectively. All the samples were 1.91 cm in diameter and 3.81 cm in length. Fig. 1(a) shows the experimental setup. Sample (3) was heated in a furnace (4) with its temperature measured by a copper-constant thermocouple (5). A cylindrical piece of alumina (2) was used to insulate the acoustic transducer (1) from heat. To insure a good acoustic coupling, all contact surfaces were cemented with a high temperature epoxy.

The acoustic emission of Westerly granite subjected to temperature changes up to 120℃ at various heating rates from 0.4 to 12.5℃/min was studied. A significant observation result in the experiments was that a temperature value ranging from 60 to 70℃ seemed to be the threshold temperature for Westerly granite, above which acoustic emission began to occur with the increase of temperature. Such a threshold temperature did not change with different heating rates. We suggest that there is an equilibrium state of the thermally induced fractures which is a function of temperature, but is independent of the heating rates. The acoustic emission results from the thermal fracturing of the boundaries of mineral grains due to the different thermal expansion of different minerals[2].

2 Thermal fracturing and rock permeability

Test carbonate sample came from Dongying City of Shandong Province with the size of 12.5 cm in diameter and 25.4 cm in length. First, the rock sample was heated to a given temperature, then cooled to room temperature, finally, the permeability of carbonate was measured in laboratory. The experimental results of permeability as a function of temperature are shown in fig. 2. There appeared to be a threshold temperature for carbonate at 110—120℃, above which the permeability of carbonate increased remarkably about 8—10 times (figure 2).

A significant feature of rock permeability during the heating process is the abruptness of its changes. Below the threshold temperature, only very little changes appeared in the heating process, while a remarkable change occurred once the threshold temperature was reached. When the temperature was increased, very little changes appeared again above the threshold temperature. The abrupt changes of per-

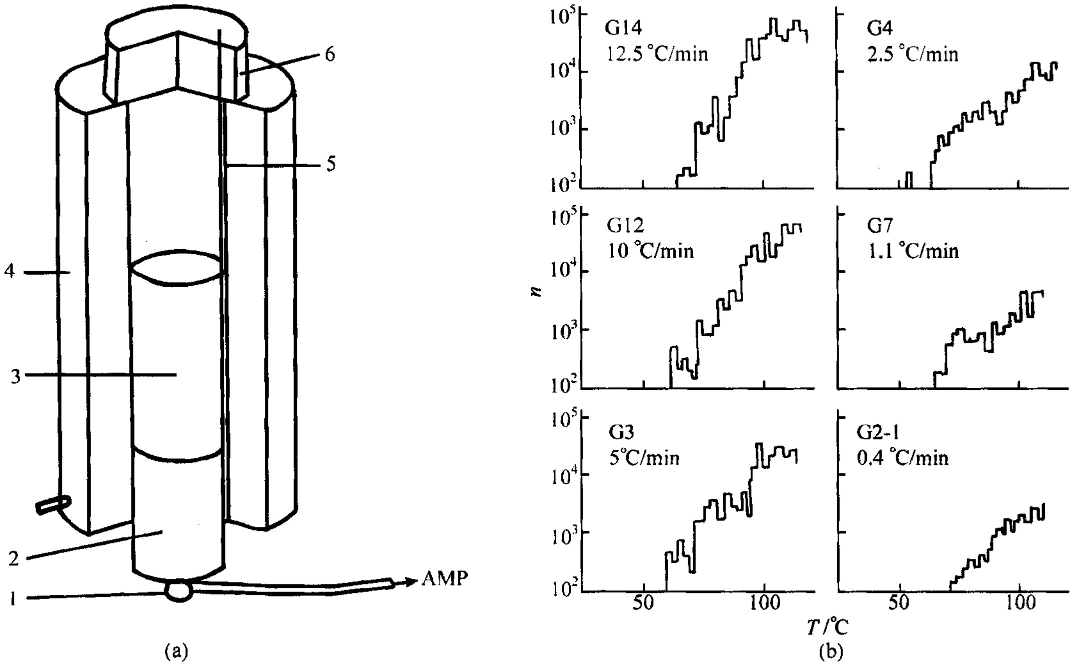

Fig. 1. (a) Furnace and acoustic emission assemble. 1, Acoustic emission transducer; 2, alumina piece; 3, rock sample; 4, furnace; 5, thermocouple; 6, cover. (b) Acoustic emission rate (n) as the function of temperature for 6 granite samples.

meability as a function of temperature can be explained with the percolation model. According to this model, the thermal fracturing begins to occur in the heating process below the threshold temperature, but the permeability as a macroscopic parameter of rock properties does not increase evidently. The remarkable change of permeability occurs only when the temperature reaches the threshold value at which the thermal fracturing connects as a network. The fracture connection is dependent on many factors, such as original density of the fracture system within rocks and the type of rocks. No obvious changes of permeability for granite, with very low permeability, were observed during the temperature range from room temperature to 200℃ in our experiments.

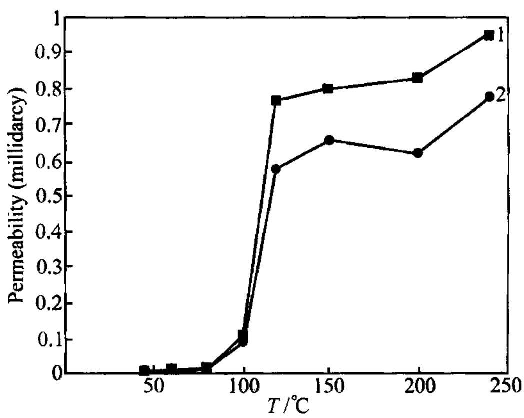

Fig. 2. Thermally induced fractures connected as a network in the temperature range 110—120℃, resulting in the increase of permeability of carbonate about 8—10 times. 1 and 2 show the experimental results of two samples.

3 Discussion

The properties of rocks dominated by fracture systems are rather complex. The fracture system parameters, such as irregular geometric shapes, fracture density, etc., have great influence on macroscopic permeability, scale dependent and anisotropic behavior of rocks. In the past few decades, many efforts focus on how to change the fracture system of rocks in the studies of rock fracture and fluid transport.

The hydraufracturing technique is widely used to change the fracture network of rocks in petroleum industry. The hydraufracturing can increase the length of cracks of limited number (including both existing cracks and newly created ones), while it prevents the expansion of major cracks. There is an urgent need to look for a new method which can increase both the length and the density of fractures.

Many studies on thermal fracturing of nonlinear optical materials[6], fire-prevention materials[7] have been performed, but there were very few studies about that of rocks. The preliminary experimental results of thermal expansion of rocks indicate that thermal expansion can change the microstructure of rock interior, not only increasing the length of cracks but also thickening fracture density[8]. Our experiments provide a new possibility to change the fracture system of rocks which has potential implication to recover petroleum, nuclear waste disposal, geothermics, environmental prevention, and understanding of earthquake process.

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References

1 Wong, T.F., Brace, W. F., Thermal expansion of rocks: some measurements at high pressure, *Tectonophysics*, 1979, 57: 95.

2 Chen Yong, Wang Chiyuen, Thermally induced acoustic emission in Westerly granite, *Geophysical Research Letters*, 1980, 7: 1089.

3 Ravalec, M. Le., Gueguen, Y., Permeability models for heated saturated igneous rocks, *J. Geophysical Research*, 1994, 99 (B12): 24,251.

4 Ravalec, M. Le., Darot, M., Reuschile, T. *et al.*, Transport properties and microstructural characteristics of a thermally cracked mylonite, *Pure and Applied Geophysics*, 1996, 146(2): 151.

5 Lee, J.K. W., Trompt, J., Self-induced fracture generation in zircon, *J. Geophysical Research*, 1995, 100(B9): 17,753.

6 Eimerl, D., Marion, J., Graham, E.K., Thermal fracture in selected nonlinear optical meterials, Lawrence Livemore, Report Ucrl-96256, 1987.

7 Hassani, S.K.S., Shields, T.J., Silcock, G.W., Thermal fracture of window glazing: Performance of glazing in fire, *Journal of Applied Fire Sciences*, 1998, 15.

8 Ogino, F., Yamamura, M., Pressure drop of water flow between injection and production wells intersected by a circular fracture, *Geothermics*, 1998, 27.

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