Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

The Study of the Effect of Water Saturation (Sw) on Fractional Flow and Water Cut to Determine Sw Cutoff

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***Abstract:*— The limited production data such as water cut value in an exploration field remains as the major problem in the determination of water saturation cutoff. Therefore, an equation which can correlate the unknown water cut value is needed. By proving that the water cut value is equivalent to the fractional flow value, this problem can be solved. The methods used in this study consist of deriving the previously known theoretical equations into a new equation which shows that the water cut value is equivalent to the fractional flow value. Next, fractional flow and water cut values are calculated and compared against the actual water cut obtained from production data in order to prove that the calculated value matches with the actual value. The results show that fractional flow is equivalent to the water cut. Based on the data obtained, the Sw cutoff is defined by plotting graphs of water cut or fractional flow against Sw. The water saturation cutoff obtained is 60%.**

Keywords:*— *Fractional flow; water cut; cutoff; water saturation(key words)

I. INTRODUCTION

Oil and gas are non-renewable resources of the world. Oil and gas industry in Indonesia have been advancing from year to year to meet the increasing domestic demand for fuel. Oil and gas sector is also the largest source of foreign exchange income for Indonesia and has become the backbone of national development. Therefore, concrete efforts to continuously optimize the increase in production and develop new fields are needed. When hydrocarbons are produced, the Water Cut of the field will increase. In other words, with higher water content, the less hydrocarbons are produced. The purpose of this study is to prove that the Oil-Water Production Performance is closely related to Water Saturation and Fractional Flow. In order to do so, production data as well as the characteristics of the rock and fluid are needed. The limitation of this study is the lack of discussion regarding its effect on temperature and pressure.

II. PROBLEM DEFINITION

It is to identify the extent of the effect of *Water Cut* on the *Fractional Flow*. By plotting *Fractional Flow* or *Water Cut* against Sw, the Cut Off of the Water Saturation can be defined.

III. LITERATURE REVIEW

Cut-off layer or boundary layer is a value of reference in removing parts of the reservoir which are deemed non-productive. The cut-off value can be determined from the *data log*, *data core*, *data test* of the production, and field experience.

Sw cutoff can be determined by the plot graph of Sw vs *water cut*. This *Sw cutoff* determination is qualitative, that is by determining the Sw cutoff value which divides the Cartesian graph into two distinct zones – the left side of the Sw cutoff value which is still pumping oil, and the right side of the Sw cutoff value.

Sw with a *water cut* value of 100% (where only water is produced). In determining the Sw cutoff by means of plottig *fractional flow* vs Sw, when two or more trends are found due to differences in *facies*, then the determination must be properly suited according to the specific *facies* as shown in the following diagram.

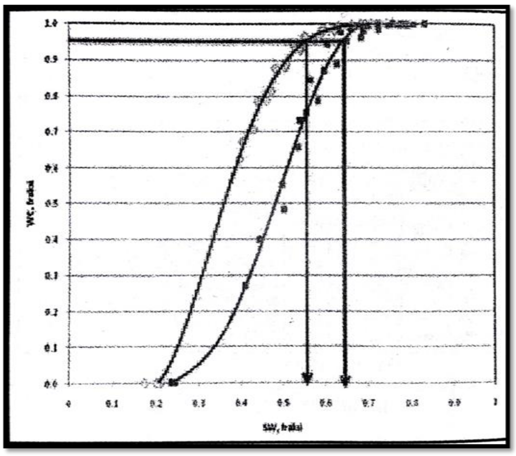

FIG 1. AN EXAMPLE OF DETERMINATION OF SW CUTOFF WITH DIFFERING FACIES[7]

A. Determination of Swirr

In order to calculate *Water Cut, the irreducible water saturation* (Swirr) has to be defined beforehand. In reservoir rocks, there are formation water which cannot be replaced by the oil and gas migrating to the reservoir rocks previously occupied only by water. This water saturation is called *irreducible water saturation* (Swirr).

The determination of *irreducible water saturation* (Swirr) can be done qualitatively by plotting depth against Sw as shown in Figure 2 below.

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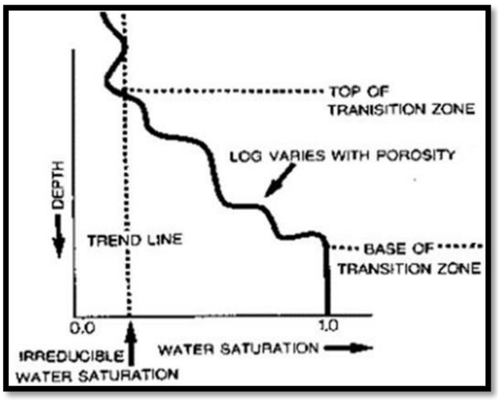

FIG 2. DETERMINATION OF IRREDUCIBLE WATER SATURATION[3]

B. Determination of Water Cut

Water Cut is the ratio of water production to production of hydrocarbon fluids. *Water cut* in exploration wells can be calculated using the following equations.

$$WCo = \frac{WOr}{(1 + WOr)} \quad (1)$$

$$WOr = Bo \times \frac{\mu_o}{\mu_w} \times KRwo \quad (2)$$

$$KRwo = \frac{Krw}{Kro} \quad (3)$$

Where:

WCo = Water cut for oil well, fraction
WOr = *Water oil ratio*, fraction
Bo = Volume factor of formation oil, bbl/stb
μo = Oil viscosity, cp
μw = Water viscosity, cp
KRwo = Permeability ratio of water to oil, fraction
Krw = Relative permeability for water, fraction
Kro = Relative permeability for oil, fraction

According to *Wyllie – Gardner correlation*, Krw and Kro can be calculated using the following equations.

$$Krw = (S_o^*)^4 \quad (4)$$

$$Kro = \frac{(1 - S_o^*)^2}{(1 - S_w^{*2})} \quad (5)$$

Where:

S_o^* = Effective oil saturation, fraction
S_w^* = Effective water saturation, fraction

In effective permeability correlation for 2 (two) phases (water and oil), the effective saturation can be calculated using the following equations.

$$S_o^* = \frac{S_o}{1 - Swirr} \quad (6)$$

$$S_w^* = \frac{S_w - Swirr}{1 - Swirr} \quad (7)$$

Where:

So = Oil saturation, fraction
Sw = Water saturation, fraction
Swirr = irreducible water saturation, fraction

C. Determination of Fractional Flow

The fractional flow equation is an equation that can qualitatively show the ratio of the flow rate of water to total flow rate of fluids at certain period of time and space in a linear system of water injection. The equation shows the relationship between the amount of water flow in every area of the reservoir with the amount of water saturation. In a homogenous, two-phase, and isothermal system, the *fractional flow* equation can be defined as:

$$fw = \frac{q_w}{q_t} = \frac{q_w}{q_w + q_o} \quad (8)$$

Where:

fw = fractional flow, fraction
q_w = flow rate of water, bpd
q_o = flow rate of oil, bpd

Aside from that, the *fractional flow* (fw) value can also be calculated using the formula below.

$$fw = \frac{1}{1 + \frac{Kro\,\mu_w}{Krw\,\mu_o}} \quad (9)$$

Where:

μo = Oil viscosity, cp
μw = Water viscosity, cp
Krw = Relative permeability for water, fraction
Kro = Relative permeability for oil, fraction

IV. HYPOTHESIS

The limitation of data in calculating *Fractional Flow* can be replaced by the *Water Cut* of the field. Therefore, the problem of the limited data can be solved.

V. METHODOLOGY

Based on the aforementioned problem definition and the hypothesis, there needs to be a correlation which can be used to determine the fractional flow equivalent to the actual water cut when the field data is insufficient.

The following flowchart explains the steps used in this study.

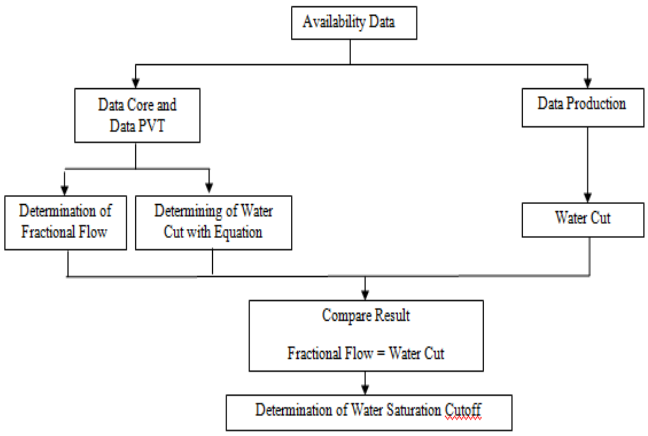

FIG 3. FLOWCHART CUTOFF SW

VI. RESULTS AND ANALYSIS

By substituting equations (1) into (4), an equation that shows that the fractional flow value is equivalent to the water cut value can be derived. The derivation of the equation is as follows.

$$WC = \frac{WOR}{WOR+1}$$

$$= \frac{\frac{fw}{1-fw}}{\frac{fw}{1-fw}+\frac{1-fw}{1-fw}}$$

$$= \frac{fw}{fw+1-fw}$$

WC = fw

Using equation (9), the fractional flow value can be determined. The following is an example of the calculation.

μ_o = 0.92 cp
μ_w = 0.48 cp
Kro = 0.07
Krw = 0.028

$$fw = \frac{1}{1+\frac{Kro\,\mu_w}{Krw\,\mu_o}}$$

$$= \frac{1}{1+\frac{0.07}{0.028}x\frac{0.48}{0.92}}$$

= 0.434

The resulting fractional flow value from the calculation above can be summarized in the following table 1.

TABLE 1. SW VS FW

No	Sw	Fw
1	0.1	0.001
2	0.15	0.008
3	0.2	0.054
4	0.25	0.098
5	0.3	0.223
6	0.35	0.345
7	0.4	0.434
8	0.45	0.657
9	0.5	0.812
10	0.55	0.935
11	0.6	0.972
12	0.65	0.989
13	0.7	0.994
14	0.75	0.996
15	0.8	0.997
16	0.85	0.998
17	0.9	0.999

By using equations (1), (2) and (3), the water cut value can be calculated. The following is an example of the calculation.

Kro = 0.07
Krw = 0.028

$$KRwo = \frac{Krw}{Kro}$$

$$= \frac{0.028}{0.07}$$

= 0.04

μ_o = 0.92 cp
μ_w = 0.48 cp
Bo = 1.118

$$WOr = Bo \times \frac{\mu_o}{\mu_w} \times KRwo$$

$$= 1.118\ x\ \frac{0.92}{0.48}\ x\ 0.04$$

= 0.856

$$WCo = \frac{WOr}{(1 + WOr)}$$

$$= \frac{0.856}{(1 + 0.856)}$$

= 0.461

The resulting fractional flow value from the calculation above can be summarized in the following table 2.

TABLE 2. SW VS WATERCUT

No	Sw	WC
1	0.1	0.002
2	0.15	0.009
3	0.2	0.06
4	0.25	0.108
5	0.3	0.243
6	0.35	0.37
7	0.4	0.461
8	0.45	0.682
9	0.5	0.828
10	0.55	0.941
11	0.6	0.975
12	0.65	0.99
13	0.7	0.994
14	0.75	0.996
15	0.8	0.998
16	0.85	0.998
17	0.9	0.999

The graph of fractional flow or water cut against water saturation was then plotted, hence the cutoff value of the water saturation of the field can be obtained. The graph of fractional flow against water saturation is shown in the following.

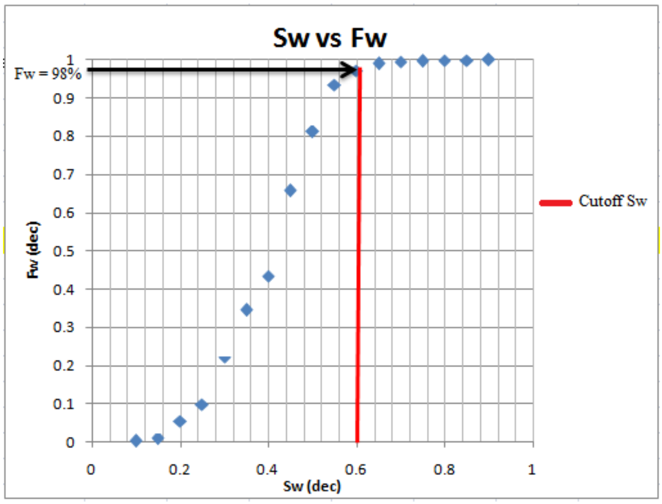

FIG 4.SW CUTOFF FROM SW VS FW

Whereas, the graph of water cut against water saturation is shown in the following.

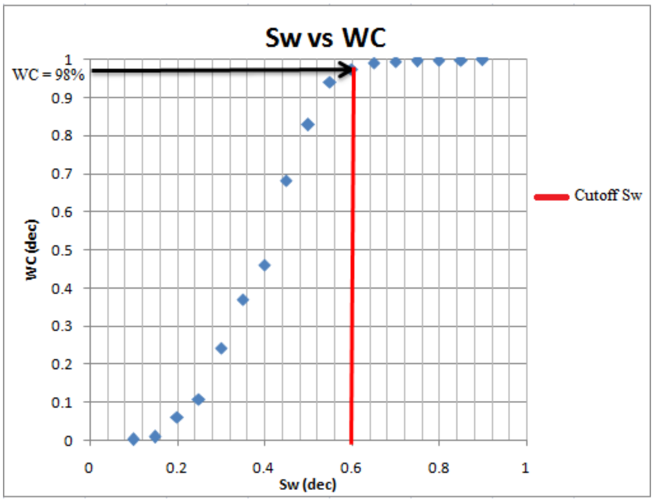

FIG 5. SW CUTOFF FROM SW VS WC

VII. DISCUSSIONS

Based on the methods used in the study, the previously defined equations can be substituted to obtain results which show that fractional flow is equivalent to water cut. In order to prove that, a study was done by calculating the data of field X.

By substituting equation (1) into (4), an equation that shows that the fractional flow value is equivalent to the water cut value can be derived, as previously explained in Section VI (Results and Analysis).

Fractional flow was then calculated using equation (10). Table 1 summarizes the results of the calculation of fractional flow of field X.

Next, water cut was calculated using equations (1), (2), and (3). Table 2 summarizes the results of the calculation of water cut of field X.

Using both fractional flow and water cut data, it can be observed that there is only little difference between the two values. This shows that frictional flow is equivalent to the water cut.

The determination of Sw cutoff was done by plotting graph of fractional flow or water cut against water saturation. In FIG 4, the graph of Sw vs Fw shows a water saturation cutoff of 60%. In FIG 5, the graph of Sw vs WC also shows a water saturation cutoff of 60%. This means that above the value of 60%, the water saturation is considered not productive.

VIII. CONCLUSION

Based on the results and analysis, as well as the discussions, the conclusions of the study are as follows:

1. The fractional flow value is equivalent to the water cut value.
2. The Sw cutoff obtained from the two methods used in the study is the same, which is 60%.
3. If the available fractional flow data is limited, Water Cut can be used to determine Sw Cutoff.

ACKNOWLEDGMENT

The author would like to thank Anastasya P. Rendrati for her contribution in the completion of this paper. The author is also in deep gratitude to the Petroleum Engineering Department, Faculty of Earth Technology and Energy, Trisakti University for providing the opportunity to successfully complete the study.

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