The Effect of Pore Geometry on the Flow Unit and Its Impact to Permeability of the Reservoir Rock

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Abstract. Rock type is defined as a rock interval with a unique pore geometry and it is related to the characteristics of the hydraulic flow unit. The quality of hydraulic unit of the rock is controlled by pore geometry which is a function of texture and mineralogy of the rock. In this research, it is conducted the study of the effect of pore geometry on the flow unit owned by the reservoir and its impact to the permeability value. This study used 191 of sandstone core samples from Upper Cibulakan Formation in the North West Java Basin. The hydraulic flow unit concept developed by Kozeny-Carman is used to determine the rock type in the reservoir. Afterward, microscopic geology features are identified based on rock texture in the form of grain size, grain sorting, and angularity as part of the pore geometry that controls the hydraulic quality of the rock. This identification was carried out to determine the pore geometry which generally composes each rock type. Based on the results of core data analysis, the reservoir under this study consists of eight flow units. Based on microscopic geology features identification, it is generally found that the better flow unit, the simpler texture it has, which is seen from the better of grain size and grain sorting. On the contrary, the lower quality of the flow unit, the texture tends to be more complex. From this study, it has also known that the better flow unit has a higher permeability value compared to the lower quality of flow unit, which causes the fluid flowing faster and the rock has the better reservoir quality index.

1. Introduction
Permeability is one of the important of rock properties and it is related to the fluid flow from the reservoir. Permeability values in the reservoir are heterogeneously distributed which are influenced by the geological and petrophysical properties of the rock, and it is also associated with rock types that are scattered in the reservoir. Rock type is defined as the interval of rocks with a unique pore geometry and is related to the characteristics of its hydraulic flow unit [1]. Rock typing is the process of classifying rocks into separate units, which is deposited in the same geological conditions and undergoes the same diagenetic process [2-6].

Amaefule introduced the HFU (Hydraulic Flow Unit) concept developed by Kozeny-Carman to classify rocks based on their rock type [7]. Amaefule have shown that the relationship between porosity and permeability in each rock type is an evidence of different hydraulic units [7]. The hydraulic quality of a rock is determined by the geometry of the rock pores [8],[9]. Pore geometry is a function of mineralogy (type, number, morphology, and relative position of pore throat) and texture (grain size, grain shape, grain size uniformity, and grain structure) [10,11].
The objective of this study is to find out the effect of pore geometry to the flow unit of the reservoir rock, then it can also conducted the impact of those to the permeability value of the reservoir. The HFU concept developed by Kozeny-Carman was used to determine the rock type of the reservoir, so that the relationship between porosity and permeability of each rock type can be obtained. After that, microscopic geology features were identified based on rock texture in the form of grain size, grain sorting, and angularity as part of the pore geometry that controls the quality of rock hydraulics. This identification was carried out to determine the pore geometry which generally composes each rock type and how it can impact the permeability value.

2. Methodology
In this study, 191 of sandstone core samples from Upper Cibulakan Formation in the North West Java Basin were used. These core samples had had porosity and permeability value from core analysis in the laboratory. The core samples were used to determine the HFU class owned by the reservoir which was analyzed using the Kozeny-Carman approach [7],[10],[12]. Kozeny-Carman considers that the reservoir pores are a collection of capillary tubes. Kozeny-Carman uses Poisseuille’s Law (for flow in capillary tubes) and Darcy’s Law (for flow in porous media), to get the relationship between porosity and permeability [13]. In general the Kozeny-Carman equation can be written as:

\[ k = \frac{\phi_e^2}{(1-\phi_e)^2} \left[ \frac{1}{F_s \tau S_{gv}^2} \right] \]  

(1)

Then, new parameter is generated that expressed in the following equation:

\[ RQI = \sqrt{\frac{k}{\phi_e}} \]  

(2)

\[ \phi_z = \left( \frac{\phi_e}{1-\phi_e} \right) \]  

(3)

From Equations (2) and (3) then a new parameter is generated, namely FZI (Flow Zone Indicator) which can be expressed in the following equation:

\[ FZI = \left[ \frac{1}{\sqrt{F_s \tau S_{gv}}} \right] = \frac{RQI}{\phi_z} \]  

(4)

Then, to grouping the data based on the flow unit, the following equation is used:

\[ FZI_{\text{discrete}} = \text{ROUND} \left( 2 \times \ln(FZI) + 10,6 \right) \]  

(5)

After determining the rock type using the HFU concept developed by Kozeny-Carman, the relationship between porosity and permeability was obtained for each rock type. It was also carried out the identification of microscopic geology features based on available core data. The identified microscopic geology features are grain size, grain sorting, and angularity as part of pore geometry that controls the quality of rock hydraulics. This is obtained to find out the pore geometry which generally compiles each HFU and distinguishes it from other HFUs and how it relates to the permeability value.

3. Results and Discussion
Determination of HFU was carried out by applying Kozeny-Carman’s approach using 191 of available sandstone core samples. From the results of this calculation, it is known that the reservoir consists of eight HFUs and it was also found the relationship between porosity and permeability of each HFU which can be seen in Figure 1.
From the relationship of porosity and permeability, the empirical equations generated by each HFU can be seen in Table 1, where \( x \) is porosity and \( y \) is permeability. Using this empirical equation, the permeability value can be calculated by entering the porosity value to the empirical equation according to the HFU group.

### Table 1. Empirical Equations of the Relationship of Porosity and Permeability for Each HFU

| HFU | Empirical Equation |
|-----|--------------------|
| 1   | \( y = 1E+07x^{3.394} \) |
| 2   | \( y = 19.8170x^{4.879} \) |
| 3   | \( y = 15.918x^{3.481} \) |
| 4   | \( y = 5.064.7x^{3.479} \) |
| 5   | \( y = 1,759.9x^{3.316} \) |
| 6   | \( y = 840.51x^{3.552} \) |
| 7   | \( y = 450.54x^{3.718} \) |
| 8   | \( y = 87.244x^{3.325} \) |

Meanwhile, the hydraulic quality of a rock is controlled by the geometry of the rock pores which is a function of the texture and mineralogy of the rock. Thus, eight types of HFU obtained from this study have certain geological features that distinguish one HFU from the other HFU. In this study, microscopic geology features were identified based on rock texture which included grain size, grain sorting, and angularity as part of the pore geometry that controls the quality of rock hydraulics, so the data that generally compile each HFU can be seen in Table 2.
Table 2. Microscopic Geology Features at Each HFU

| HFU | Grain Size        | Angularity            | Grain Sorting        |
|-----|-------------------|-----------------------|----------------------|
| 1   | Fine Grain        | Sub Angular-Sub Rounded | Well Sorted          |
| 2   | Fine Grain        | Sub Rounded           | Moderate-Well Sorted |
| 3   | Very Fine-Fine Grain | Sub Rounded       | Moderate Sorted      |
| 4   | Very Fine-Fine Grain | Sub Rounded       | Moderate Sorted      |
| 5   | Very Fine-Fine Grain | Sub Rounded       | Poor- Moderate Sorted |
| 6   | Very Fine-Slightly Fine Grain | Sub Rounded | Poor- Moderate Sorted |
| 7   | Very Fine-Fine Grain | Sub Angular-Sub Rounded | Poor- Moderate Sorted |
| 8   | Very Fine-Fine Grain | Sub Angular-Sub Rounded | Poor- Moderate Sorted |

From Table 2, it can be seen that in general, the better HFU, which is indicated by a small HFU number, the simpler texture it has, that can be seen from the better grain size and grain sorting. Conversely, the lower quality of HFU, which is indicated by the greater number of HFU, the texture tends to be more complex. To be clearer, then the relationship between grain size and permeability was made from the available core data, which can be seen in Figure 2.

![Figure 2. Grain Size vs. Permeability.](image)

From Figure 2, it can be seen that in general, a better HFU has a larger grain size than a lower quality of HFU. In addition, it is also seen that pore size is not only related to the rock volume, but also relates to the ability of rocks to flow the fluid, that named permeability. In general, the increasing grain size will have an effect on increasing permeability value which is also has the better HFU class. For more details, the tabulation of the smallest, the largest, and average permeability value for each HFU can be seen in Table 2.
Table 3. The Smallest, the Largest, and Average Permeability for Each HFU

| HFU | Permeability, mD |       |       |
|-----|------------------|-------|-------|
|     | Min              | Max   | Mean  |
| 1   | 2258.000         | 5153.000 | 3705.500 |
| 2   | 112.000          | 2191.000 | 650.182  |
| 3   | 40.500           | 298.000  | 134.656  |
| 4   | 0.050            | 168.000  | 26.499   |
| 5   | 0.030            | 43.000   | 12.412   |
| 6   | 0.050            | 9.550    | 2.946    |
| 7   | 0.060            | 3.500    | 0.763    |
| 8   | 0.040            | 0.920    | 0.191    |

From the results of the tabulation, it is known that the good HFU, which is a small HFU number, has a higher permeability value than the low quality of HFU, which results in faster fluid flow and better reservoir quality index.

4. Conclusions
The results of this study show that the pore geometry composing the rock affects the flow units of the rock and influences the permeability value as well. According to the results of the analysis on 191 of core data from Upper Cibulakan Formation in the North West Java Basin, eight different HFUs were obtained with different equations to estimate permeability value for each HFU. It is also known that the better HFU has the simpler texture of pore geometry that can be seen from the better grain size and grain sorting. Conversely, in the lower quality of HFU, the texture tends to be more complex. Furthermore, the better HFU has a higher permeability value than the low quality of HFU, so that the fluid flows faster and the reservoir quality index gets better.

5. References
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