RELATIONSHIP BETWEEN RESERVOIR PRODUCTIVITY AND PORE PRESSURE DROP

Musaed N. J. Al-Awad
Petroleum Eng. Dept, College of Eng., King Saud University,

ABSTRACT

The significance of permeability sensitivity to changes in pore pressure (i.e., to change in effective overburden stress) has been examined using three Saudi oil reservoir rock samples as well as Berea sandstone. All of these cores were free of microfractures. The relationship between the overburden pressure and absolute permeability of these samples were determined at several levels of confining pressure at which the permeability was calculated. The experimental work performed in this study showed that reservoir rocks of high initial porosity and permeability are highly affected by reservoir (pore) pressure drop and resulting increase in the effective stress. For example, the production rate from sandstone sample N3 decreased 25% of its initial value when the pore pressure decreased by 25% of its initial value, whereas the production rate from carbonate sample N4 decreased 8% for the same pore pressure decrease. Moreover, it was observed that, the reservoir rock permeability under in-situ conditions strongly depends on its initial porosity and permeability values.

INTRODUCTION

The consequences of the change in the in-situ stress state is the change in rock properties including porosity, permeability and mechanical properties. A number of researchers have investigated the changes in reservoir rock porosity, compressibility, density, resistivity, permeability and relative permeability with changes in effective confining pressure as well as reservoir compaction [1-14]. The results all indicated that the permeability is reduced when the net confining pressure is increased. The aim of this study is to incorporate the experimentally obtained relationship between the effective overburden stress (i.e. change in pore pressure) and the absolute permeability of reservoir rocks into Darcy law for radial single phase steady state flow and the resultant model is used to predict the magnitude of decrease in petroleum reservoirs productivities.

EXPERIMENTAL WORK

A saturated cylindrical core sample is loaded into Hoek cell and the axial load is applied to the flat sample ends using a stiff compression tester. The radial load (confining pressure) is generated using an automatically controlled constant pressure pump. Test sample is brought to the in-situ conditions and left for a while to equilibrate under such conditions. Then the pore pressure is reduced by a specific value (while the confining pressure is kept constant) and the sample permeability is measured using a liquid permeameter. In this work, the four cores were cut and their dimensions were measured, then saturated with 1% NaCl solution. After full saturation, the physical properties of the four core samples were

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measured. The permeability of the rock samples was measured using a steady state liquid permeameter. This was done by forcing an aqueous solution (1% NaCl) of known viscosity through a core plug of known cross sectional area and length. Pressure and flow rate of liquid through the sample were measured and initial permeability was calculated using Darcy law for single phase steady state flow. The same procedure was applied when measuring the permeability-stress relationship.

FORMULATION OF THE MODEL

Based on the obtained experimental data, the permeability change due to the decrease in pore pressure can be expressed as follows:

$$k = a_o + a_1 Pp + a_2 Pp^2 + a_3 Pp^3 + \ldots \tag{1}$$

By the incorporation of Eq. 1 into Darcy law for radial single phase steady state flow through porous media and integrating the resulted formula, the following equation is obtained:

$$\int_{r_1}^{r_2} \left[\frac{q}{2\pi rh} \right] dr = \frac{1.127}{\mu} \int_{Pp_1}^{Pp_2} \left[a_o + a_1 Pp + a_2 Pp^2 + a_3 Pp^3 + \ldots \right] dP_p \tag{2}$$

Therefore, two expressions for the fluid flow can be derived: firstly, by neglecting permeability-pore pressure relationship assuming the permeability will remain constant at its initial undisturbed value and secondly, taking into account permeability-pore pressure relationship (Eq. 2). Thus, there are two mechanisms governing the flow of fluids in the petroleum reservoir firstly, the difference between the wellbore pressure and the average reservoir pore fluids pressure, and secondly, the difference between the overburden stress and the average reservoir pore fluids pressure. The first mechanism is a flow driving force, which tends to increase the amount of produced fluids, whereas the second one is an obstructing force causing a reduction in the amount of produced fluids by reducing the porosity and, consequently, the permeability of the reservoir rock.

RESULTS AND DISCUSSION

The relationship between the absolute permeability and the total confining (overburden) pressure was experimentally determined for three sandstones and a carbonate reservoir rock sample. It was found that there is a decrease in permeability with the increase in the total confining (overburden) pressure. The carbonate core sample had little decrease in permeability when compared to the decrease in the permeability of the sandstone cores. This difference in permeability reduction can be attributed to the difference in the initial porosity and permeability of the two types of rock (see **Table 1**). Based on the experimental results shown in **Fig. 1**, correlations between the absolute permeability and the pore pressure drop in the form of polynomials of the 4th degree were obtained. It was found that all the tested core samples restore their initial permeability when the applied confining pressure is released from 5000 psi to its initial value of 500 psi indicating that these samples had no permanent reduction in permeability (pore collapse). If any rock sample is loaded above its yield strength, a permanent reduction in permeability will be the result due to pore collapse. It must be kept in mind that the loss of permeability due to pore collapse may not be restored by acidizing, fracturing or other well stimulation techniques. The correlation data was used to predict the decrease in reservoir productivity due to pore pressure drop. Two models were used in this analysis: the first based on pore pressure independent permeability and the second is the pore pressure dependent permeability (Eq. 2). It was found that if the reservoir pore pressure is decreased by 25% of its initial value the productivity will decrease by 8%, 13%, 25% and 3% for samples N1, N2, N3 and N4, respectively (see **Fig. 2** for example). Thus, the assumption that permeability is independent of pore pressure will yield overestimated production rates.

CONCLUSIONS

This study suggests that a severe error in productivity predictions can result on assuming that the formation permeability at depth is independent of the effective stress. Because the increase in the effective stress decreases porosity which, in turn, changes permeability.

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Table 1 Physical properties of the tested core samples

Core no.	Type	Diameter, cm	Length, cm	Dry weight, g	Pore volume, cc	Porosity, %	Initial absolute permeability, Darcy
N1	Berea sandstone	3.82	8.80	204	21	20.7	0.2186
N2	Saudi sandstone	3.82	8.80	165	19	23.3	0.4030
N3	Saudi sandstone	3.82	8.80	169	16	18.6	0.6930
N4	Saudi carbonate	3.82	8.80	203	10.5	11.6	0.1900

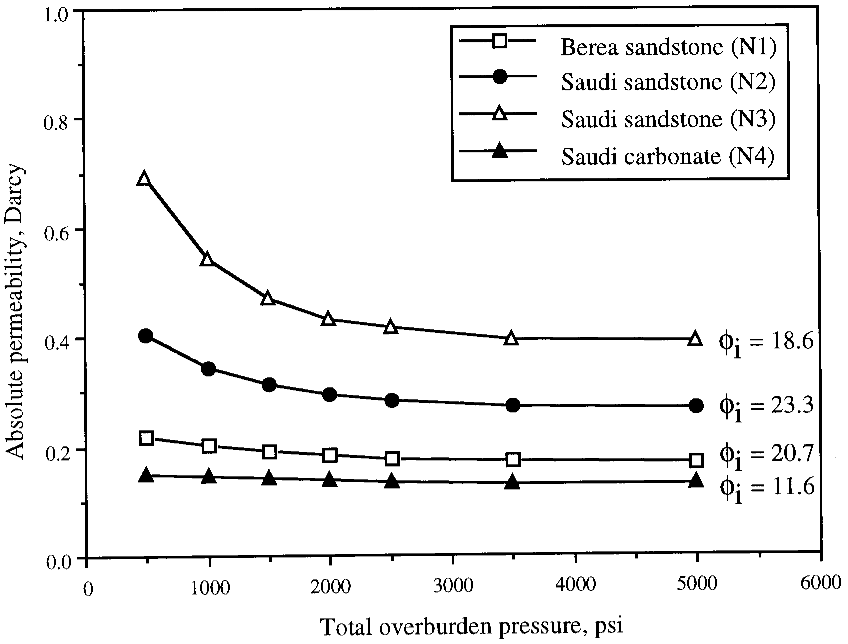

Fig. 1 Reduction of absolute permeability with total overburden pressure.

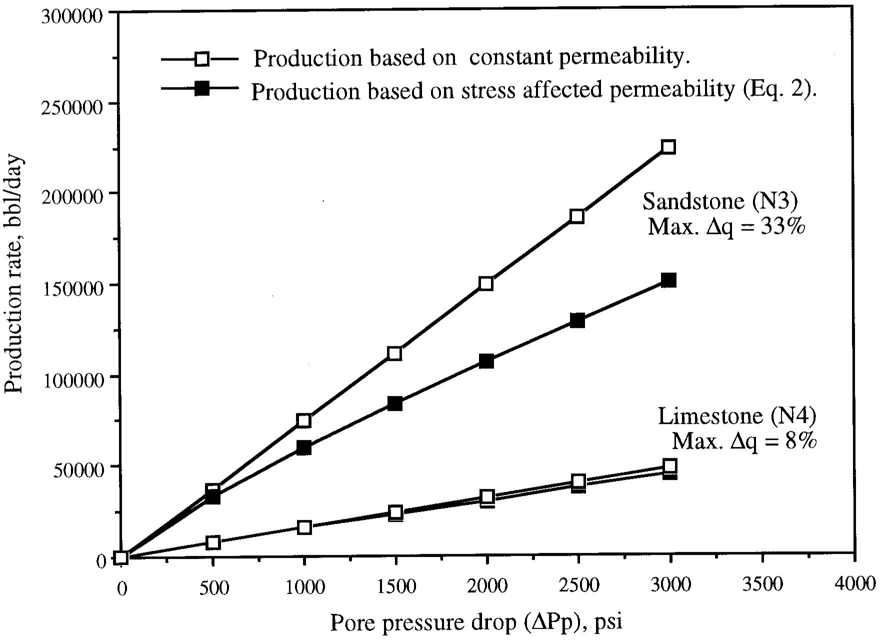

Fig. 2 Effect of pore pressure drop on formation productivity for samples N3 and N4.

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