Experimental Relationship Between Confining Pressure, Fluid Flowrates, Flow Time Period and Temperature on Effective Permeability to Water in High Porous Sandstone

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Abstract

This study uses a computerized formation evaluation system to investigate the permeability variation of high porous sandstone with reference to varying confining pressure, flowrate, time period of flow and temperature using brine as reservoir fluid. Permeability increases with increasing confining pressure, temperature and fluid flow period; however, it decreases with increasing fluid flowrates. The various permeabilities were determined at a confining pressure of 1060–3091 psi, a flow rate of 0.1–0.4 cc/min, an experiment duration of 10–40 min and a temperature of 26–42.3 °C. The results show that the time period of flow and fluid flowrates are two important parameters that are essential to obtaining an accurate permeability measurement but these cannot be operated at reservoir conditions during permeability determination, as these two parameters remain variables throughout the producing life of the reservoir.

Keywords

Permeability • Effective permeability • Confining pressure • Back pressure • Reservoir flow

1 Introduction

Permeability is an intrinsic property of porous materials and measures the easiness of a fluid flow within the reservoir rock. It is of great importance in determining the flow characteristics and production rate of hydrocarbons in oil and gas reservoirs. Permeability varies from tens to hundreds of milliDarcies, but when permeability is greater than 100 mD [1], the reservoir is producible naturally, i.e., without artificial stimulation. Many researchers have studied the effect of confining pressure, P_C, and pore pressure, P_p, on the permeability of rocks. Bruce et al. [2] measured the permeability of granite under high pressure (i.e. $25 < P_c < 444$ MPa and $15 < P_p < 40$ MPa) and concluded that the permeability of granite was decreasing when the effective confining pressure (defined as P_c–P_p) was also increasing. Similar conclusions were found by Patsouls and Gripps [3] on the permeability of Yorkshire chalk. Walch [4] researched the effects of pore pressure and confining pressure on fracture permeability. Experiments showed that the effective fluid permeability, K_{eff}, is proportional to (P_c–sP_p) where s is a constant depending on the fracture characteristics. During the study of the effects of both pore and confining pressure on supercritical CO_2 permeability of sandstone, it was discovered that different permeabilities of the rock were obtained when water and gas were used as the flowing fluid, while varying the confining pressure and pore pressure [5].

A non-Darcy flow test with a high flow rate was conducted with the permeability estimated using the Forchheimer equation. An effective pressure coefficient χ, which is a function of Pc and Pp, was estimated to increase non-linearly as the difference between Pc and Pp decreased, with a maximum of 1.36 being observed. This helped to conclude that the power law model was appropriate to estimate the change in supercritical CO_2 permeability with varying confining and pore pressures. Caulk et al. [6] experimentally observed a fracture aperture change in an enhanced geothermal system. Specimens of granite were used in a column-like flow model to measure evolution of fracture permeability for 20 and 40 days using granite rock and in temperature conditions of 120 °C and 25–35 MPa pressure range. Effective permeability, fracture aperture, and mass of minerals dissolved were computed in relationship to the pore-pressure using X-ray computed tomography (CT) scan imaging. It was observed that increasing pore pressure correlates with declining permeability due to dissolution of minerals and formation of mechanical creeps. Arash [7] carried out an experimental study of fracture response in granite specimens subjected to wide ranges of temperatures

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and pressures. Series of experiments were performed on artificially-fractured granite specimens at a pressure range of 5–36 MPa and rock temperatures of 25 and 130 °C. Fluids were injected and the effect on permeability and fractures closures were examined. It was discovered that increasing the temperature of the injected fluid resulted in increases in the recovery percentages of fracture openings and permeability after pressure was reduced. This paper presents the effect of confining pressure, flowrate, period of flow and temperature on the permeability of high porous sandstone, using brine as reservoir fluid. Tests were done using a computerized formation evaluation system.

2 Methods

The steps of investigation in this research are as follows;

- A computerized porosimeter-permeameter (Vinci) was used to measure the porosity and permeability of the sample.
- The sample was transferred to a computerized formation evaluation system and the permeability was measured for a confining pressure of 1060–3091 psi; a flowrate of 0.1–0.4 cc/min; within a flow period of 10–40 min experimental duration and at various temperatures.

3 Results

The permeability obtained, using a computerized formation evaluation system, when flowrates and temperature were varied is shown in Table 1. Permeability to water at different experimental durations and confining pressures is shown in Table 2. Permeability variation with flowrates and temperature is presented in Fig. 1, while permeability variation with length of experiment time and confining pressure is presented in Fig. 2.

4 Discussion

Permeability was observed to increase with increasing temperature at the flowrate of 0.1 cc/mins but the same permeability was observed to decrease with increasing flowrate, even when temperature increased slightly as shown in Fig. 1. This comes as a result of the fact that water mobility increases with increasing temperature, leading to a better and more effective permeability to water. Permeability was also observed to increase with increasing experimental time and

Table 1 High porous sandstone's permeability to water variation with flowrates and temperature using computerized formation evaluation system

Flowrate (cc.min^{-1})	Temp. (°C)	Effective permeability
		Keff (mD)
0.1	26.5	3.4149
0.1	38.2	4.4914
0.1	38.2	4.6391
0.1	42.6	5.6109
0.1	42.6	4.8739
0.1	42.6	4.4726
0.1	42.6	4.0786
0.2	38.2	7.3572
0.2	38.2	7.4046
0.2	38.2	7.9526
0.2	42.8	6.8049
0.2	42.8	5.4076
0.2	42.8	5.6722
0.2	42.8	5.8387
0.3	38.2	6.6404
0.3	38.2	7.1157
0.4	38.2	6.5298

Table 2 High porous sandstone's permeability to water variation with experiment duration and confining pressure using computerized formation evaluation system

Experiment duration (mins)	Effective permeability Keff (mD)	Confining pressure (psi)
10	5.4076	2508
10	5.6722	2508
10	5.8387	2508
20	7.4046	3091
20	7.9526	3091
20	7.3572	3091
20	6.6404	3091
20	7.4575	3091
20	7.1157	3091
20	6.5298	3091
30	4.4914	3091
30	4.6391	3091
40	3.4149	1060
40	5.6109	1279
40	4.8739	1279
40	4.4726	1279
40	4.0786	1279

confining pressure, as shown in Fig. 2. The increase of permeability with increasing flow time period is probably due to a better flow stability with time, resulting in less frictional loss.

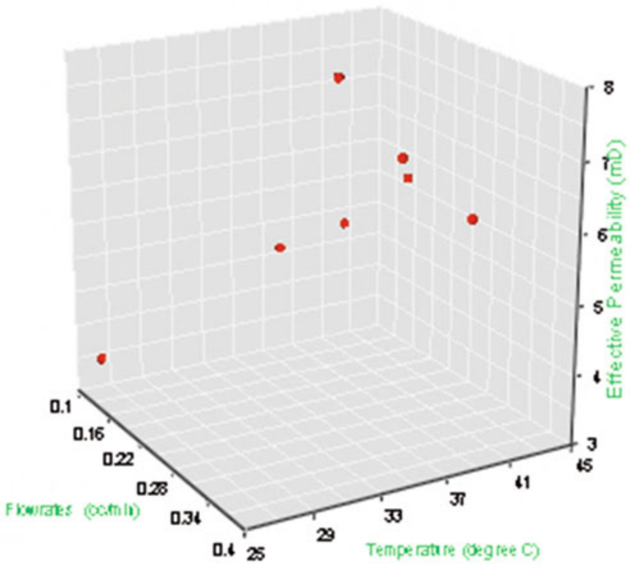

Fig. 1 Effective permeability variation with flowrates & temperature for sample 1

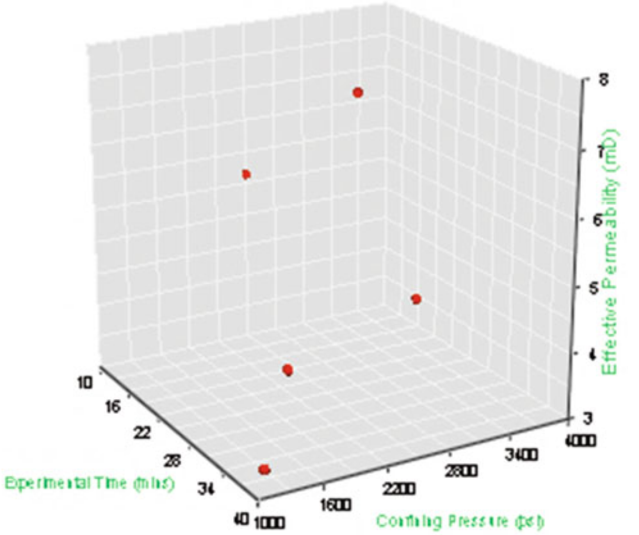

Fig. 2 Effective permeability variation with experiment time & confining pressure for sample 1

5 Conclusions

The influence of fluid flowrate, temperature, confining pressure and length of experiment on permeability was observed and measured. All these parameters should be considered at reservoir conditions, as much as possible, while determining the permeability of a reservoir rock. Unfortunately, it is not possible to run the experiment in reservoir conditions, especially for flowrate and the length of flow period. There is a need to run various permeability measurement experiments and find a mean value at various possible conditions.

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