DATA PREPARATION FOR WATER INJECTION LABORATORY TEST

by
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I. INTRODUCTION

Oil production limit that is usually followed by decrease of oil productivity in old fields is a major problem and can't be avoided. This case happened when cumulative oil production has approached primary recovery method. Decrease of the action of native reservoir energy is followed by drastically increase of production of water (saturation almost 100 %).

In relation to this, a method is needed to obtain the additional oil recovery. Water injection method is one of the solutions to solve oil production problem that happened in old fields. It is expected that by using water injection method, productivity and oil recovery in old fields can be improved. Water that is used as the fluid injected into reservoir to improve oil recovery is *sea water*. How far oil recovery can be improved by using water injection method, is determined by a laboratory research. Before carrying out water injection laboratory test; one has to know what are the main points that play important role in determining the optimal oil recovery by water injection method. These are: firstly, basic parameters, secondly, laboratory test for water flooding, thirdly, the displacement of water injection process, then, standard operational procedure, next, water injection to obtain the additional oil recovey, lastly, the results are plotted a figure and or tabulated as the result of water injection laboratory test is obtained. In relation to the mentioned above, it will be better to write a scientific paper of water injection laboratory test. This paper is written based on our experience in enhanced oil recovery research (EOR), supported by textbook, such as American Petroleum Institute, Petroleum Production Handbook and Standard Corrosion and water Technology For Petroleum Producers. Therefore, the main focus of this paper is *"Data Preparation for Water Injection Laboratory Test"*. Hopefully, the contents of this paper give precious and useful informations, that is extremely valuable not only for LEMIGAS as Research and Development Centre for Oil and Gas Technology, but also for the oil industry or the Department of Petroleum Engineering of the universities in Indonesia.

II. BASIC PARAMETERS

This section explains what basic parameters play important role, that are needed to support the determination of oil recovery by water injection method in EOR laboratory, Exploitation Division of Lemigas. These are as follows:

- Samples : core, oil, formation water and sea water.
- Reservoir data : reservoir pressure, tempera ture, depth
- Rock properties : permeability and porosity.
- Fluid properties : oil density, water specific grav ity.
- Chemical composition : formation water, and sea water.

III. REQUIRED LABORATORY TEST FOR WATER FLOODING

To determine oil recovery factor by using water injection in laboratory, it needs a core for water injection test, core vs fluid for compatibility test. Two types of fluid are formation and sea water as injected water. Water injection laboratory test is carried out in the Enhanced Oil Recovery Laboratory (Exploitation Division, Lemigas) under certain reservoir pressure and temperature conditions, based on laboratory analysis standard operational procedure, that involves five main points:

1. Determination of chemical composition and physical water properties.
2. Measurement of physical core properties.
3. Water compatibility test (formation water vs sea water) at reservoir conditions.

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4. Compatibility test; core vs fluid (formation water and sea water) at reservoir conditions.
5. Water Flooding.

IV. THE DISPLACEMENT PROCESS

Secondary recovery of oil deals essentially with the flow of oil and water in a porous reservoir rock. The relative flow rates determine the efficiency of the process. The process by which water occupies pore space formerly filled by oil is called the displacement process. Briefly, the displacement process is dependent upon the nature and characteristics of the water involved, the physical characteristics of the reservoir, certain physical relationship between the fluid and the reservoir rocks. One of the basic equation used in fluid displacement work is the fractional flow formula of Buckley-Leverett. The simplified equation for linear flow of water is:

$$f_w = \frac{1}{1 + \frac{K_o}{K_w}\frac{u_w}{u_o}}$$

where:

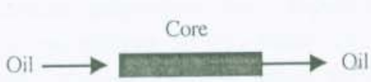
Fw	= fraction flow
Ko (mD)	= oil permeability
Kw (mD)	= water permeability
μw (cp)	= water viscosity
μo (cp)	= oil viscosity

This equation states that the fractional flow depends solely upon the relative permeability-saturation characteristics of the porous system and upon the fluid viscosities. Thus, the curve of fractional flow (fw) should be plotted against water saturation. The process of water injection to improve oil recovery by using core media that is carried out in EOR laboratory, is described schematically in Figure – 4.1 below :

a. Formation water saturation.

Formation water (F_w) is injected into core, expected saturation 100 %.

b. Determination of connate water saturation (Swc).

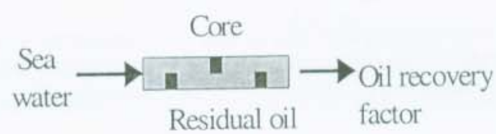


Oil is injected into the core, so that the whole core is filled by oil totally. From this stage, connate water saturation data will be obtained.

c. Determination of oil effective permeability.

Formation water is injected into the core, so that oil is displaced by formation water. However, not all of oil is displaced out of the core, part of amount of oil is left in the core, this is called residual oil. From this stage, oil effective permeability will be calculated.

d. Determination of residual oil saturation (water flooding)



The residual oil that is left in the core, can be displaced and produced by water injection (sea water). Before carrying out water injection, it must be considered that the sea water used as injected water vs formation water should be compatible, and also that core vs fluid (formation water & sea water) should be compatible too. Oil recovery factor can be determined after water injection process done.

V. STANDARD OPERATIONAL PROCEDURE

It is very important to prepare laboratory standard operational procedure for the five main points that will be tested.

Each stage in implementation of water injection laboratory test to obtain the additional oil recovery should fulfill laboratory standard operational procedure, such as American Petroleum Institute (API), Standard Corrosion and Water Technology for Petroleum Producers, Petroleum Production Handbook, also is supported by ISO 17025. Application of laboratory standard operational procedure for the required test (see Section III) will ensure that the obtained analysis result will be accurate. Table – 5.1 shows the standard operational procedure, that contains the five types of analysis, method, equipment and the used standard for water injection laboratory test.

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Table - 5.1
Laboratory standard operational procedure for water injection laboratory test

No.	Types of analysis	Analysis / method	Equipment	Standard
1	Determination of chemical compositions and physical water properties	- Chemical composition	Water analysis aboratory	API - RP 45
		- Water spesific gravity	Spesific gravity tool	API - RP 45
2	Measurement of physical core properties	- Porosity	Helium Gas expansion porosimeter	API recommendet practise no. 40, supported by ISO 17025
		- Permeability	Digital gas permeameter	API recommendet practise no. 40, supported by ISO 17025
		- Oil density	Densitometer	API - RP 45
3	Water compatibility test (fromation water vs sea water) at reservoir conditions	- Compatible or not between formation water and sea water	Water comptibility test equipment	Standard corrosion and water technology for petroleum producers, Jones, L.W, OGGI, Publication, 1988, Tulsa.
4	Compatibility test; core vs fluid (formation water vs sea water) at reservoir conditions.	- Compatible or not between core vs formation water and sea water	Core vs water compatibility equipment	Standard corrosion and water technology for petroleum producers, Jones, L.W, OGGI, Publication, 1988, Tulsa.
5	Water flooding	- To determine oil recovery by water injection laboratory test	Water flooding equipment	Petroleum production Handbook, Vol. II, by Thomas C Frick.

VI. THE OBTAINED RESULT

This section describes the obtained result of the five analyzed main point (mentioned in Section III) sistematically. The obtained results of the five analyzed main points are as follow:

1. Determination of chemical composition and physical water properties. (see Table - 6.1.1 and Table - 6.1.2).
2. Measurement of physical core properties (see Table - 6.2.1 and Table - 6.2.2).
3. Water compatibility test (formation vs sea water) at reservoir conditions (see Table- 6.3.1 and Figure – 6.3.1).
4. Compatibility test: core vs fluid (formation water and sea water), can be seen in Table – 6.4.1a, Table – 6.4.1b and Figure – 6.4.1.
5. Water Flooding (see Table - 6.5).

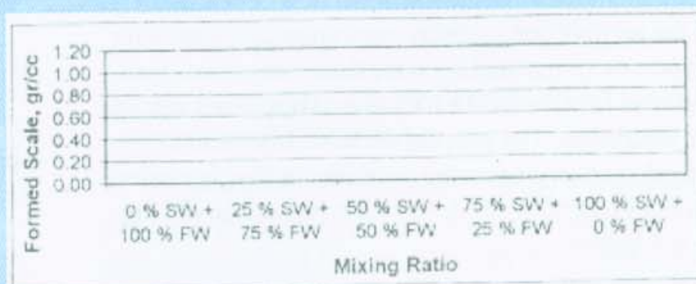

Figure - 6.3.1
Compatibility test sea water vs formation water @ reservoir temperature

A. *The result of determination of chemical composition and physical water properties*

The results of determination of chemical composition and physical water properties for each formation water and sea water can be written on separate tables with using the same format as expressed in Table –

Table - 6.1.1
Water analysis

Company		Well Name		Sampled From	:
Formation		Depth		Province	:
Location		Field		Country	:
Date Sampled		Date Received		Date Analyzed	:

Total Dissolved Solids		mg/L (Calc.)	Sp. Gr.		at $60^0F/60^0F$
Total Dissolved Solids		mg/L (Evap.)	pH		
Resistivity		Ohm-meters @ 125^0F (Calc.)	Hydrogen Sulphide		
		Ohm-meters @ 77^0F (Meas.)	Total Equiv. NaCl Conc.		mg/L

Constituents	meq/L	mg/L	Constituents	meq/L	mg/L
Sodium			Chloride		
Calcium			Bicarbonate		
Magnesium			Sulphate		
Iron			Carbonate		
Barium			Hydroxide		
Total Cations (excl. Fe)			Total Anions		

Table - 6.1.2
Measurement of fluid physical properties

Oil		Sea water		Formation water	
Density (gr/cc)	Viscosity (cp)	Density (gr/cc)	Viscosity (cp)	Density (gr/cc)	Viscosity (cc)

Table - 6.2.1
Measurement of core physical properties

Core No.	L cm	D cv	A cm^2	BV cc	Density gr/cc	Weiht gr	GV cc	PV cc	Porosity %	Ka md

6.1.1 below. While the results of measurement of fluid physical properties (oil, water formation and sea water) can be seen in Table – 6.1.2.

B. *Measurement of physical core properties*

Length (L) and diameter (D) of the core are measured, its density is determined, the core is weighed, then acre (A), bulk volume (BV), grain volume (GV), pore volume (PV) of the core can be calculated by using formula. While porosity (D) is measured by porositimeter and permeameter to measure air permeability (Ka). The measurement of core physical properties can be seen in Table - 6.2.1.

C. *Water compatibility test at reservoir conditions*

The term compatibility as used here relates to the chemical reactions resulting when two or more waters are mixed. If waters are compatible, no new solids are formed on mixing. Incompatible waters interact to form new solids and the total suspended solids (TSS) of the mixture is greater than the sum of fractional TSS of the individual waters prior to mixing. Water compatibility test data are written in Table - 6.3.1, then plotted between mixing ratio vs the formed scale (gram/cc), the performance of curves can be seen in Figure - 6.3.1.

D. *Core vs fluid compatibility test (formation water and sea water)*

Core - fluid compatibility test are carried out to know whether there is compatibility or not between formation water vs core and sea water vs core at reservoir conditions. Each formation water and sea water is injected into core, and the following is recorded: flow rate cc/second (Q), delta pressure psig (DP), volume cc (V) and time second (t). After that water permeability, K (mD) can be calculated by using formula. The values of water permeability for formation and sea water are evaluated, next, performance of water permeability curves to describe whether they are compatible or incompatible are shown in Table-6.4.1a, Table-6.4.1b and Figure – 6.4.1 as example data.

E. *Water Flooding*

Section IV has desribed the displacement process of the additional oil recovery by using water injection method schematically that consists of four types of work descriptions, these are: determinations of formation water saturation, connate water saturation (Swc), effective oil permeability (Ko) and residual oil saturation (Sor) with water flooding.

Each type of work descriptions mentioned above has been done, analyzed, evaluated, plotted and summarized in one table. The result of all analysis can be seen in Table - 6.5.

Table - 6.3.1
Water compatibility test sea water vs formation water at reservoir temperature

No.	Sample sea water and formation water	Compatibility gr/cc	pH initial	pH final
1	0 % SW + 100 % FW			
2	25 % SW + 75 % FW			
3	50 % SW + 50 % FW			
4	75 % SW + 25 % FW			
5	100 % SW + 0 % FW			

Table -6.4.1a
Compatibility test (formation water vs core) at reservoir conditions

Q cc/second	DP psig	Volume cc	Time second	K md

Table - 6.4.1b
Compatibility test (sea water vs core) at reservoir conditions

Q cc/second	DP psi	Volume cc	Time second	K md

VII. CONCLUSIONS

1. Waterflooding is a secondary recovery method in which water is injected into a reservoir to obtain the additional oil recovery by movement of reservoir oil to a producing well *after* the reservoir has approached its economic productive limit by primary recovery methods.
2. To obtain accurate data, optimum and reliable results, it is very significant and valuable to carry out a sequence of stages from initial until final stage of data preparation for water injection laboratory test, including:
   - Determination of chemical composition and physical water properties.
   - Measurement of physical core properties.
   - Water compatibility test (formation water vs sea water) at reservoir conditions.
   - Compatibility test; core vs fluid (formation water and sea water) at reservoir conditions.
   - Water flooding.
3. Five types of work descriptions (mentioned in Sec-

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tion 7.2) are completed by laboratory standard operational procedure, such as American Petroleum Institute-API, Standard Corrosion and Water Technology for Petroleum Producer and Petroleum Production Handbook, even, supported by ISO 17025.

VIII. REFERENCES

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1. Buckley, S.E and Leverett, M.C.: "Mechanism of Fluid Displacement in Sands", Trans, AIME 146, p. 107-116, 1942.
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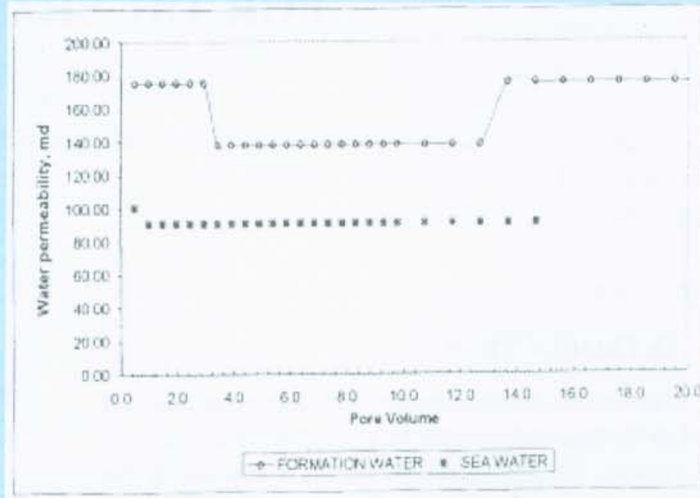

Figure - 6.4.1
Compatibility test (core vs water @ reservoair conditions

Table - 6.5
Water injection process

No.	Work descriptions	The result
1 2 3 4	Determination of formation water saturation Determination of connate water saturation (Swc) Determination of oil efective permeability (Ko) Determination of residual oil saturation (Sor) with water flooding	- Table. Formation water saturation - Table. Connate water saturation (Swc) - Table. Residual oil saturation - Table. Oil effective permeability - Tabel & graphic breakthrough point - Tabel injection of water - Graphic oil recovery, % pore space vs water cut (%) and water input, % pore volume - Calculations of oil - water relative permeability - Calculation Kw/Ko, Krw, krw and fv (flow fraction) - Graphic water saturation vs Kw/Ko - Graphic water saturation vs Kw - Graphic water saturation vs relative permeability - Graphic water saturation vs water flow fration (fw) - Calculation of water injected and oil recovery factor - Graphic water injected (PV) vs oil recovery factor (%)

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6. Rapoport.L.A and Leas.W.J.: "Labo ratory Studies of Five Spot Water Flooding Performance", Trans. AIME, Vol. 213, 1958.
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