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Preface: 3rd International Conference on Earth Science, Mineral, and Energy

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Preface: 3rd International Conference on Earth Science, Mineral, and Energy

This year, the 3rd ICEMINE proudly present the theme of "Challenges and Opportunities of Mineral and Energy Exploration, Exploitation and Extraction to Improve Economic Growth". More than 100 presenters from several universities and companies coming from 9 countries (Indonesia, Canada, Taiwan, China, Malaysia, Australia, New Zealand, USA, and Japan) participate in this conference.

Indonesia has abundant natural resources including renewable and nonrenewable. The utilization of natural resources needs to be adjusted with the area development as well as control enhancement by implementing regulations. Energy sector activities should be done with the concept of environmental sustainability starting from exploration, exploitation, until extraction. This concept could preserve the energy resources for the future as well as improve the economic growth. Not only the environmental sustainability issue, but also the exploration, exploitation, and extraction process have the challenges and opportunities to optimize the national economic growth and energy resilience.

Tedy Agung Cahyadi – **UPN Veteran Yogyakarta, Indonesia**

Madi Abdullah N –**Misurata University, Libya**

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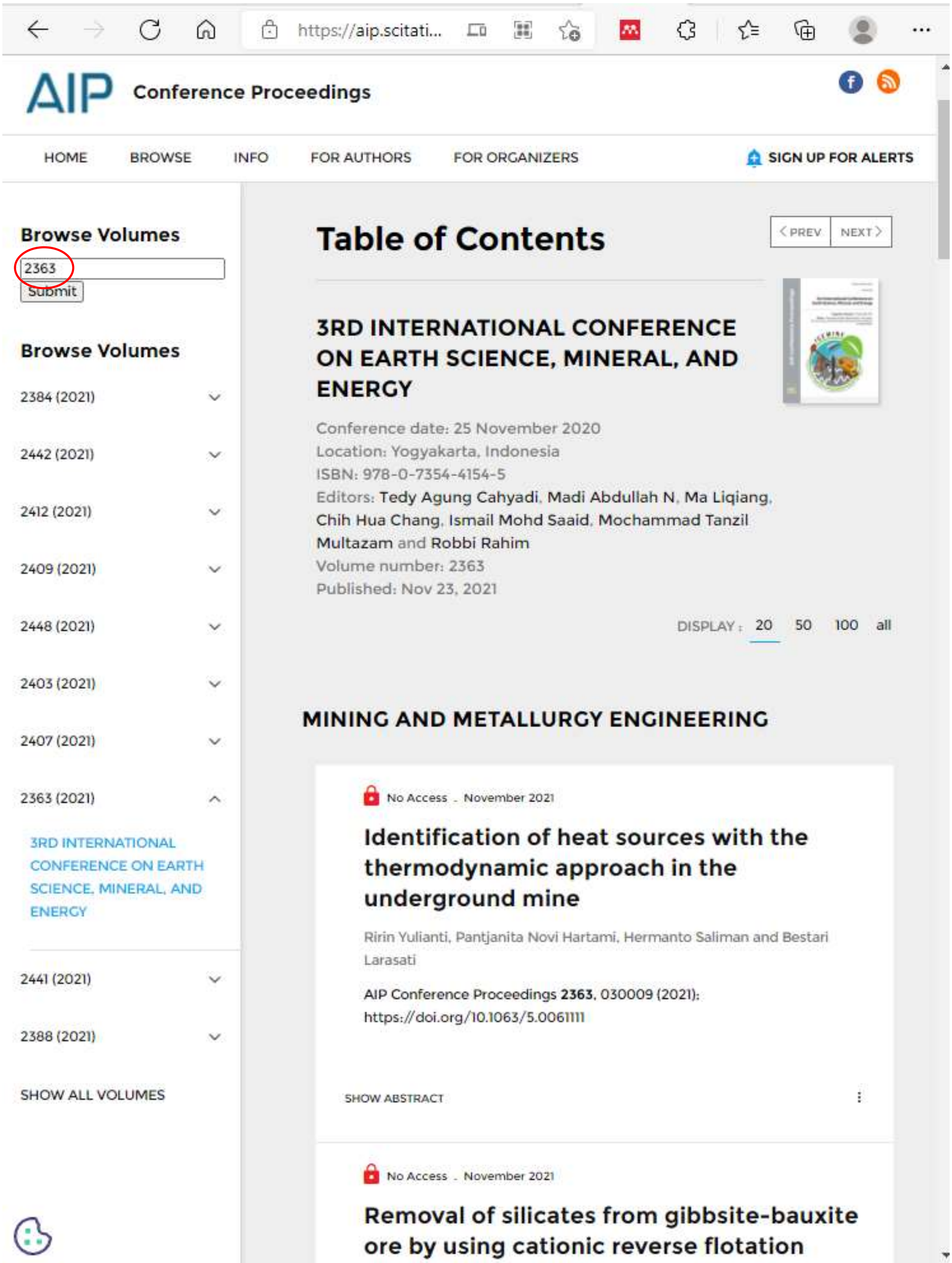
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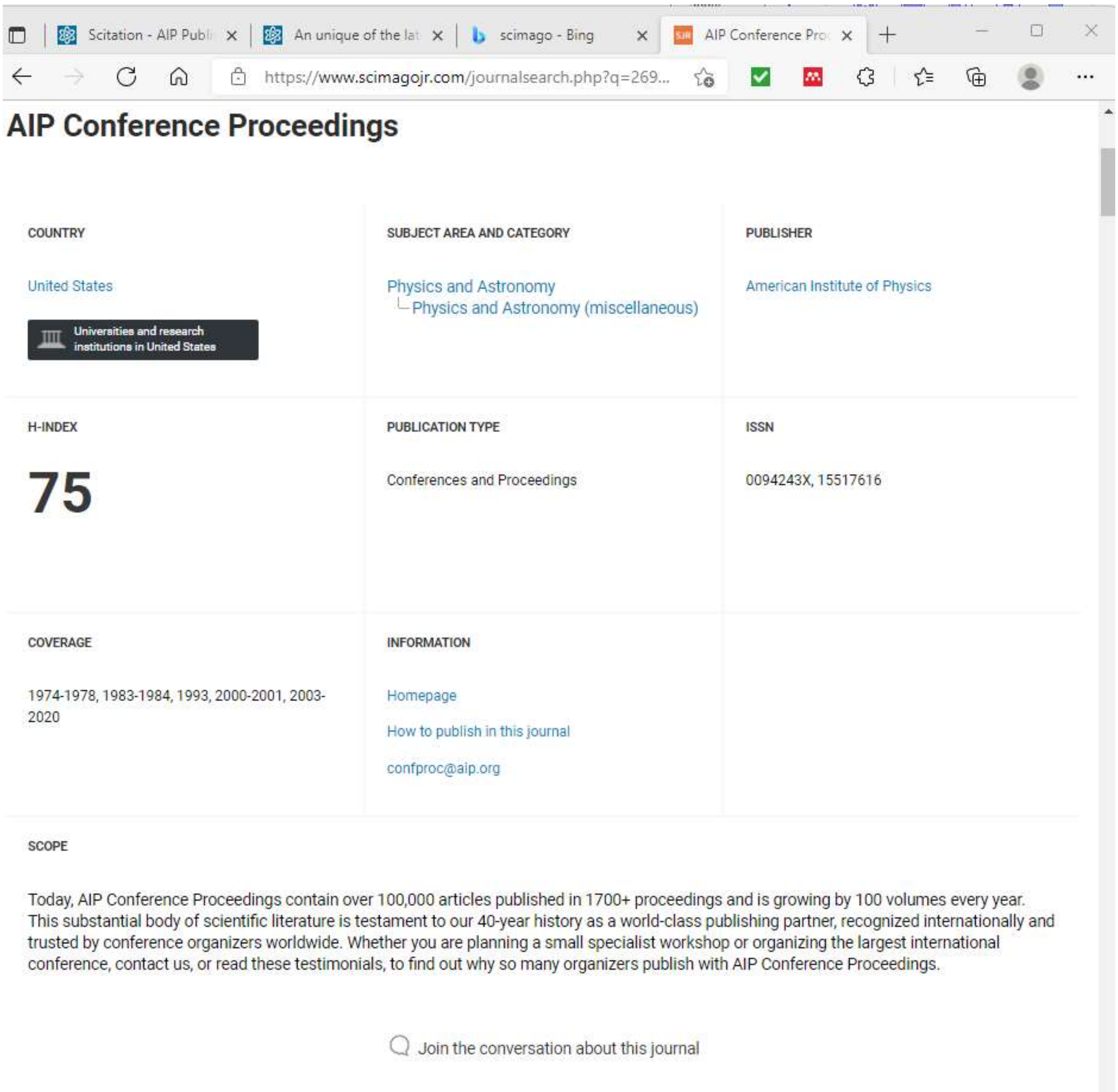

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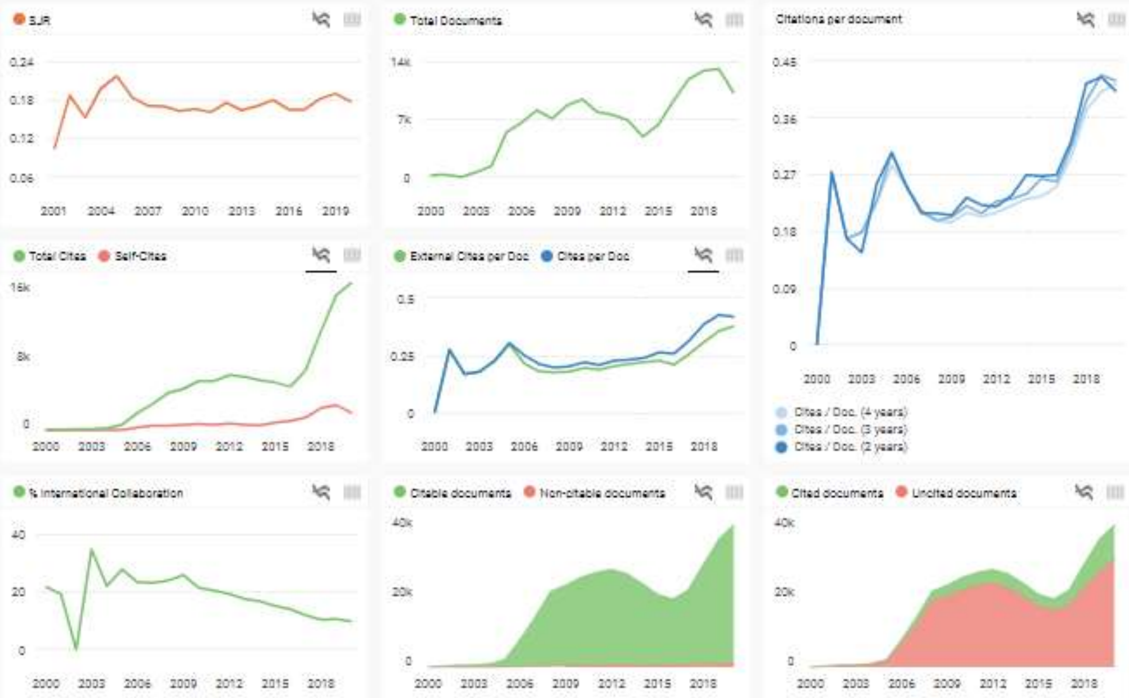

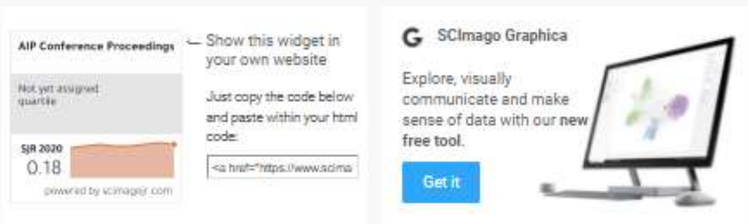

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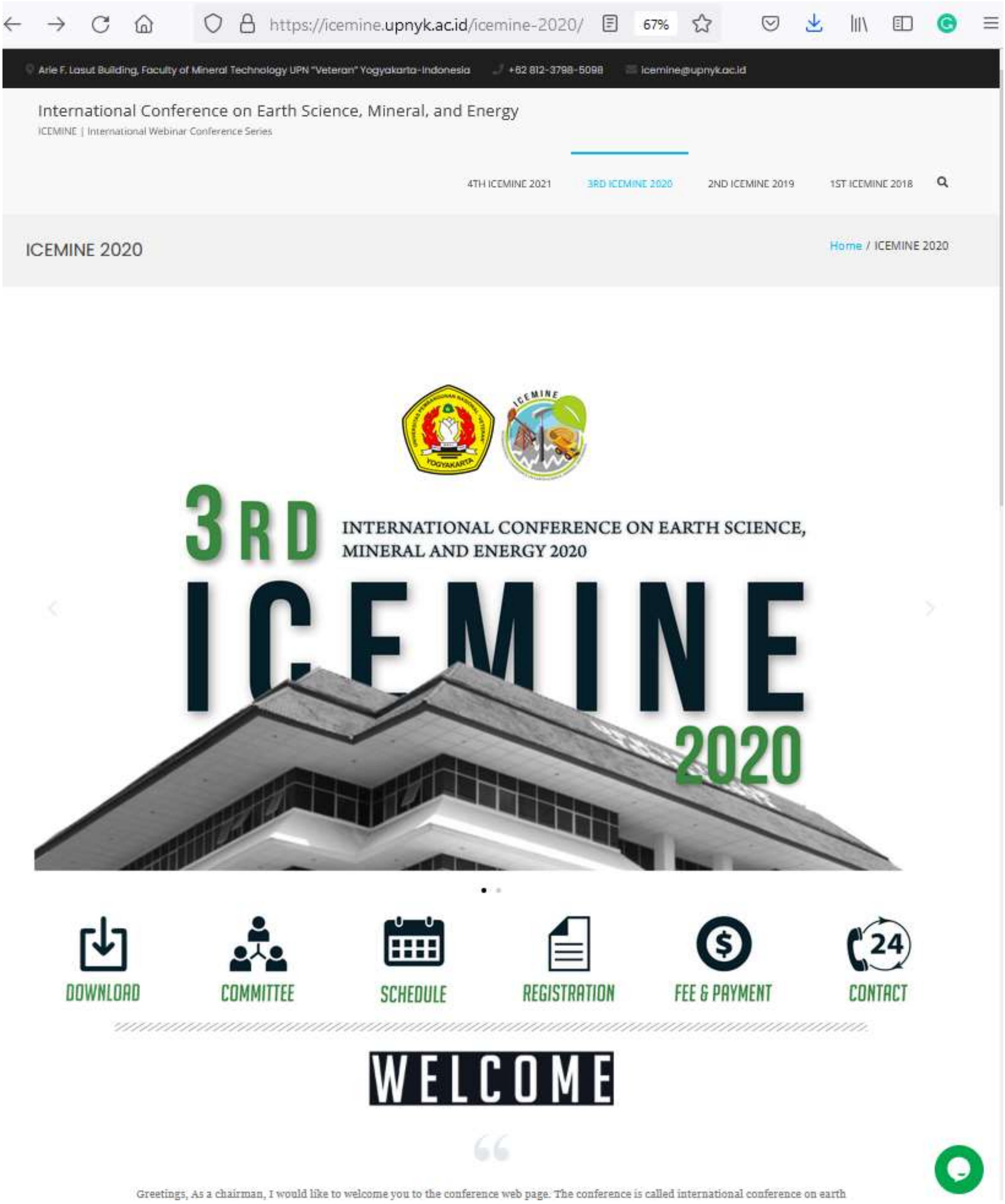

Linkage of cementation factor on rock quality in sandstone

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Suryo Prakoso, Muhammad Burhannudinnur, Syamsul Irham, et al.

Linkage of Cementation Factor on Rock Quality in Sandstone

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Abstract. Accuracy of cementation factor *m* is crucial for water saturation calculation. Water saturation calculation usually only uses single value of *m* obtained from core analysis at certain intervals. Then m is applied to calculate water saturation for entire depth interval of formation. Several studies have shown that the values of *m* depend on lithology and also affected by rock quality. Thus the value of *m* should be influenced by complexity of pore arrangement. This research is intended to understand the effect of pore complexity expressed by pore geometry and pore structure on cementation factor. Research uses sandstone reservoir data from several formation and oil field in Central Sumatra and Jambi. The power law method is used to analyze the relationship of pore complexity and cementation factor. Based on these methods, an empirical relationship of pores complexity with parameters *m* can be arranged. The resulting empirical equation provides a fairly accurate prediction of cementation factors.

Keywords: pore complexity, cementation factor, saturation exponent, power law

INTRODUCTION

Cementation factor (*m*) is the most important parameter in calculating water saturation. In calculation of water saturation, cementation factor here is a parameter that affects the volume of pore space. Several studies have shown that cementation factor is not a constant value, but varies widely according to the reservoir characteristics of an oil and gas field. In general, the most reliable cementation factor was those obtained from core analysis. However, not all sandstone intervals have core data. Thus, an effort is needed to obtain *m* by a certain method using the most effective reservoir parameters for each different reservoir interval.

Looking at Archie's equation, the value of *m* has an effect in form of power so that a small change will cause a significant difference in water saturation calculation result. As is well known, reservoir rocks are not always homogeneous. In heterogeneous reservoir rocks, of course, the changes in the petrophysical properties of rock per feet vary greatly. This variation in petrophysical properties is related to pore complexity which is the result of both deposition and diagenetic processes. Thus *m* parameter should be related to pore complexity of rock. Many studies have been conducted to develop empirical equations to estimate the variation in m associated with porosity and rock type

It is incorrect to apply a constant cementation factor "*m*" to calculating water saturation for entire depth interval. The cement factor varies with rock and fluid properties of a reservoir. The application of the variable cementation factor in water saturation calculation provides a more accurate oil volume estimation [l]. Focke and Munn evaluated formation resistivity factor (*F*) and cementation factor (*m*) of carbonate rocks [2]. *F* and n in carbonate rocks have a very large variation. This variation can be recognized by distinguishing rock type and porosity type. This leads to a practical method in which a representative *m* can be given for a given reservoir interval.

Borai revealed that in carbonate reservoir the use of the empirical equation of m to calculate water saturation often fails, especially at low porosity [3]. By constructing the relationship of *m* and porosity from 4 formations and

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l4 structures, a new empirical equation for prediction of m is obtained. By using this empirical correlation, the difference results of Sw calculation and Sw test can be reduced.

Several other researchers have also developed equations for prediction of *m*. In log analysis, the value of m can be predicted using resistivity obtained in zone l00% filled with formation water. The *m* value is obtained by plotting formation resistivity factor *F* with porosity in wet zone. Formation resistivity factor *F* is obtained based on the R_o obtained from deep resitivity in wet zone and resistivity water (R_w). However, not always found a wet zone near the zone analyzed. Several empirical equations have been published to predict *m* but these equations are arranged for specific types of porosity such as vuggy and low porosity carbonates [4], vuggy and interganular/intercrystalline porosity carbonates [5], low porosity and tight carbonates [3]. Mahmood Akbar developed an estimation technique for *m* which takes into account the texture of the carbonate, to estimate the cementation factor (*m*) for reservoir carbonate [6]. It has been applied to calculate *m* in carbonate reservoirs in the Middle East and Europe. The estimation results show good results when verified with core data and production results.

From some studies mentioned above, it can be seen that *m* value is strongly influenced by pore complexity of rock. This study aims to determine the relationship between pore complexity and *m* so that the representative *m* value can be predicted. The pore complexity here refers to combination of porosity and permeability which is commonly known as pore geometry and pore structure. Several studies have shown that these two parameters have a systematic effect on the petrophysical properties of rocks [7][8][9][l0]. The pore complexity determines the rock quality and can be identified using the pore attributes [ll]. This concept will be used as the basis of analysis in this study.

DATA AND METHODS

Data Description

The data used in this study are sandstones from the Central Sumatra and Jambi basins. In order to represent variations in pore complexity of sandstones, the results of core analysis obtained from several oil fields in the Central Sumatra and Jambi basins are used. The available core analysis results include routine core analysis, namely porosity and permeability as well as special core analysis, namely formation factor, formation resistivity index, *m* and *n*.

The Concept of Formation Resistivity Factor and Power Law

R_o is defined as the resistivity of a rock whose entire pore space is filled by water. The value of R_o here depends not only on the resistivity of water but also on resistivity of solid. The relationship between resistivity of rocks saturated with l00% formation water and water resistivity shows a linear trend with a constant *F* [l2]. This relationship can be written:

$$R_o = FR_w \tag{l}$$

F is the formation resistivity factor and R_w is the resistivity of formation water

Referring to the definition of R_o, Equation 1 confirms that the value of *F* is not constant but varies depending on the lithology and characteristics of rock. *F* value is inversely proportional to porosity. Semilog plot *F* with porosity will form a straight line and empirical equations can be arranged in form of power [l2]. This equation can be written:

$$F = \phi^{-m} \tag{2}$$

m hereinafter known as cementation factor. Since *m* is a constant power of porosity, a small change of *m* will greatly affect the formation resistivity factor. Substitution of equation 2 to equation 1 can explain the effect of formation characteristics on R_o.

$$R_o = \phi^{-m} R_w \tag{3}$$

It can be seen here that R_o is not only influenced by resistivity of formation water but also the petrophysical properties of rock, namely porosity. Porosity is formed as a result of deposition and diagenesis process. Thus it does not only depend on lithology and texture of rock but also pore complexity of rock. Regarding pore complexity, Wibowo and Permadi compiled a power law model based on Kozeny equation (Eq. 4) [7]. Pore complexity is described by pore geometry $(k/\phi)^{0.5}$ and pore structure (k/ϕ^3).

$$\left(\frac{k}{\phi}\right)^{0.5} = a\left(\frac{k}{\phi^3}\right)^b \tag{4}$$

Equation 4 is a power law equation to describe the relationship of pore geometry $(k/\phi)^{0.5}$ and pore structure $(k/\phi)^{0.5}$. This relationship can be used to rock grouping of similar quality.

RESULTS AND DISCUSSION

By using the power law concept, all data can be grouped into several groups. Starting from rock type 4 which is the best quality rock type to rock type l4 which is the highest pore complexity rock type (**FIGURE 1**). This rock grouping will be the basis for analyzing the effect of pore complexity on *m*.

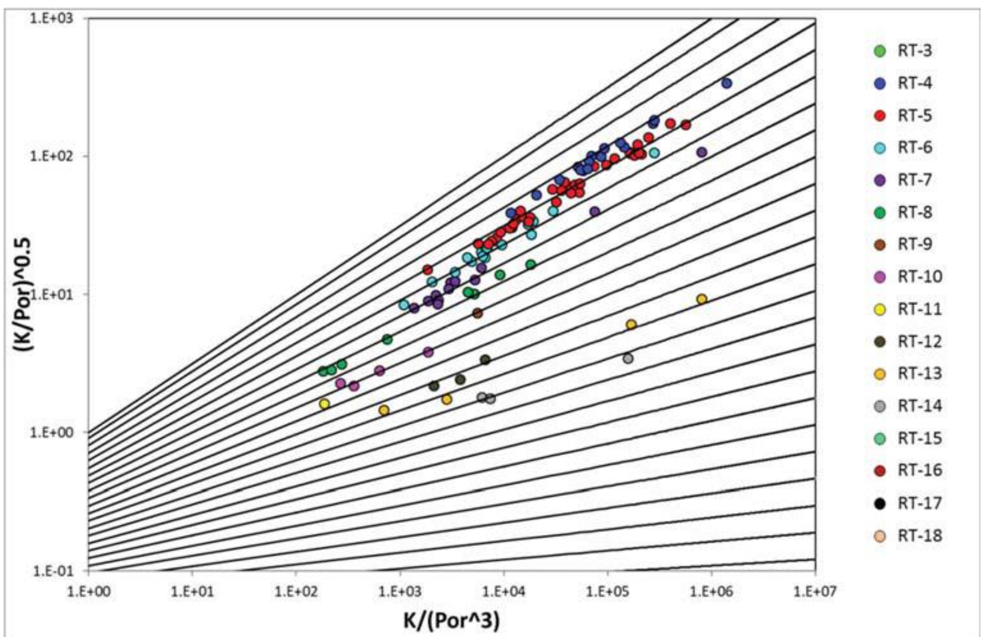

FIGURE 1. Rock grouping using power law model

As discussed in the previous section, the Formation Resistivity Factor (F) is strongly influenced by the characteristics of formation. The value of F is not constant but varies depending on the lithology and pore complexity. **FIGURE 2** shows the relationship between porosity and F. F value increases exponentially with decreasing porosity. If observed, at porosity above 22%, there is a linear relationship between porosity and F. This linear relationship occurs in good quality rock groups characterized by simple pore shapes, large pore sizes, simple sorting and simple grain arrangements. Low rock quality is characterized by high pore complexity so that it tends to reduce pore volume. In **FIGURE 2**, the decline in rock quality causes the formation resistivity factor to increase exponentially. From the value of F l0 at 22% porosity increases to 8000 at porosity below 2%. This proves that F is greatly affected by pore complexity.

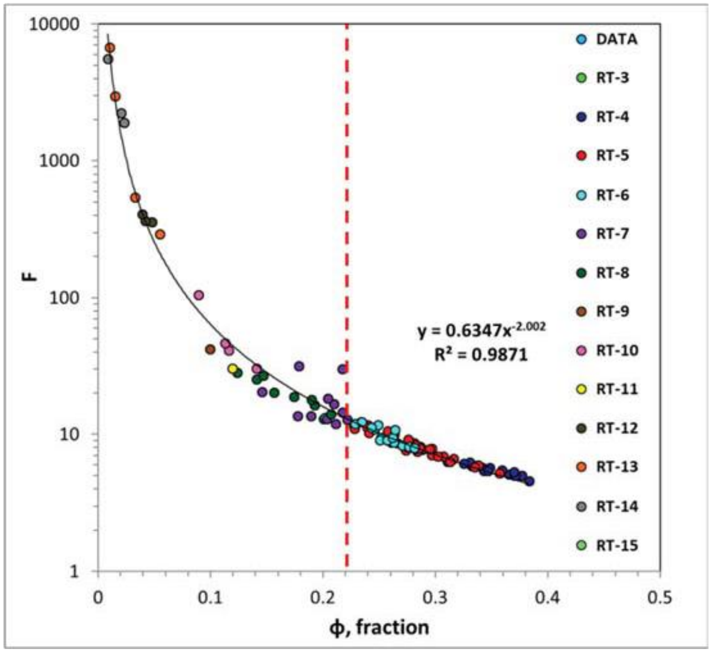

FIGURE 2. Relationship of Formation Resistivity Factor with Porosity

This phenomenon can be explained by **FIGURE** 3A and 3B. The pore geometry is proportional to the mean hydraulic radius [l3][7]. The pore geometry here are pore shape and pore size so that pore geometry will affect pore volume. Good quality rock type tend to be composed by rock samples with a large mean hydraulic radius (Figure 3A) and a simple pore structure characterized by high value of kl/ϕ^3 (Figure 3B). Conversely, the lower quality of rock type, the mean hydraulic radius tends to decrease. Low quality rock types are identified with increased pore complexity, characterized by lower value of kl/ϕ^3. Pore structure here is related to the pore connectivity system of rock, variation in pore size and ratio of pore volume to surface area of the grain wetted by fluid. Thus, the pore structure is a characteristic of interconnected pore spaces related to fluid flow in the porous media including pore attributes, namely tortuosity, surface area, and pore size distribution of a porous medium.

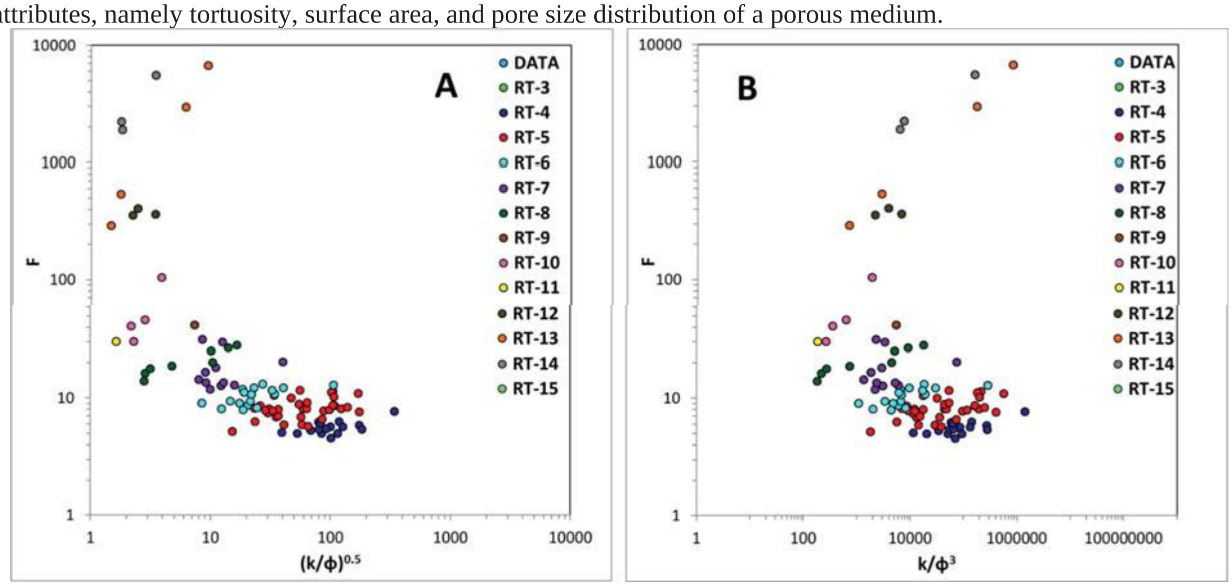

FIGURE 3. Relationship of Formation resistivity factor (F) with Pore Geometry (A) And Pore Structure (B)

Equation 3 explains that R_o is not only influenced by resistivity of fluid filling the pore space but also formation characteristics manifested in formation resistivity factor. Even though the data looks scater, **FIGURES** 4A and 4B explain how pore complexity represented by attributes of pore geometry and pore structure affects R_o. **FIGURES** 4A and 4B confirm the effect of formation characteristics on R_o. The smaller pore size tends to increase R_o (**FIGURE** 4A). Likewise, the complex pore structure (**FIGURE** 4B).

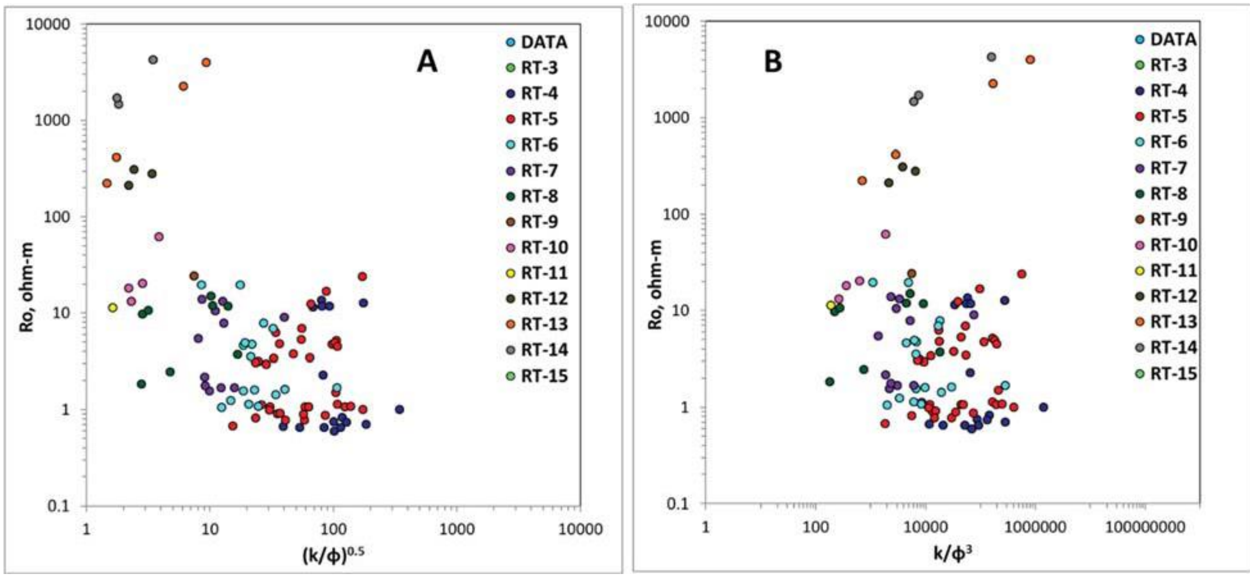

FIGURE 4. Relationship of R_o with pore geometry (A) and pore structure (B).

Equation 3 illustrates the effect of cementation factor m on R_o. m here is power exponent of porosity so that a small change in value of m cause a significant change in R_o. As is known, ranges value of m from l.3 for unconsolidated sandstone to 2.2 for highly cemented sandstone [l4]. This range of m illustrates the increased pore complexity of rock as shown in **FIGURES** 5A and 5B. The increase in m was caused by lower pore size (**FIGURE** 5A) and more complex of pore structure (**FIGURE** 5B). These two figures explain that lower rock quality, the higher of m value. Effect of m on R_o is very large, especially for low porosity or lower quality rock type. This has been explained in **FIGURE** 2 where a small change of m will increase the value of F exponentially.

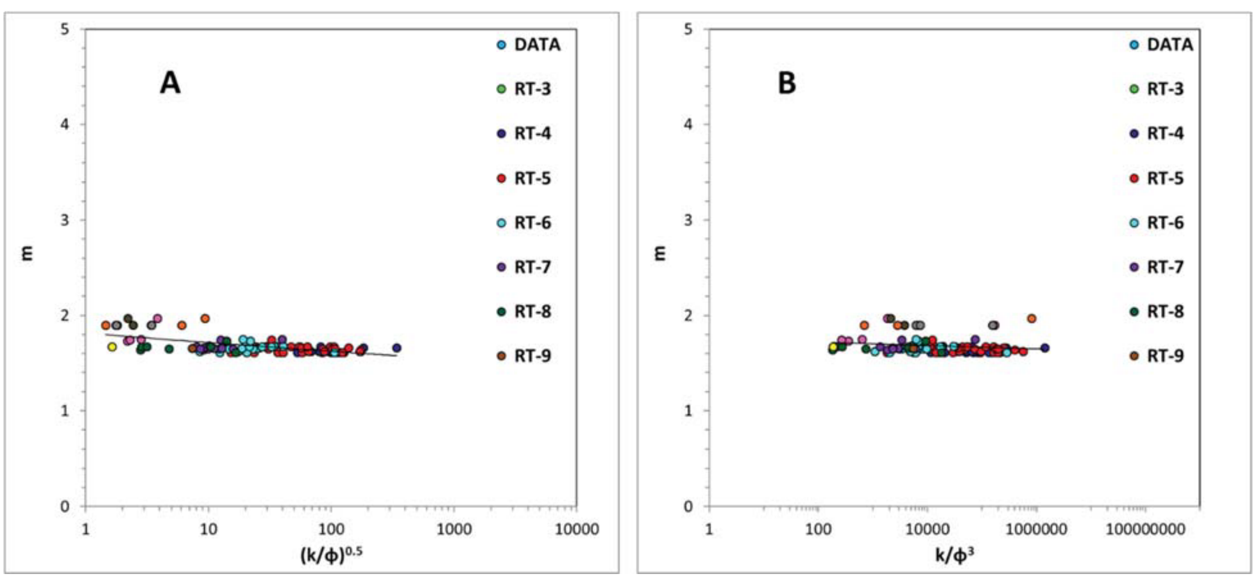

FIGURE 5. Impact of pore geometry and pore structure on cementation factor (m)

Porosity is one of petrophysical properties of rock where usually the data is quite widely available. In oil and gas industry, porosity can be obtained from routine core analysis as well as from log analysis. It is well known that porosity depends on deposition and diagenetic process. Thus, porosity is greatly influenced by pore complexity of rocks. Likewise *m*, the previous discussion shows that *m* is strongly influenced by pore complexity. Thus, it should be possible to establish an empirical relationship between porosity and *m*. **FIGURE** 6 shows that *m* increases with decreasing porosity. If we relate to rock quality, good quality rock types have a lower *m* value than low quality rock types. Based on the data, the relationship between porosity and *m* is obtained with a good correlation coefficient R^2 above 0.7.

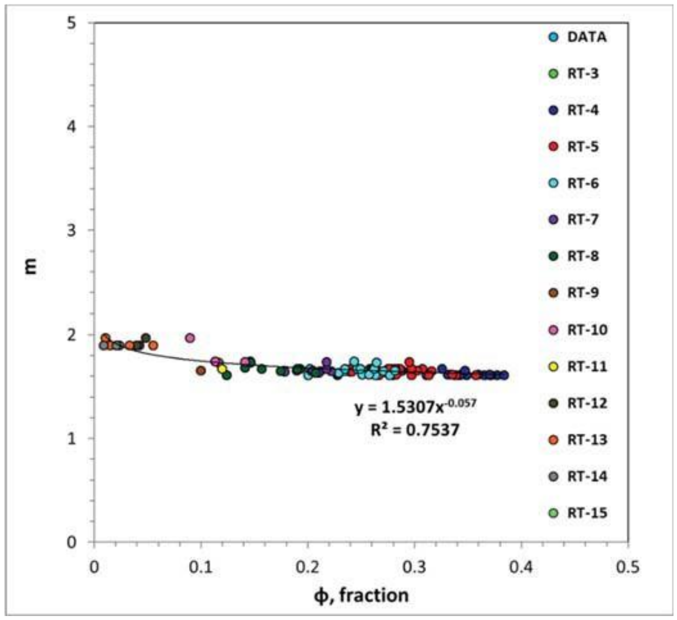

FIGURE 6. Relationship of *m* with porosity

Referring to the power law concept, both pore geometry and pore structure are mainly influenced by shape factor, tortuosity, and specific surface area. In the form of a simple mathematical equation this relationship can be written:

$$k = \frac{\phi^3}{F_s \tau {S_b}^2} \tag{5}$$

$$\frac{k}{\phi^3} = \frac{1}{F_s \tau {S_b}^2} \tag{6}$$

k is permeability, ϕ is porosity, F_s is *shape factor*, *r* is *tortuosity*, and S_b is *specific surface area* per unit *bulk volume*.

Parameter *Fsr* here is commonly known as the Kozeny constant. These two parameters shape factor and tortuosity are parameters that greatly affect by pore complexity of rocks. To determine the value of $Fs\tau$, a model constructed by Mortensen is used where the value of $Fs\tau$ can simply be estimated as a function of porosity (Eq. 7) [l5].

$$\mathrm{Fs}\,\tau = \left(4\cos\left(\frac{1}{3}\arccos\left(\phi\frac{8^2}{\pi^3} - 1\right) + \frac{4}{3}\pi\right) + 4\right)^{-1} \tag{7}$$

A simple and perfectly round pore shape has an *F* value equal to l, while the more irregular and elongated pore shape shows the greater *Fs* value [l6]. Likewise with tortuosity. Tortuosity describes the length of flow fluid through interconnected pore spaces. Complex pore arrangement causes the length of flow fluid to be longer and tortuosity value will be higher. Thus more complex pore shape and pore arrangement of rock, the value of $Fs\tau$ will increase. If associated with *m*, a linear relationship is obtained where increasing $Fs\tau$ causes increasing in *m* (**FIGURE 7**). Linier relationship is obtained with a correlation coefficient R^2 greater than 0.7.

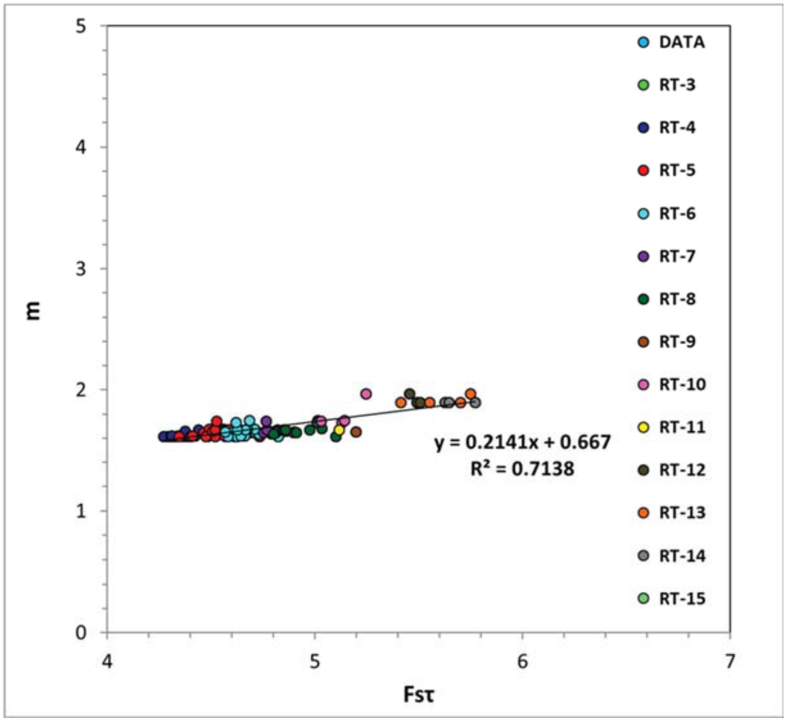

FIGURE 7. Relationship of Fs1 with *m*

Comparison of predictive results of *m* using porosity and $Fs\tau$ with *m* from laboratory measurements is shown in FIGURES 6A and 6B. The value of *m* can be predicted better using a porosity with a correlation coefficient of R^2 greater than 0.7.

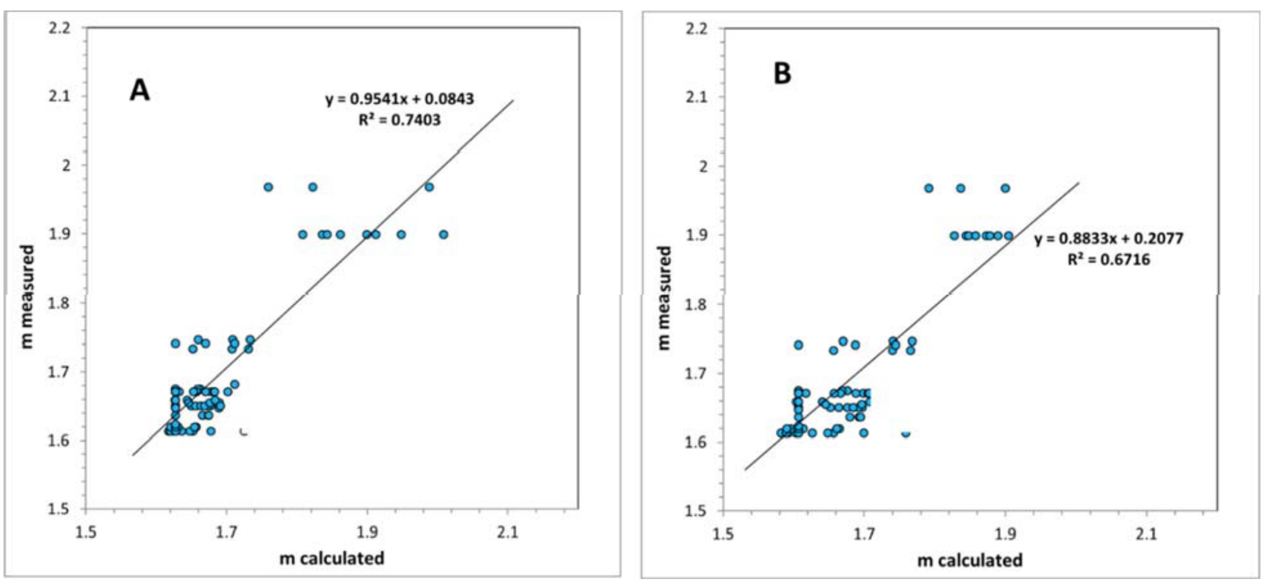

FIGURE 8. Comparison of *m* data and *m* calculated base on porosity (A) and *m* data and *m c*alculated estimated using $Fs\tau$ (B).

CONCLUSION

This study confirms the effect of rock quality on cementation factors. The decline in rock quality increases value of *m* exponentially, especially in low quality rocks characterized by very low porosity. The value of *m* in sandstone in the Central Sumatran and Jambi basins can be predicted well using the empirical relationship obtained from relationship of *m* with porosity and *m* with combination of shape factor-tortuosity ($Fs\tau$).

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by Muhammad Burhannudinnur