9 The Influx of Water into the Reservoir

9.1 Introduction

Chapter 1 explained how all hydrocarbon reservoirs, at the time of their formation, must have been in contact with an aquifer; the very existence of a hydrocarbon accumulation depended, of course, on the migration of oil or gas through permeable strata saturated with water.

If, over geological time, subsequent faulting or diagenesis happened to create a localised zone of zero permeability somewhere between the reservoir and the aquifer, hydraulic continuity would be interrupted. This might have occurred close to the reservoir or some distance from it, and, consequently, the volume $V_{aq}$ of aquifer remaining in communication could be anything from zero to a very large value.

In any case, there is no such thing as an infinitely large aquifer. The term “infinite aquifer” is however a commonly used reservoir engineering term; its meaning will be explained shortly.

The decrease in pressure which results from the production of oil or gas from the reservoir, propagates with a finite velocity into the aquifer if it is in hydraulic communication. The reduced pressure allows the water to expand.

As long as the pressure disturbance has not reached the external limits of the aquifer, it is said to be “infinite acting” – it is in this context that the term infinite aquifer is used.

The expansion of aquifer water induced by the declining pressure over a period of time $t$ since the onset of production, represents a volume $W_e(t)$. The water/hydrocarbon contact will be displaced upwards from its original position by a corresponding amount – this is “water drive”.

The calculation of $W_e(t)$ from the production history of the reservoir is straightforward.

As a simple example, we can consider a dry gas reservoir. $G$ is the initial volume of gas in place, $G_p(t)$ is the volume of gas produced in time $t$, and $B_{gi}$ and $B_g(p)$ are the gas volume factors (Sect. 2.3.1.1) at initial pressure $p_i$ and $p(t)$, respectively.

If we ignore any change in the porosity of the reservoir rock with pressure, we have by material balance:

$$G B_{gi} = [G - G_p(t)] B_g(p) + W_e . \tag{9.1}$$

Equation (9.1) is in fact saying that the pore volume $V_p$ above the initial gas/water contact remains constant with time (Fig. 9.1).

$W_e(t)$ can of course only increase with $t$. In reality, successive estimations of $W_e(t)$ calculated with Eq. (9.1) at various times in the producing life of the reservoir often display a quite irregular trend (Fig. 9.2), especially in the early stages. This is primarily the result of errors in the evaluation of the initial reserves $G$ (calculated
The Influx of Water into the Reservoir

\[ \text{INITIAL GWC} \]

\[ \text{GWC AT TIME } t \]

\[ (G-G_p) B_g \]

\[ W_e(t) \]

\[ \text{AQUIFER} \]

**Fig. 9.1.** Representation of the terms in Eq. (9.1) for material balance in a gas reservoir under water drive.

**Fig. 9.2.** Water influx \( W_e(t) \) calculated by material balance (points), and average trend (dashed line).

volumetrically as described in Chap. 4), and the pressures \( p_i \) and \( p(t) \), on which \( B_g(p) \) depends.

The actual trend more closely follows an average curve through the data, as shown in Fig. 9.2.

*Prediction of \( W_e(t) \) is far more difficult* when production constraints are imposed. Nevertheless, it is absolutely essential to know \( W_e(t) \) if we are to evaluate the future productivity and pressure behaviour in any hydrocarbon reservoir in communication with an aquifer.

If the geometry and lateral extent of the aquifer are known, and its thickness, porosity and permeability are known and constant, \( W_e(t) \) can be calculated from \( p(t) \) quite easily using the theory introduced in Chaps. 5 and 6 for wells producing from reservoirs containing fluids of small but constant compressibility.

The reservoir itself can, in fact, be represented as a very large well which is draining the surrounding aquifer.

Unfortunately, the aquifer geometry is frequently known only roughly, through a study of the basin geology. Also, its thickness, porosity and permeability cannot be measured directly, and are far from constant. Since wells are rarely drilled intentionally into the aquifer, information about it can only be obtained from “dry” wells (unsuccessful exploration or development wells), which are usually in the immediate vicinity of the reservoir and therefore provide only a local picture.

This chapter will introduce a number of methods which have been developed to estimate \( W_e(t) \). In the period from the mid-1930s to the early 1970s, computational