AN INVESTIGATION OVER ROCK WETTABILITY AND ITS ALTERATION ON SOME INDONESIAN SANDSTONES

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ABSTRACT

Wettability is a reservoir rock property that is not easy to measure and quantify but has a crucial effect on other rock properties such as relative permeability, capillary pressure, and electrical properties. Problem that may occur with regard to this matter is that those properties are often measured on already cleansed core samples as part of the standard procedure. Having undergone the normally utilized heated cleansing process alteration in the rock's original wettability was often reported. Under such condition, unrepresentative wettability certainly leads to unrepresentative measured data with all of consequences. This article presents a study that uses 363 sandstone samples retrieved from 28 oil and gas fields in Indonesia. The study consists of two stages of analysis. First analysis is performed on data obtained from three wettability tests results while the second one is made with using water-oil relative permeability data, that is usually measured on cleansed core samples. Original wettability data shows that the sandstones varry in wettability from water-wet to oil-wet (48.2% and 30.2% of total samples, respectively). Comparison between data of the two analyses shows that original wettability tends to degrade in strength after cleaning down to neutral wettability, among which neutral wettability appears to be the largest in number (49.1% of total sample). Results also show that weak wettability tends to endure more than stronger ones. The overall results have demonstrated the need for caution in core handling and for measures that can minimize the risk.

Key words: *wettability, sandstones, alteration, core cleansing, wettability degradation, misleading petrophysical data, cautious core handling*

I. INTRODUCTION

One of the most important properties of reservoir rocks is wettability. Wettability is basically an inclination of reservoir rocks to be wetted by certain fluids, either oil or water, due to which other rock physical properties such as capillary pressure and relative permeability are influenced. Reservoir rocks that tend to be water-wet respond differently to oil flow compared to what is shown by oil-wet ones, which in turn controls capillary pressure and relative permeability behavior hence governing hydrocarbon displacement and ultimate hydrocarbon recovery.

In oil saturated water-wet rocks the oil rests on thin film of water spread over the rock's interior surface area. When the rock is in contact with water the water imbibes and displaces the oil out. Water tends to fill all pores including the smallest ones. On the contrary, in oil saturated oil-wet rocks the oil tends to act as water in a water-wet system. The oil displaces water and enters into the finest pores. The two different tendencies shown by the two different preferences to wettability certainly have different consequences on any attempt to produce the oil out from the rocks.

The fact stated above has been long studied by engineers and earth scientists. It is known that sandstones tends to exhibit neutral to water-wet characteristics (e.g. Block and Simms, 1967, as quoted in

Tiab and Donaldson, 2004) due to the acidic nature of the rock's surface that repels most crude oil behaving as weak acid. This wettability characteristic of sandstones is also stated in various sources (e.g. Archer and Wall, 1986) and is widely presumed in day-to-day related activities. Nevertheless, other sources (e.g. Amyx et al. 1960) state that rocks can have both wettability characteristics depending on their mineral composition.

Considering Indonesia's geological complexity and the importance of wettability characteristics in influencing hydrocarbon displacement and recovery, a study on wettability characteristics of Indonesian sandstones has become a necessity. To conduct the study various data obtained from laboratory tests on hundreds of core samples were used. The study also investigates whether core cleaning – a common practice in preparation for core analysis – inflicts wettability alteration in the sandstone samples hence undermining the validity of core analysis results in general. As suspected in various sources (e.g. Timmerman, 1982), laboratory core extraction using hot solvent and the subsequent drying process may lead to changes in rock-wetting characteristics. Through this study it is hoped that better understanding over wettability characteristics of some Indonesia's sandstones can be attained including of how extensive the core preparation-related wettability alteration may have occurred among the reported laboratory testing results.

II. WETTABILITY: A BRIEF INTRODUCTION

In a porous rock, wettability characteristic is essentially resulted from interactions between active surface forces, not only between two immiscible liquid phases but also between liquid and the rock's solid surfaces. The interactions produce forces including adhesive tension that determines what liquids would wet the rock surfaces. Figure 1 exhibits a simple illustration of a condition in which a droplet of water sticking to a solid surface and is surrounded by oil. For determining the degree of wetness raised by two liquids, by convention, contact angle (θ) is measured referring to the heavier among the two (in reservoir rocks water is usually taken) within a range of 0° to 180°. In a simple manner, the adhesive tension can be presented by (Amyx et al. 1960):

$$A_T = \sigma_{so} - \sigma_{sw} = \sigma_{wo} \cos \theta_{wo} \qquad (1)$$

where A_T, σ_{SO}, σ_{SW}, and σ_{WO} are adhesive tension, interfacial tension between solid and the lighter liquid (usually oil), interfacial tension between solid and the heavier liquid (usually water), and interfacial tension between the two liquids. By arranging Equation 1, and in accordance with illustration in Figure 1, contact angle can be expressed as

$$\cos \theta = \frac{\sigma_{so} - \sigma_{sw}}{\sigma_{wo}} \qquad (2)$$

Positive adhesive tension indicates that the heavier liquid tends to wet the solid's surface while zero adhesive tension is resulted from a condition showing the two liquids as having similar affinity towards the solid's surface. The larger adhesive tension (i.e. the smaller contact angle) the easier for the wetting phase to stick and spread on the solid's surface. On the contrary, smaller adhesive tensions (i.e. larger contact angles) require external energy to force the wetting phase to spread on the same surface. By convention, it can be taken that if the contact angles are less than 90° then the heavier liquid phase acts as wetting phase, and at contact angle of 90° the wetting characteristic is considered as neutral with equal wetting tendencies for both liquids. As a guiding cri-

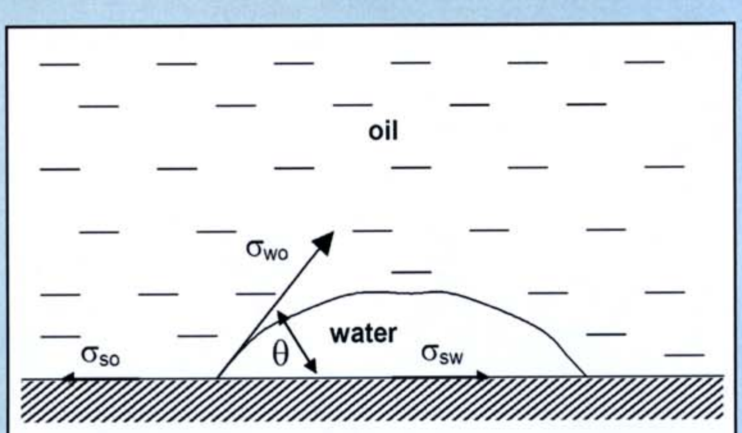

Figure 1
Equilibrium of interfacial forces in water – oil – solid system

terion, Treiber et al (1972) for water – oil system established 0 – 75° for water-wet, 75 – 105° for neutral, and 105 – 180° for oil-wet.

In sandstones, the rock's solid surface usually tends to be acidic hence inclined to react easily with basic substances. The reverse is true when the solid is exposed to acidic liquid substance. The main organic component in most crude oil usually tends to behave like weak acids leading to be expelled by the rock's acidic silica and forming water-wetting tendency. In their experiment Block and Simms (1967) showed that the basic octa-decylamine organic substance was easily absorbed by glass surfaces while the also used stearic acid was not absorbed at all.

As stated above, even though most crude oil has weak acid components some types of oil can be of either basic or acidic in nature especially with those containing resins and asphaltenes (e.g. Denekas et al. 1959). With presence of these components sandstones can actually behave both in water-wet and oil-wet manners, even though the degree of strength is very much governed by the quantity of the two components. Table 1 presents results of laboratory study from Treiber et al. (1972) and Chillingarian and Yen (1983) regarding wetting tendencies of some sandstone samples. The table also shows some results for carbonate samples for comparison.

The brief discussion and past laboratory studies presented above imply that wettability is strongly related to rocks' and fluids chemical compositions and the resulted relative pH. Differences in chemical compositions are also likely to respond differently to external factors such as pressure and heat. All petroleum reservoir rocks are believed to have inclination towards water-wetness originally (Tiab and Donaldson, 2004) but it is most probably due to these different responses that changes in wettability had occurred and eventually produced the rock wettability we encounter today.

III. INDICATORS OF WETTABILITY

Considering the importance of wettability, this rock property is among the most important properties, information regarding them is compulsory for acquisition. In very careful experiments, direct measurements can basically be made to obtain contact angle data in water – oil system. Sessile Drop (e.g. Treiber et al, 1972) and Wilhelmy Plate (e.g. Mennella et al. 1995) measurements. These techniques can

Table 1
Relative wetting tendencies in sandstones and carbonates (from Tiab & Donaldson, 2004)

Wettability	Treiber et al. (1972)		Chilingarian & Yen (1983)
	Silicates, %	Carbonates, %	Carbonates, %
Water wet	43	8	8
Neutral	7	4	12
Oil wet	50	88	80

certainly provide the needed information but are often considered as too meticulous in preparation and their need for homogeneously smooth solid surface implies that test results may not represent the commonly multi-mineral reservoir rocks.

In addition to the direct measurement methods mentioned above, there are several laboratory indirect techniques such as Amott Wettability Index, one suggested by the United States Bureau of Mines (USBM), and Direct Imbibition (DI). There is an even more indirect indicator that plays a very important role in this study, water-oil relative permeability curves. The four methods are briefly described as follows:

Amott Wettability Index. This technique was suggested by Amott (1959) and is essentially based on spontaneous imbibition and forced displacement of oil and water out of tested core plugs. Through spontaneous imbibition two indexes are made, the oil index (I_O) and water index (I_W). The oil index is a ratio between volumes of water in a water-saturated core sample displaced by oil, if any, in an imbibition (immersion in oil) process and volumes of all remaining water displaced through forced displacement by oil until irreducible water saturation (S_{wirr}) is reached. The volume of displaced water resulted from slow imbibition process is denoted by V_{wi} whereas V_{wd} symbolizes the water volume yielded through the forced displacement by oil (includes V_{wi}) following the completion of imbibition process. The process for producing water index follows, in which the already oil-saturated sample (at S_{wirr}) is imbibed with water (immersion in water) leading to some displaced oil, if any, (V_{oi}) and – in the same manner with oil forced

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displacement – is followed by water forced displacement to yield total produced oil volume of V_{od} (includes V_{oi}). Mathematically, the two indexes are expressed as:

$$I_O = \frac{V_{Wi}}{V_{Wd}} \tag{3}$$

and

$$I_W = \frac{V_{oi}}{V_{od}} \tag{4}$$

Forced displacement is usually performed using centrifuge or core flow apparatus while imbibition process is suggested to take at least 20 hours (Amott, 1959) or much longer for rocks with neutral wettability (Anderson, 1986a).

Interpretation using the two indexes is somewhat relative in nature and there is no guideline for definitive judgment. Amott (1959) put 1.0 as strong wettability while a value of zero indicates neutral wettability, and values approaching zero are indication of preferential wettability. Inclination towards either wettability is judged from relative comparisons between the two indexes. When wettability is put as $I_W - I_O$ then the Amott wettability index would vary from +1 for absolute water wet to -1 for absolute oil wet with zero indicating neutral wettability.

For the purpose of clear classification and comparison with other wettability indicator techniques wettability in this study is divided into 'strong oil wet', 'oil wet', 'preferential oil wet', 'neutral', 'preferential water wet', 'water wet', and 'strong water wet'. Table 2 presents value ranges for the wettability categories. The established value ranges are indeed subjective in nature but their assignments are considered appropriate to accommodate reasonable discretization on gradation in the wettability strength.

USBM Wettability Index. The technique basically uses capillary curves obtained through displacing oil and water using centrifuge equipment (Donaldson et al. 1969). The displacement is peformed alternately in a way similar to forced displacement process in the Amott technique, in which a water-saturated sample is spun under various rotational speeds while immersed in oil to reach S_{wirr}. The process is repeated by spinning the now oil-saturated sample in water immersion. Capillary pressures are calculated based on the known rotational speeds.

The fundamental principle of the method is that displacement of a non-wetting phase by a wetting phase requires less force than the reverse. This results in different capillary pressure curves with the

Table 2
Value ranges established for wettability classification used in the study

Wettability class	Amott	USBM	Relative permeability
	$\Delta I = I_W - I_O$	I	S_w at $K_{ro} = K_{rw}$
Strong water-wet	$0.8 < \Delta I \leq 1$	$1 < I \leq +\infty$	$0.85 < S_W \leq 1$
Water-wet	$0.5 < \Delta I \leq 0.8$	$0.25 < I \leq 1$	$0.65 < S_W \leq 0.85$
Preferentially water-wet	$0.1 < \Delta I \leq 0.5$	$0.1 < I \leq 0.25$	$0.55 < S_W \leq 0.65$
Neutral	$-0.1 \leq \Delta I \leq 0.1$	$-0.1 \leq I \leq 0.1$	$0.45 < S_W \leq 0.55$
Preferentially oil-wet	$-0.5 \leq \Delta I < -0.1$	$-0.25 \leq I < -0.1$	$0.35 < S_W \leq 0.45$
Oil-wet	$-0.8 \leq \Delta I < -0.5$	$-1 \leq I \leq -0.25$	$0.15 < S_W \leq 0.35$
Strong oil wet	$-1 \leq \Delta I < -0.8$	$-\infty \leq I \leq -1$	$0 \leq S_W \leq 0.15$

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case of non-wetting phase displacing wetting phase having higher and steeper curve. This means the areas under the two curves between S_{wirr} and water saturation at residual oil saturation (S_{wor}) are different, and the ratio between the two is indicator of the rock's wettability. Figure 2 shows the hysteresis in capillary curves as results of the alternately forced displacements. Donaldson et al. (1969) then put

$$I = \log\left(\frac{A_1}{A_2}\right) \quad (5)$$

as the wettability index, with A_1 and A_2 are respectively area under curve of oil displacing water (from S_{wor} to S_{wirr}) and area under curve of water displacing oil (from S_{wirr} to S_{wor}).

The index presented in Equation 5 show that wettability index values could range from $+\infty$ (complete water wet) to $-\infty$ (complete oil wet) with zero for neutral wettability. No guideline in regard to classification of wettability. Therefore, in the same fashion used for Amott wettability index, the USBM index is also divided using the same categorization into the same seven wettability types. Table 2 presents the value ranges in the categorization.

Direct Imbibition. The technique is based on recognition that spontaneous imbibition on porous rocks leads to volume and rate of imbibition that relate directly to the rocks' general wettability. Unlike Amott and USBM techniques, Direct Imbibition technique relies solely on liquid imbibition process despite the knowledge that imbibition rate is also influenced

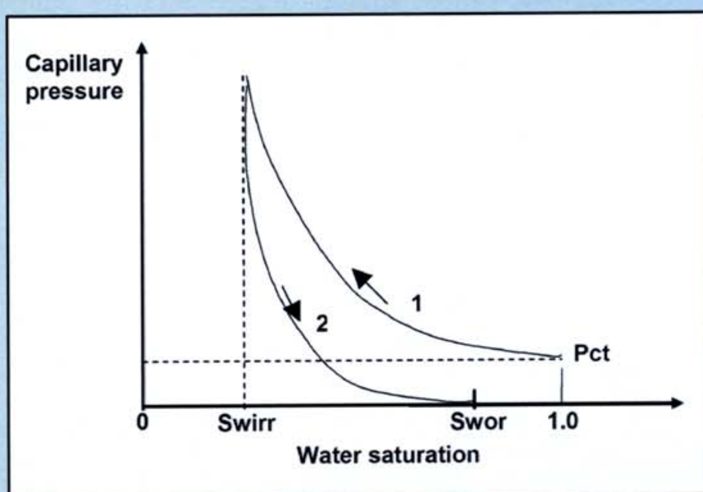

Figure 2
Oil displacing water curve (1) and water displacing oil curve (2) for a water wet system. Swirr is irreducible water saturation whereas Swor is water saturation at residual oil saturation. Note the threshold

Table 3
List of data used in the study

Sedimentary basin	Number of fields	Wettability indicator			
		Amott	USBM	Imbibition	Rel perm
South Sumatra	10	38	10	-	65
Central Sumatra	4	20	-	-	38
North Sumatra	5	18	8	-	31
Northwest Java	5	23	2	-	47
Northeast Java	1	4	-	-	6
Tarakan	1	5	-	-	8
Barito	1	-	4	2	14
West Natuna	1	5	-	-	15
Total	**28**	**113**	**24**	**2**	**224**

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by other factors such as imbibing liquid viscosity, permeability, porosity, artificial tension, and sample's edge condition (Tiab and Donaldson, 2004). Acknowledging these factors, Ma et al. (1999) used scalling correlation for evaluating imbibition-driven oil recovery in fractured water-drive reservoir introduced by Mattox and Kyte (1962) for evaluating wettability in this Direct Imbibition method. Nevertheless, the most common judgment for establishing wettability type is through relative comparison between imbibition rates of water and oil, and the reported conclusion for the two sandstone samples (see Table 3) is used without any further review. Deeper description is not spent and index categorization is not established for this technique.

Water-oil relative permeability curves. As wettability tendencies affect capillary pressure curves in the form of hysteresis, the tendencies also affect water-oil relative permeability curves. Basically, a core flow test designed to obtain relative permeability curves is meant to observe on how a particular rock sample pore system influences the multiphase flow behavior. With presence of different wetting inclination shown by different reservoir fluids, however, this porous medium – fluid interaction is biased. Different degrees of wettability lead to different fluid saturating characteristics within the rock hence changing the effective permeability of the fluids present.

Figure 3 illustrates changes in relative permeability due to different wettability. In comparison, water-wet system and oil-wet system become different even though the shape of curves remains the same. At condition of oil-wet system the flow tends to be of earlier water breakthrough due to easier movements of water compared to oil. In this condition, the point of Kro = Krw occurs at lower values of water saturation with higher values of Krw and lower Kro values at most values of water saturation. Change in wettability towards more water wettability shifts the Kro = Krw point to higher water saturation points due to the fact that the water tends to lose mobility hence requiring higher water saturation to enable it to move under the same pressure difference (Amyx et al. 1960; Archer and Wall, 1986). Anderson (1986b) discussed further in more depth the influence of wettability on relative permeability curves.

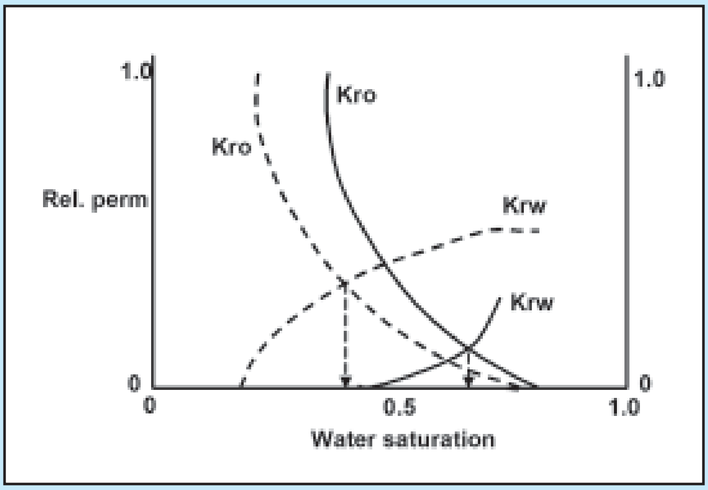

Figure 3
Shift in permeability curves intersects due to change in wettability system. Relative permeability of an oil-wet system (dashed curves) tend to show higher water effective permeability leading curve intersect at lower water saturations. On the contrary, higher oil effective permeability in water-wet system (solid curves) tends to yield intersects at higher water saturations

Wettability is indeed not the sole factor that can influence water-oil relative permeability curves. In their report on a series of experimental works Geffen et al. (1951) put that variation in overburden pressures and the resulting changes in pore size distribution may provide blocking effect to the two liquid phases' movements and shifts the relative permeability curves. Increases in temperature also change wettability towards a more water-wet tendency. These all imply that any test for relative permeability has to be performed under reservoir condition (i.e. overburden pressure, pore pressure, and temperature). However, common industrial practices in this regard rarely meet this ideal condition for various reasons including equipment limitation and simplicity. All relative permeability data used in this study was obtained under atmospheric temperature. This is also the case for measurements on wettability, for which both imbibition and forced displacement processes were carried out under atmospheric temperature. Similarity in testing condition for the three wettability indicators therefore suggests that wettability remains the sole predominant factor in the shift of relative permeability intersects (i.e. Kro = Krw).

Through the use of this later conclusion, shift in intersect between the two curves can therefore be used as indicator for rock's wettability. Water-wet rocks tend to have curves' intersect to be at water saturation values lower than 50%, and the reverse is true for oil-wet system. No clear guideline has been given by past studies regarding values or value ranges that represent certain degrees of wettability. It is logical, however, that neutral wettability systems would have curve intersect at around 50% water saturation, and strong wetting tendencies at water saturation values approaching S_{wirr} and residual oil saturation (S_{or}) for water-wet and oil-wet systems, respectively. Gradual degrees in wetting tendencies for both wettability systems naturally fall between neutral and the two strong wetting tendencies.

In order to make this indirect wettability indicator comparable two the other two standard techniques discussed earlier, a clear guideline is needed. Similarly, the seven-class wettability divison used for the other two techniques are also used here, with water saturation ranges representing the permeability curves' intersects as ref-

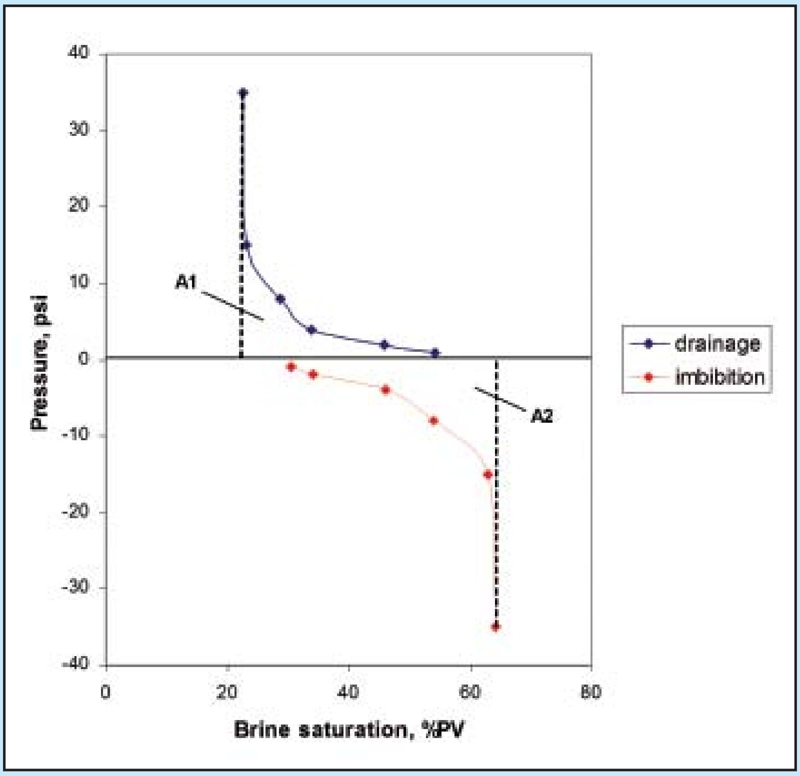

Figure 4
Figure 4 – Example of USBM wettability test graphical result for a core sample taken from T – 105 well, Barito basin.
The test yields *I* = log(*A*l/*A*2) value of -0.140 indicating preferential tendency towards oil wetness (preferential oil-wet)

Table 4
Result example of wettability test using Amott technique.
The generally preferential water-wet rocks are from BK – 232 well, Central Sumatra Basin

Sample number	Permeability (mD)	Porosity (%)	Wettability Index W-wet	O-wet	ΔI	Interpretation
1	23	25.4	0.4167	0.0000	0.4167	preferential water-wet
10	3251	32.5	0.4355	0.1719	0.2636	preferential water-wet
13	772	31.4	0.3352	0.0789	0.2563	preferential water-wet
19	22	22.6	0.4800	0.0000	0.4800	preferential water-wet
20	9	25.5	0.4857	0.4113	0.0744	neutral

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Table 5
Result example of wettability test using USBM technique.
The generally oil-wet rocks are from T – 105 well, Barito Basin

Sample No.	Permeability (mD)	Porosity (%)	$I = log\left(\frac{A1}{A2}\right)$	Interpretation
276	147	24.7	-0.336	oil wet
265B	47	21.8	0.106	preferential water wet
217[a]	29	23.6	-0.346	oil wet
216	34	24.6	-0.392	oil wet
119B	844	28.1	-0.199	preferential oil wet
105	62	27.5	-0.140	preferential oil wet

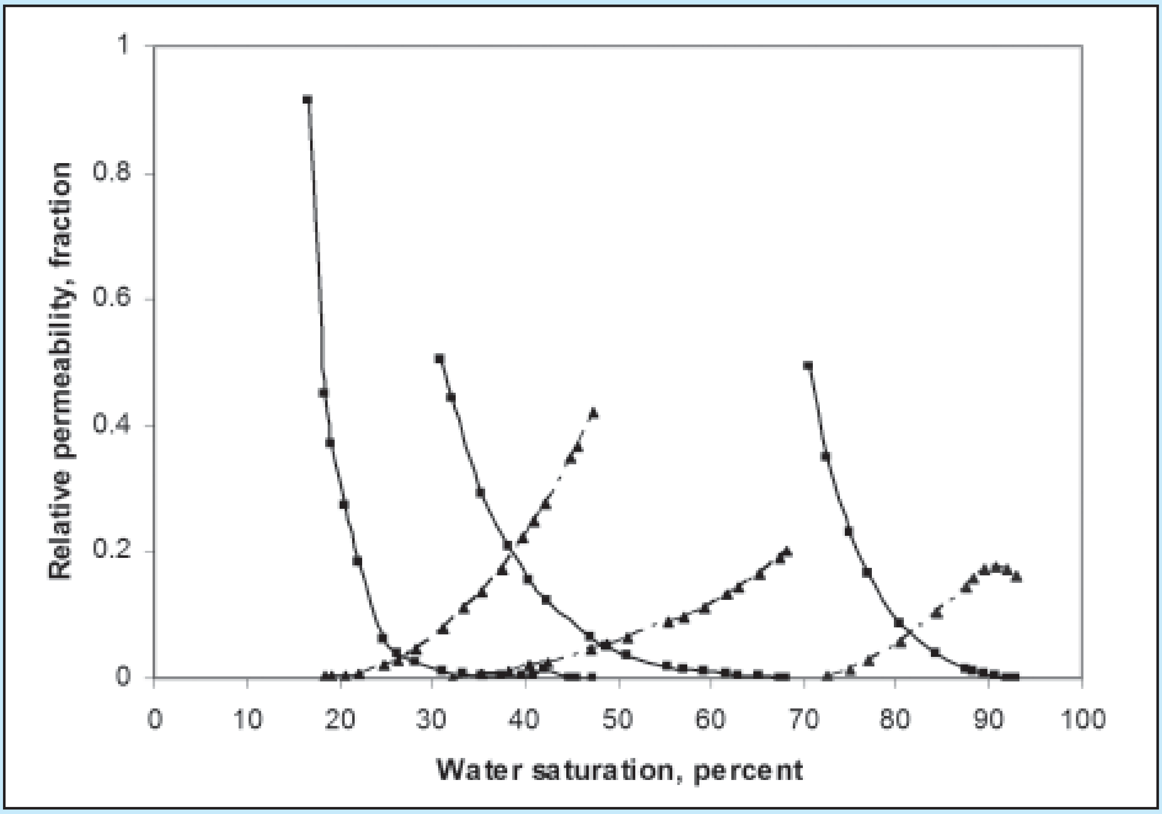

Figure 5
Three pairs of relative permeability curves (solid and dashed ones for Kro and Krw, respectively) taken from; a) PP-CC5 well (N Sumatera Basin), b) KW P6 well (NE Java Basin), and FW-2 well (NW Java Basin). In accordance with the criteria established in this study, the three exemplary data sets tend to exhibit wettability tendencies of oil-wet, neutral, and strong water-wet, respectively.

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erence. Table 2 presents the water saturation ranges assigned to serve the purpose.

IV. LABORATORY DATA

Wettability data used in the study was derived from various Lemigas Core Laboratory Reports of testing on 363 sandstone core samples taken from 28 oil and gas fields in Indonesia. Table 3 presents list of data covering sample origins and their type of wettability indicators. Amott technique appears to make the bulk of wettability test results (113 samples) among the three wettability test methods while relative permeability, as a non-wettability test technique, is also available in even larger number (224 samples).

All data was obtained from Lemigas Core Laboratory archives and in the form of unpublished reports. Amott test results are presented in tabular form whereas the USBM and relative permeability data is both tabular and graphical forms. Table 4 depicts an exemplary Amott test data (BK – 232 well, Central Sumatra Basin) from which overall preferential to water wetness is concluded. Table 5 and Figure 4 present example (T – 105 well, Barito Basin) for USBM technique, the resulting *I* values indicate sufficiently strong inclination to be oil-wet. All wettability tests were performed using native cores – i.e. uncleansed – leading to results representing their unaltered wettability.

For relative permeability data, most data available to the study has complete curves to enable observation on the curves' intersects. Nevertheless, in some cases (less than 3% of overall data) with incomplete data, extrapolations were made so that the desired information is obtained. Figure 5 exhibits three examples with three different wetness tendencies. All samples were cleansed using solvent prior to relative permeability tests meaning that the resulting data is likely to represent 'un-restored' or 'altered' wettability condition.

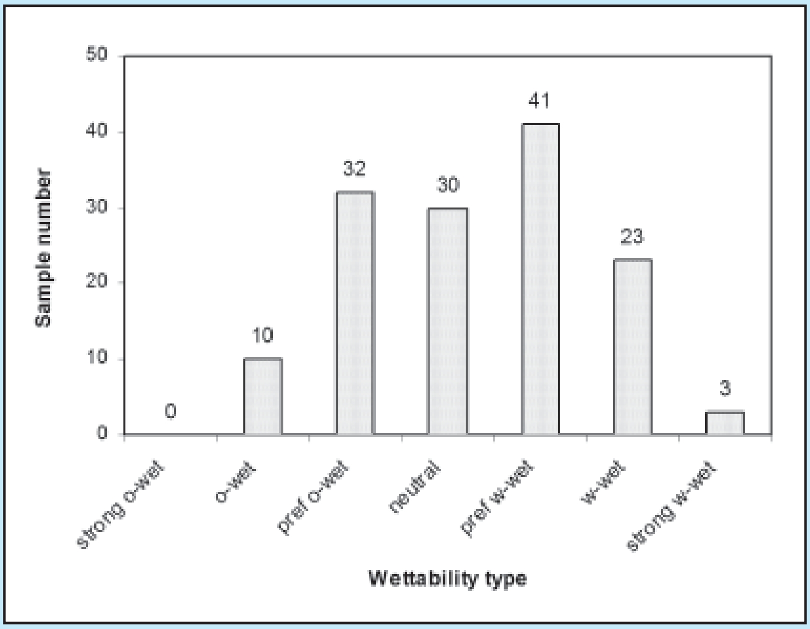

Figure 6
Wettability composition of the sandstone samples, which wettability test results are used in this study. Water-, neutral-, and oil-wet groups make 48.2%, 21.6%, and 30.2% of the total core samples, respectively

V. ANALYSIS

In analysing the data, observations were performed on two issues; original wettability as indicated by wettability tests and wettability alteration due to core cleansing.

Original wettability. In general, results from three wettability indicating techniques have exhibited no strong preference towards specific wettability types. As depicted in Figure 6, 'preferential water-wet', 'water-wet', and 'strong water-wet' are respectively represented by 39, 21, and 3 samples. Combination of these figures make 48.2% of all samples are grouped into water-wetness tendency. On the other hand, combination of 'preferential oil-wet' and 'oil-wet' – 32 and 10 samples, respectively – tendencies establishes a correponding figure of 30.2% for oil-wetness tendency. No 'strong oil-wet' result has been observed.

These 'oil-wet' and 'water-wet' compositions – along with 21.6% of 'neutral' wettability – have shown that Indonesian reservoir sandstones are not different to other sandstones from other places in the world.

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As put earlier, even though Block and Simms (1967) showed that silicate glass tends to show strong water-wetness but combined presence of rock mineral impurities and oil pH preference – as proved by Treiber et al. (1972) – tends to exhibit even tendencies toward oil- and water-wetness (Table 1). Comparing these results and those shown in Figure 7 comparable compositions are obvious with strong similarity in water-wetness. Larger amount of samples on both sides may probably lead to more similar compositions.

Wettability alteration. As put earlier, core plugs are usually cleansed and extraxted of all salts normally present in native cores prior to measurement for rock basic properties. This is often, and indeed has become a recommended practice (API, 1960), for both practical and objective reasons (e.g. air permeability and helium porosity are measured on cleansed core plugs). Therefore, it is expected that wettability alteration has occurred.

In analyzing the alteration, assumptions are taken:

1. For original wettability from wettability tests, overall wettability of one sample set (i.e. from a well) is adopted based on majority in wettability type shown by the tested samples. This is due to the fact that samples used in wettability tests were not of same samples used in relative permeability test, even though they belonged to the same sample set. This ‘overall wettability‘ was then compared with relative permeability curves intersects from individual samples in order to observe changes in wettability.

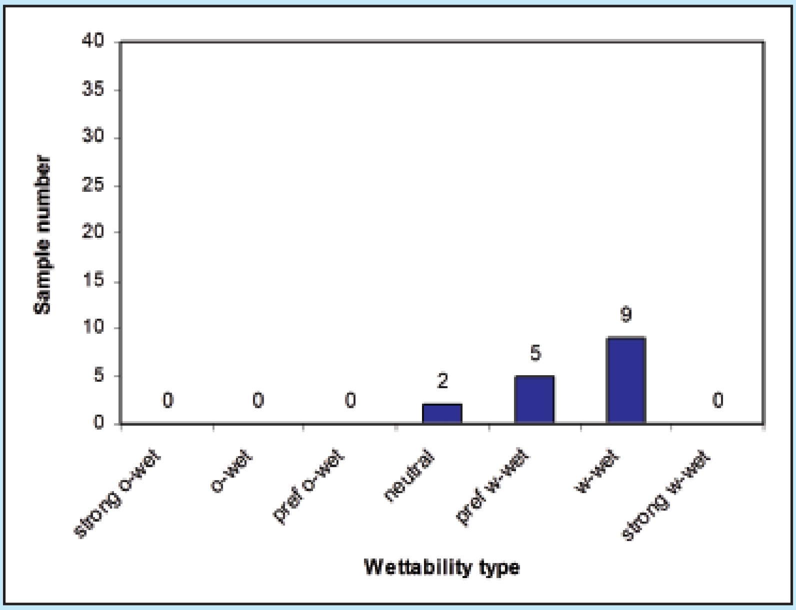

Figure 7
Wettability composition of samples that originally belonged to ‘strong water-wet’ class. Although most samples still retain water-wetness inclination some have lost their preference to water-wetness

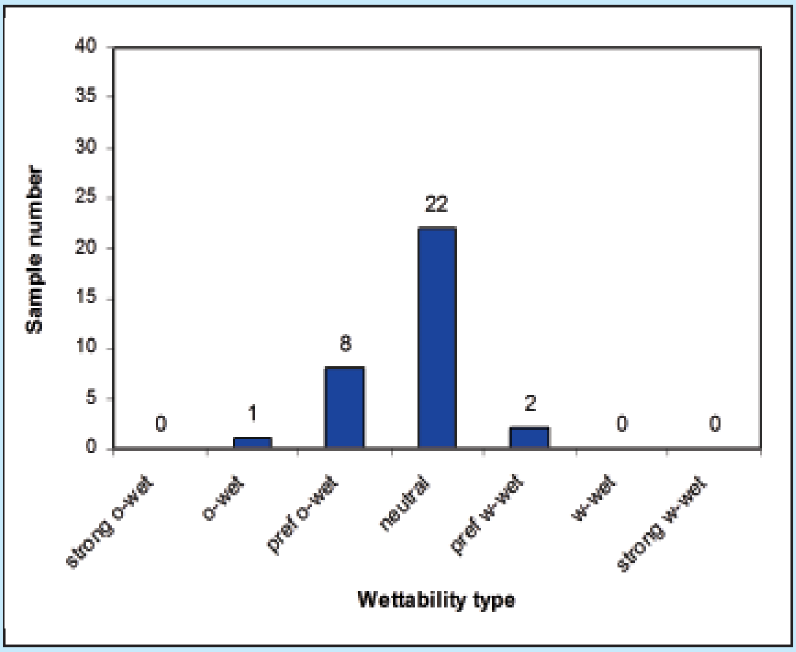

Figure 8
Wettability composition of samples that originally belonged to ‘water-wet’ class. Most samples vave become ‘neutral’ but oddly enough some of them ‘switch side’ into ‘oil-wet’ group

2. Relative permeability curves' intersect (@ Kro = Krw) can be used as wettability indicator based on recognition that the pair of curves shift along water saturation axis with changes in rock sample's wettability type.
3. The established index categorization for wettability classification serves well for the three wettability indicators (minus the Direct Imbibition technique) to justify comparison among results of all the four techniques.

Using this three-point assumption, analysis was made through observing the change of samples originally belonging to each wettability class. Figures 7 through 12 present the results.

From the originally described as belonging to a strong water-wet sample sets – as indicated by the wettability tests – no one of the 16 samples tested for water-oil relative permeability data indicates strong water drive class of wettability (Kro = Krw @ $S_w > 0.8$) (Figure 7). The changes in wettability, some samples still retain water-wetness at lesser degrees, even extend to 'neutral' (Kro = Krw @ $S_w \cong 0.5$) meaning that the samples of concern have lost affinity tendency towards water (and also oil).

Similarly to the case of 'strong water-wet', all samples that originally belonged to 'water wet' category have degraded in wettability strength against water (Figure 8) and most of the samples have become 'neutral' and even 'switch side' into the oil-wet group. The case is not entirely the same for 'preferentially water-wet' class, out of which some still retains their original wettability (18 samples) even though most of the samples

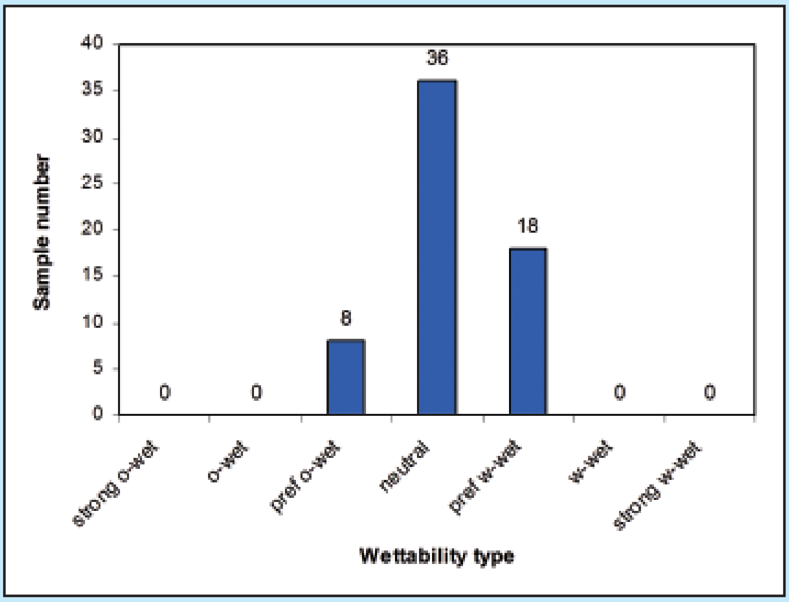

Figure 9
Wettability composition of samples that originally belonged to 'preferentially water-wet' class. Some samples retain their original wettability but most samples have become 'neutral'. Small portion of samples also become 'preferentially oil-wet'

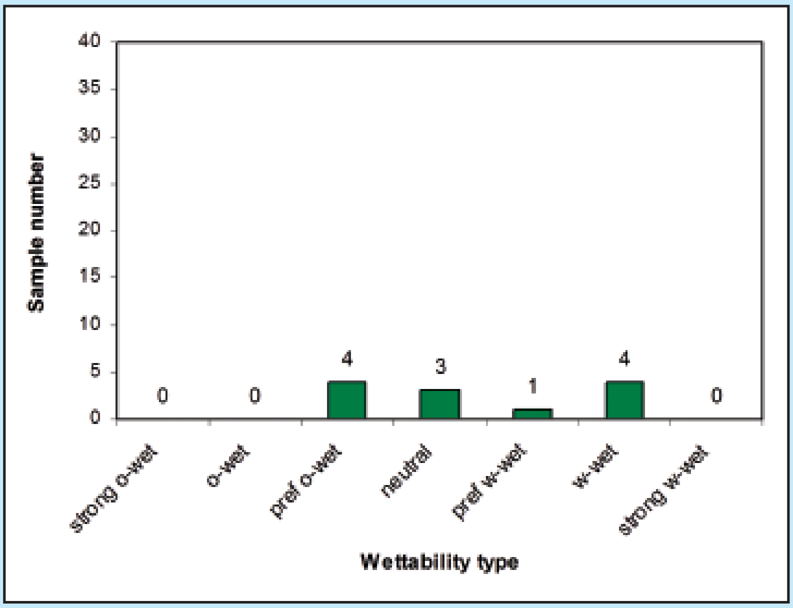

Figure 10
Wettability composition of samples that originally belonged to 'oil-wet' class. None of the samples retain their original wettability and most samples have degraded into 'softer' wettability, and some even become inclined into the 'water-wet' group

have become 'neutral'. Similar to the case of 'water-wet' class, some of the originally 'preferentially water-wet' samples have become 'preferentially oil-wet'. The degradation in water-wetness due to core cleansing is understandable, but change into oil-wetness indeed requires more thorough explanation.

In the oil-wet group no originally strong oil-wet samples are at disposal, which means only two classes available; 'oil-wet' and 'preferentially oil-wet'. In a manner similar to the cases in the 'water-wet' class the samples belonging to 'oil-wet' samples have degraded into 'preferentially oil-wet' and 'neutral' classes with some even switched wettability into more oil-wet orientation (Figure 10). A resemblance in behavior to 'preferentially water-wet' class samples is also shown by its counterpart in the 'preferentially oil-wet' class. Many of the originally preferentially oil-wet samples retain their wettability while most have become 'neutral' with the remaining few jump onto the other side of the wettability spectrum (Figure 11). Although this wettability switch occurred only on few samples (22% of total in the class) this phenomenon requires attention.

For 'neutral' class (Figure 12), the samples' wettability behavior differs significantly from the tendencies shown by the wettability groups on the two sides of the spectrum. This case is characterized by the retaining of wettability by the bulk of the samples (65% of total), and if samples of the two preferential wetness are included – on the

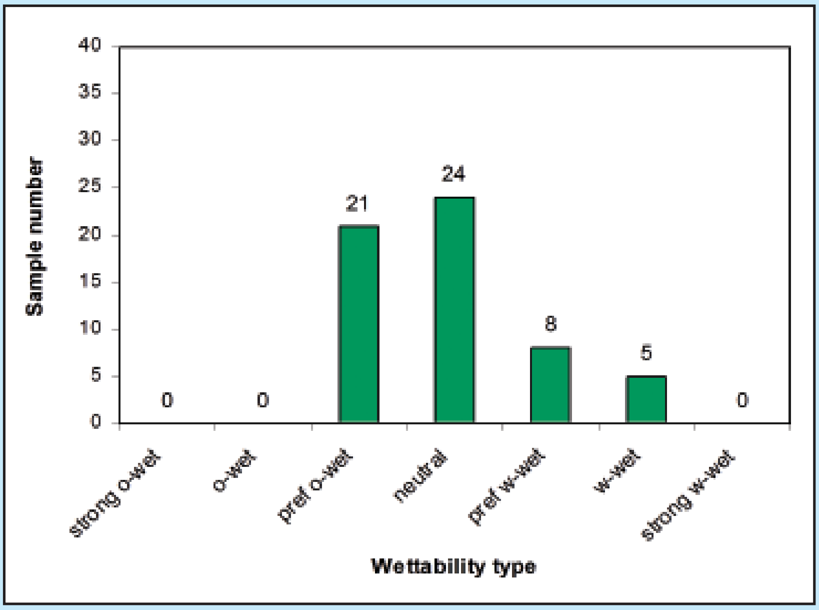

Figure 11
Wettability composition of samples that originally belonged to 'preferentially oil-wet' class. Similar to the case of 'preferentially water-wet' class, many of the samples retain their original wettability and most became 'neutral'. Some few samples have gone to oil-wet tendency, however

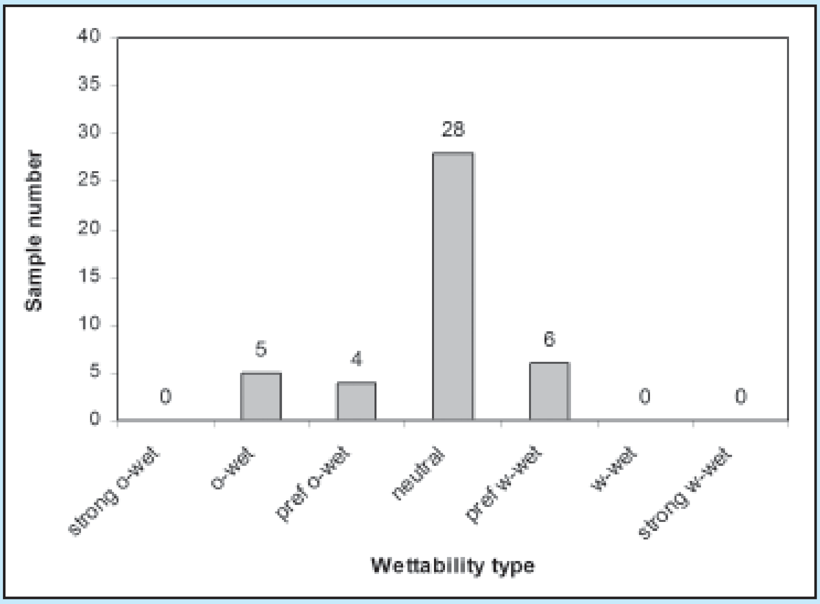

Figure 12
Wettability composition of samples that originally belonged to 'neutral' class. Majority of samples remain 'neutral', and if samples of the two preferential wetness classes are included on the ground of classification uncertainty this portion is even higher to reach 88.4% of total samples

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ground of uncertainty in boundaries between classes – the portion is even higher (88.4%). This fact, combined with wettability degradation in strength after core cleansing, has led into a thought that rock wettability tends to move toward neutrality if the causes of the original wettability have removed from the rock's surfaces.

From individual analysis based on individual wettability class (Figures 7 through 12), overall figures have shown that out of 224 water-oil relative permeability samples only 67 (29.9%) retain their original wettability. If this group is expanded to include samples that remain in their wettability group (e.g. a water-wet sample that was originally strong water-wet) the overall number becomes 80 (35.7%) only. These figures correspond to the total figure of samples that remain or become 'neutral' – after core cleansing – of 110 or 49.1% of total samples. This further underlines the fact that cleansed core samples tend move toward neutrality in wetness tendency, along with all validity consequences on the data measured afterward.

VI. FURTHER DISCUSSION

As put by Tiab and Donaldson (2004), rock's surface mineral composition and polar organic components in crude oil – act as either weak basic or weak acidic compound depending on the amount of resin and aspalthene contents – that can react to each other to form a very thin layer of active compounds on the rock's solid surface. This thin layer of active compound affects wetting characteristics of the rock-fluid system. During core cleansing prior to many laboratory applications and tests, this thin layer is to be either completely or partially removed. The result is degradation in wettability strength, or a full shift to 'neutral' wettability if the thin layer is completely wiped out. This mechanism is likely to serve as an explanation over the wettability change commonly observed during the study.

One question related to wettability change remains. What actually causes the switch in wettability, from water-wetness to oil-wetness and vice versa? The only possible explanation at this stage is that hot solvent (usually toluent and methanol) used in the core sample cleansing has somehow chemically reformed the thin layer of wettability-affecting compound on the rock sample's surface to form an opposite wetting tendency. However, since this occurred on 50 samples only (22.3% of the total 224 samples) – and is further reduced to 10 samples (4.5%) if 'preferentially oil-/water-wet' samples are excluded on classification uncertainty ground – this 'switch' is likely to be caused by other factor than reform of the 'thin layer compound' by hot solvent. Generalization of original wettability on heterogeneous rocks and the fact that samples used in wettability tests are usually different from the ones used in water-oil relative permeability test – even though belonging to the same rock formation – are probably the factors causing this apparent wettability switch. Speculatively therefore, the process of core cleansing using hot solvent causes degradation in wettability down to the point of neutral wetness tendency at most.

Regardless the real cause of change and switch in rock wettability, however, this occurrence may affect validity of the ensuing tests performed after the core cleansing. As previously discussed changes in wettability affect relative permeability curves with all of its consequences. Furthermore, Widarsono (2008) pointed out in length the effect of wettability alteration on rock electrical properties, which in turn through well log analysis may affect severely any estimation of water saturation. In the article, he also underlined the need to either restore rock's wettability through core-ageing or use cold core cleansing technique that utilizes cold solvent flow in order to dissolve oil and salts within samples. Through these methods, invalidity of laboratory test results caused by wettability alteration can hopefully be minimized.

Attempts were initially made to see whether there is any relation between wettability and sedimentary basins. However, it was then realized that wettability is much governed by mineral and oil composition rather than by any other factors specifically related to individual regions. Different basin may have accumulated similar minerals – depending to depositional environments – to others, and vice versa. Nonetheless, a more thorough study may have to be made in order to investigate this matter.

VII. CONCLUSIONS

Analyses and evaluations on all data used in this study have led into some main conclusions, namely:

- Like all reservoir sandstones throughout the world Indonesian sandstones also tend to have both water-wet and oil-wet tendencies. Rock mineralogy appears to play an important role in determining wetness characteristics.

- Core cleaning, as a standard practice in laboratory core analysis tends to weaken wettability strength, which results in wettability degradation. However, complete change in wettability is likely to reach no further than neutral wettability.
- Wettability switch – from water-wet to oil-wet and vice versa – due to core cleansing probably does not occur. However, if it actually does more thorough study and investigation are required for better understanding.
- Weak wettability – i.e. preferentially oil-wet and preferentially water-wet – appear to be more resilient against wettability change. This is likely due to actual similarity between weak- and neutral wettabilities in a way that external factors such as core cleansing cannot change much.
- Strong proof that standard laboratory core handling (i.e. core cleansing) changes rock sample wettability has emphasized the need to utilize necessary measures to prevent/minimize its occurrence. Core-ageing and cold core cleansing are among the suggested methods to serve the purpose.

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