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Well logging in oil fields

9.1 INTRODUCTION

Contrary to what one might expect, little information is obtained on the production potential of an oil well as it is being drilled. The reason is that, for from hydrocarbons 'gushing out', they are actually pushed back by the drilling mud and although cuttings reveal the general lithology in the well and may perhaps show traces of hydrocarbons, they furnish no estimates of oil and gas in place. It is through the data of measurements of various kinds in the wells that such estimates can be made.

If \( A (\text{m}^2) \) and \( h (\text{m}) \) are the area and thickness of an oil reservoir then

\[
\text{Oil in place} = A h (1 - S_w) \phi \text{ m}^3
\]

(9.1)

where \( \phi \) is the porosity of the oil-bearing stratum and \( S_w \) is the fraction of total pores that contains water so that the fraction \( 1 - S_w \) contains oil. An exactly similar equation can be written down for gas in place but the gas volume exists at the temperature \( t (^\circ \text{C}) \) and pressure \( P (\text{Pa}) \) at the depth in question. Using Boyle's law, however, it is very easy to show that at standard pressure \( (P_o) \) and temperature \( (t_o) \), usually atmospheric pressure and surface temperature,

\[
\text{Gas volume} = \frac{P}{P_o} \frac{273 + t}{273 + t_o} (1 - S_w) \phi \text{ m}^3
\]

(9.2)

where \( t, t_o \) are in degrees Celsius. If \( P \) at the depth \( d (\text{m}) \) is not known it may be taken as \( 10000d (\text{Pa}) \), this being the hydrostatic pressure assuming the water throughout the geologic column to be freely communicating.

9.2 PERMEABLE ZONES

While porosity is effective in determining the quantity of oil or gas in place it is not in itself sufficient to ensure recovery. A high porosity with little or no
connection between pores (and between fractures and other similar spaces) will not lead to any recovery. For recovery it is also necessary that the formation be permeable, that is, allow the flow of hydrocarbons under a pressure gradient.

Permeability is expressed in the oil industry in darcy (or the subunit millidarcy), after H. Darcy who first studied the flow of fluids through porous media in the 19th century. Physically, it has the dimensions (length)$^2$ and, in particular, 1 darcy = $0.987 \times 10^{-12}$ m$^2$. The quantitative aspects of rock permeability will not concern us since they belong to the province of reservoir engineering. Suffice it to say that permeabilities are usually such that the recoverable quantity of oil is about 20% of the in situ estimate, that for gas may be as much as 70%.

From the point of view of estimating hydrocarbon quantities in place the primary aim of logging is to locate permeable zones and determine $\phi$ and $S_w$ in Eqs (9.1) and (9.2). The logs easily yield $h$ for the bed in question but not $A$. If no other information is available, $A$ can be taken as the square of the spacing between two wells in which the bed has been observed.

The most important hydrocarbon-bearing rocks are sandstones, limestones and dolomites, all of which can have high porosities and permeabilities. The porosity of sandstones is largely a primary one due to spaces between sand grains. It is rather uniform and averages about 20%. Limestones and dolomites possess in addition secondary porosity due to fractures and due to cavities formed by the solution of some rock matrix through the action of water. The porosity of limestones and dolomites is much less uniform than that of sandstones.

Besides the above three rock types, shales, a category that also includes clays in the present context, are an important constituent of the sedimentary rocks of oil and gas fields. Shales may have high porosity but their permeability is practically zero since the clay fraction is them effectively binds practically all water and renders it immobile.

Briefly, then, the impermeable sections on a log are shales, the permeable ones non-shales. The latter may be clean, that is, devoid of any shaly beds, or dirty, containing shales to a greater or smaller extent. Accounting for the shaly fraction in non-shales can be a major problem in estimating hydrocarbons in place.

### 9.3 Archie’s Law

Using the notation common in the logging industry this law (Section 4.4.1) can be written as

$$R_t = \frac{R_w}{\phi^m S_w^n}$$  \hspace{1cm} (9.3)