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EFFECT OF CONFINING PRESSURE ON PORE VOLUME IN
TIGHT SANDSTONES

Topical Report

By
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May 1982
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Institute of Gas Technology
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Bartlesville, Oklahoma

U. S. DEPARTMENT OF ENERGY

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IN TIGHT SANDSTONES**

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ABSTRACT

The effect of confining pressure on the pore volume of some tight sandstones from the Uinta Basin, Utah, was investigated. A new method based on the pressure-volume relationships of a gas was developed and used to measure pore volume reduction. The results were compared with the results obtained using the more common method that involves the measurement of liquid expelled from a saturated core and were found to be in good agreement. Pore volume compressibility of the samples studied is in the range of values reported by other investigators and ranges from 2.0×10^{-6} to 1.3×10^{-5} pv/pv/psi at a confining pressure of 5,000 psi.

INTRODUCTION

The permeability and porosity of tight sandstones are two petrophysical properties that must be known when evaluating geological formations and calculating reserves. Extensive research has shown that confining pressure significantly affects the permeability of tight sandstones. The effect of confining pressure on the porosity of tight sandstones, however, has not usually been taken into consideration. Because porosity measurements are generally taken at ambient conditions, the effect that confining pressure can have on these conventional porosity measurements must be understood before they can be used to evaluate reservoirs.

In a partially water-saturated gas reservoir, the combined effects of fluid expansion and pore volume reduction can result in increasing water saturation, which, in turn, decreases the reservoir's effective permeability to gas. This relative permeability effect is especially significant in tight sandstones. In addition, because partial water saturations are measured at ambient conditions, any reduction in porosity caused by confining pressure will affect the interpretation of relative permeability measurements made in the laboratory.

In the most common method reported in the literature for measuring pore volume reduction in sandstones, the fluid expelled from a liquid-saturated core sample is monitored while the effective confining pressure is increased (1-3). Low-permeability sandstones tend to contain water-sensitive clays (4); thus, it is advantageous to use a method that is applicable to dry samples. Such a method has been developed and successfully used to measure the pore volume reduction in some low-permeability sandstones. It can be considered an extension of the classic Bureau of Mines' Boyle's law method for determining porosity. The details of the experimental method and the results are presented in this report.

The low-permeability sandstones investigated are from the Mapco RBU 11-17F well (Section 17, T10S, R20E) in the Uinta Basin, Utah. The samples were obtained from depths that ranged from 8,234.4 to 8,365.9 feet. They are petrographically similar to other low-permeability sandstones of the Late Cretaceous Age from this region. They are fine to very fine grained, moderately well sorted, and rich in detrital quartz and rock fragments. A detailed mineralogical description of the samples has been presented elsewhere (4).

APPARATUS AND EXPERIMENTAL METHODS

Core plugs approximately 2 inches long and 1 inch in diameter were used in the experiments. Two different methods were used to measure pore volume reduction. In the first method, the fluid expelled from a water-saturated sample was monitored; in the second method dry samples were used.

The experimental setup for the first method is shown in Figure 1. The apparatus is similar to that described by Hall (1). The core plugs were evacuated and saturated with de-aerated water. These saturated plugs were placed in a core holder, and the flow lines were also filled with de-aerated water. Initially, a confining pressure of 200 psi was imposed on the sample. Subsequently, the confining pressure was increased in steps to 5,000 psi. At each confining pressure, the amount of water expelled because of pore volume reduction was monitored by a calibrated micropipet. The amount of time needed to achieve equilibrium at each confining pressure varied from sample to sample, but was generally about an hour at each new confining pressure. The pore volume measured by weighing before and after saturation at ambient conditions was assumed to be the initial pore volume.

A schematic diagram of the experimental setup for the second method is shown in Figure 2. Pore volume reduction was directly measured by a calibrated positive displacement pump in conjunction with pressure monitoring instruments. A dry sample was placed in the core holder, and a nominal confining pressure of 200 psi was imposed on it. Nitrogen gas was then expanded into the core from the pump with an initial pressure of 80 psi. The position of the piston in the positive displacement pump was altered until the pressure was increased back to 80 psi. Confining pressure was then increased in steps to 5,000 psi. As it was increased, the pore volume reduction of the sample caused an increase in the pore pressure. The position of the piston was adjusted at each stage to maintain a constant pressure at the initial value, and the change in pore volume was directly measured. The use of a strip-chart recorder and a pressure transducer enabled the visual ascertainment of equilibrium. The amount of time required to achieve equilibrium was usually a few minutes. Thus, the time needed for each measurement was modest. In addition, the proper choice of transducer range enabled operation at pressure conditions such that any errors that could result from the instrumentation were minimized.

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Figure 1. SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SETUP FOR METHOD 1

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Figure 2. SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SETUP FOR METHOD 2

EXPERIMENTAL RESULTS AND DISCUSSION

A typical pore volume reduction curve is shown in Figure 3 for a sample from a depth of 8,298.4 feet. (Sample numbers correspond to the depths in feet.) Results of both experimental methods are shown, and they agree with each other reasonably well. The close agreement between the results indicates that the pore volume reduction of tight sandstones is not significantly affected by the nature of the pore fluid. There are conspicuous advantages to the new (dry) method over the more commonly used earlier (wet) method. First, the time required for measurements is reduced considerably; also, the attainment of equilibrium is readily observed by a strip-chart recorder. Second, there is no need to expose the samples to water or brine, which could react with the sample material. In addition, the new method has other applications to laboratory measurements of petrophysical properties. For example, to obtain the partial water or brine saturation of samples during relative permeability measurements, the partially saturated sample is usually weighed under ambient conditions. Then the level of saturation is calculated, also under ambient conditions, using values of pore volume. Using the new dry method described here, it is possible to measure saturation levels under confining pressure conditions and at elevated pore pressures. Furthermore, because the pore volume of the samples under confining pressure can be measured so easily, the measurement of partial water saturation under in-situ conditions of pressure is also facilitated. The method can also be adapted for use at elevated temperatures.

The data obtained by the dry method for several samples from this well are summarized in Table 1. The pore volume retained by most of the samples under a confining pressure of 5,000 psi was 85% or more of the initial value. The two exceptions were sample Nos. 8,234.4 and 8,234.9, which suffered a much more severe reduction in pore volume and retained only 65.5% and 57.7%, respectively, of their initial pore volume. These two samples also had very low porosity (less than 2%). Mineralogical examination indicated that these two samples contained a much larger amount of calcite (20% to 42%, respectively); the others had less than 2% calcite. It is apparent from the data that there is little or no change in in-situ water saturation in the reservoir because of increasing net confining stress due to drawdown. But because most laboratory methods for estimating water saturation involve weighing the partially saturated sample and estimating the saturation from the weight, there can be a significant difference between saturations under ambient conditions and those under high confining pressures. For example, if the partial water saturation determined by weighing was 60%, the value at in-situ pressures would be approximately 70% for the same water content.

Permeability measurements conducted on the same samples indicate that increasing confining pressure causes the permeability to decrease almost tenfold (4); the pore volume decreases only 10% to 15%. This adds credence to the hypothesis that permeability reduction in tight sandstones is mainly caused by the sealing off of intergranular pore spaces or slits due to confining pressure.

Pore volume compressibility, C_p , is defined at a particular confining pressure, P_c , as –

$$C_p = \frac{1}{V_p} \frac{dV_p}{dP_c}$$

where V_p is the pore volume at the confining pressure of interest (5000 psi in this case) and dV_p/dP_c is the slope (at $P_c = 5000$ psi) of the curve relating pore volume and confining pressure. The pore volume compressibilities, listed in Table 1, ranged between 2.0×10^{-6} and 1.3×10^{-5} pv/pv/psi. A plot of pore volume compressibility versus initial porosity is shown in Figure 4. The relationship between the two parameters is similar to that reported by Hall (1) for sandstone and limestone samples. The pore volume compressibility values are in the range of values reported by Jones and Owens (5) for other low-permeability sandstones.

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Figure 3. PORE VOLUME REDUCTION CURVE FOR A SAMPLE FROM A DEPTH OF 8298.4 FEET

Table 1. SUMMARY OF PORE VOLUME REDUCTION DATA

Sample No.	Initial Porosity, Fraction	Percent of Initial Pore Volume Retained at a Confining Pressure of 5,000 psi	Pore Volume Compressibility at a Confining Pressure of 5000 psi, $pv/pv/psi$
8,234.4	0.017	65.5	1.28×10^{-5}
8,234.9	0.014	57.7	1.58×10^{-5}
8,243.3	0.098	89.0	4.20×10^{-6}
8,243.9	0.111	90.0	2.00×10^{-6}
8,290.4	0.067	86.7	3.90×10^{-6}
8,298.4	0.066	87.6	3.90×10^{-6}
8,290.8	0.053	86.7	4.70×10^{-6}
8,358.3	0.077	85.4	4.70×10^{-6}
8,358.7	0.079	86.4	2.80×10^{-6}
8,365.4	0.058	90.1	4.30×10^{-6}
8,365.9	0.059	85.5	5.10×10^{-6}

Figure 4. PORE VOLUME COMPRESSIBILITY COMPARED TO INITIAL POROSITY

CONCLUSIONS

A new method has been developed to measure the pore volume compressibility of sandstones. It has been tested on some low-permeability sandstones. The values obtained were found to be in the range of values reported by other investigators for low-permeability sandstones. The method is easily applicable to different porous media and can be used over a wide range of pore pressures and confining pressures.

For the samples studied, pore volume reduction due to production would not be significant enough to cause concern in the analysis of reservoir performance. It would be an important factor, however, in the interpretation of core measurements of water saturation. Pore volume compressibility of the samples investigated varied from 2.0×10^{-6} to 1.3×10^{-5} pv/pv/psi.

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