Introduction

The deep naturally fractured tight reservoir is of great resources, whereas, the reservoir pressure and temperature are very high, significantly affecting gas flow mechanism in the system of matrix, activated natural fracture and hydraulic fracture. In order to achieve economical production and maximum recovery, most tight reservoir wells need to be fractured to stimulate natural fractures and form artificial fractures. After the natural fracture is stimulated, they connect with the artificial fracture to form a complex fracture network, and a complex coupled flow form occurs in the matrix-natural fracture-artificial fracture system (Mordis et al., 2010; Freeman et al., 2013). For artificial fractures with large permeability, the gas flow state is turbulent. The natural fractures with smaller aperture are susceptible to slippage, and the Darcy flow law is not applicable in two cases (Karniadakis et al., 2006; Economides and Martin, 2007; Hornyak et al., 2008).

The pore structure and fluid properties of the reservoir under high temperature and high pressure are different from those under conventional conditions, which causes significant changes in gas diffusion and permeability, and affects the non-Darcy flow of gas and its mass exchange law in various levels of flow systems (Sinha et al., 2013; Haddad et al., 2012). The gas slippage effect is affected by the effective stress of the reservoir. The diffusion capacity of the matrix and the conductivity of natural fractures and artificial fractures decrease with increasing effective stress (Yuan et al., 2014; Ghanizadeh et al., 2014).

Due to the constraint of experimental methodology, most of the experiments are conducted under the room temperature and relatively low pressure, while the physical simulation technology under the high pressure and high temperature is not well developed, impeding the understanding of the gas flow mechanism in the deep reservoir and the development and advancement of gas flow models. Flow experiments using fractured core samples are a common method for simulating mass exchange between the matrix and the fracture (Ferno et al., 2011). However, most of the existing researches focus on conventional reservoir.

In this work, a series of experiments were performed in matrix-fracture system simulated by core combinations with different matrix permeability and permeability ratio of matrix cores to naturally fracture cores to compare and analyse the gas flow under different thermal and stress conditions.

Methodology

Natural cores were selected as matrix cores and naturally fractured cores in our laboratory experimental study, which are from production wells in Tarim basin, at the depth from 6300m to 7700m. The core samples were cored to about 24.7mm in diameter. Compared with matrix cores, naturally fractured cores have higher permeability and only one axial fracture which is various in the extent of filling and fracture dip of running through the core (Figure 1).

![Figure 1 Naturally fractured core samples for the experiment.](image)

Only one splitting artificial steel block core was used in experiment. Artificial steel block core is split by wire electrical discharge machining (WEDM) to simulate hydraulic fracture. The length and width
of the fracture surface are 5cm and 2.54cm respectively. After splitting, the parts of the artificial steel block core are put together and wrapped with thermoplastic tube which is heated to make the core wrapped tightly.

![Image of artificial core](image.png)

**Figure 2** The axial surface of the artificial core after being split.

Experiments were performed in the simulation apparatus of gas flow in matrix-fracture system, which was developed to simulate gas flow in matrix-fracture system under variable temperatures and pressure. Two piston containers are in parallel with different capacities and pressure limits. The piston container with larger capacity can withstand lower pressure, while the piston container with smaller capacity does the opposite. Gas pressurization is achieved by repeatedly compressing the nitrogen provided by the gas source tank from the larger container into the smaller container. The gas source tank is full of nitrogen to provide adequate experimental fluid. Injection pump with high pressure limits and large displacement is used to control gas pressure and inject experimental fluid into matrix-fracture system. There are three core holders for the core samples. Matrix cores with lower permeability were selected to represent the reservoir matrix and placed in the first core holder. In sequence, naturally fractured cores were placed in the second core holder, and the artificially fractured core was in the third core holder. Three pressure gauges are placed in front of each core holder for the three core holders, and they can accurately record the inlet pressure of each holder. Due to the pressure drops after the fluid flows through the matrix-fracture system, the range of each stage of the pressure gauge is likewise gradually reduced. The confining pressure on each core is simultaneously provided by the confining pump. The flow meter and temperature sensor are connected to the outlet to monitor the flow and temperature respectively.

The initial injection pressure and effective stress were set as 10MPa, and the initial experimental temperature is 30°C. The experimental temperature was increased from 30°C to 80°C, while the initial injection pressure and effective stress were kept constant. With pressure interval of 10MPa, the gas pressurization and injection at various temperature were repeated until the temperature was gradually increased to 80°C and the injection pressure reached 70MPa. Remaining constant pressure and increasing temperature is to reduce the effect of confining pressure loading and unloading on the core samples in each experiment. Previous studies indicated that repeated loading and unloading can cause irreversible damage to the core permeability, which covers the true law of the whole experiment. The outlet flow rate and pressure under variable temperature and pressure conditions were recorded and processed to analyse the effects of temperature and pressure on gas flow in the matrix-fracture system of tight sandstone.

**Results**

The results of measurement are shown in Fig. 3. Since the naturally fractured core was damaged along the fracture surface at 70MPa, only 60MPa of pressure was achieved in this experiment. Both flow rate and gas pressure after the matrix and natural fracture under different condition of temperature and injecting pressure shows similar trend. As the temperature increases, the flow rate of the outlet decreases significantly when the temperature is below 60°C, and then changes slowly. The increase in gas pressure leads to an increase in the flow rate, but the contribution of higher pressure to flow rate is very limited. Simultaneously, the gas pressure of natural fracture and artificial fracture decreases with the increase of temperature. The increase of temperature causes the core samples to expand, compressing the pore volume and reducing the permeability to a slight extent. The difference of pressure between the natural fracture and artificial fracture changes little with the increase of
temperature under the condition of same gas pressure. The pressure of natural fracture and artificial fracture gets closer respectively as gas pressure rises, especially at higher pressure. However, the difference of pressure between natural fracture and artificial fracture increases with the increase of gas pressure, because the gas pressure gradually decreases when gas flows through the matrix-fracture system while the confining pressure is still constant, resulting in an increase in the effective stress applied on the downstream of matrix-fracture system. According to the typical stress sensitivity curve of the core, the effective stress increases above a critical value, and the permeability of the core changes slowly, it means that the resistance of the gas flowing through the core does not change significantly. The higher the gas pressure, the closer the pressure of natural fracture and artificial fracture at different temperatures respectively. Since the stress sensitivity of the natural fracture core is stronger than that of the artificial core, the increase in effective stress results in a large pressure loss and larger pressure difference between the natural fracture and artificial fracture.

Conclusions

In this work, the gas flow under different thermal and stress conditions were compared and analysed through a series of experiments in matrix-fracture system. Some main conclusions were drawn as follows,

(1) In general, the effect of temperature on flow rate and pressure of natural fracture and artificial fracture is limited, which is more obvious below the temperature of 60°C. It may not be feasible to reduce the reservoir temperature to increase gas production.

(2) Reasonable differential pressure should be set to ensure proper effective stress applied on the natural fractures and artificial fractures, to main optimal permeability during the production.

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References


