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Implementation of overlap degree in sphere packed sedimentary rock model and its impact to pore structure characteristics

Fourier D E Latief *, Genki T Pantouw, Hessel J Wongkaren, and Nashih Amien

Laboratorium Fisika Bumi, Kelompok Keilmuan Fisika Bumi dan Sistem Kompleks, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia

E-mail: fourier@fi.itb.ac.id

Abstract. Computerized rock modelling is studied and developed because natural rock samples can sometimes be difficult and expensive to obtain. Sedimentary rock modelling is a process of generating a digital sedimentary rock model using numerical methods which resembles the ideas and processes of natural sedimentary rock formation. One of the most important physical characteristics in generating the model is how the pore structure is affected by overlap degree among each grain. The overlap degree simulates the output of compaction process in natural sedimentary rock formation. The approach to implement such idea is by using spherical grains so that the degree of overlap could exactly be determined quantitatively. Stochastic method is used in the algorithm to map each grain positions based on a desired range of overlap degree. From previous trials it shows that higher overlap degree produces lower porosity. The algorithm is implemented in generating two dimensional cross sections of the model as well as in generating three-dimensional structure. Characteristics of pore structure are analyzed for various modelling parameters to obtain better understanding of the modelling nature.

1. Introduction

Modelling a rock sample, in this case sedimentary rock sample, is developed based on natural changes in the rock formation process. The sum of processes that bring about changes in a sediment or sedimentary rocks is called diagenesis. Diagenetic processes, more specifically advective processes, cover several major subjects and one of them is compaction which is defined as the loss of pore from a layer of sediment due to compression [1]. This process of mechanical compaction resulted in a drastic decrease in infiltration rates [2]. Microscopically, compaction is observed when sediments get pressed and the grains get squeezed closer which results in a decrease of porosity value. Such idea or phenomenon could be simulated or approximated while generating rock models by implementing a concept called degree of overlap in the rock model generation algorithm. Degree of overlap is utilized as one of several limiting parameters in determining grain positions so that the grains do not overlap too much. Grain positions are determined by generating random numbers, thus called stochastic modeling. Stochastic approach has been developed previously on modelling fluvial sandstone bodies [3] and Berea and Fountainebleau sandstone [4,5,6,7]. The goal of this modelling study is to analyze

* To whom any correspondence should be addressed.

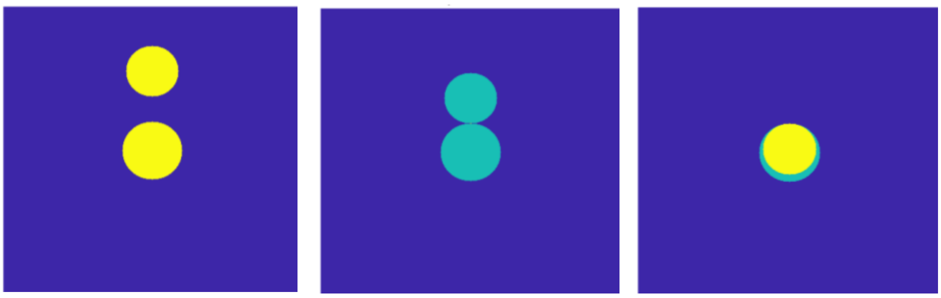
the impact of overlap degree value by evaluating pore structure characteristics of the generated porous medium model.

2. Method

One of the simplest ideas in pore structure modelling is stochastic geometry using ellipsoid model [8]. The concept is to determine grain coordinates, size, or orientation randomly within a desired limit. In this study, the size and orientation of the grains are set as constants. It is done by using spherical grains with uniform radii. Spherical grains are also used so that the degree of overlap among each grain could exactly be determined quantitatively. Degree of overlap O between two spherical grains are defined as [6]

$$\boldsymbol{O}_{1,2} = \frac{\boldsymbol{R}_1 + \boldsymbol{R}_2 - |\boldsymbol{x}_1 - \boldsymbol{x}_2|}{\boldsymbol{R}_1 + \boldsymbol{R}_2 - |\boldsymbol{R}_1 - \boldsymbol{R}_2|}. \quad (1)$$

The value overlap degree between two grains relies on the grain size or radius R and the distance between grain centers $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$. Based on the previous definition, overlap degree is valued negative for separated grains, zero for touching grains, and one if a smaller grain is located inside a bigger grain and touches the inner surface of the bigger grain, as illustrated in figure 1.



(a) (b) (c)

Figure 1. Overlap illustration of two circles with different sizes.

The definition of overlap degree above is applied to three distinct modelling algorithm which is developed from *random-penetrable* algorithm [8]. The first algorithm is utilized to see the impact of overlap degree with number of deposited grain and its relationship with porosity value:

```
SET model size, grain radius (maximum and minimum limits), reference
overlap degree, and maximum iteration limit
     WHILE position accepted
          RANDOMIZE deposition coordinate, grain radius
          calculating overlap degree with previously deposited grains
               IF overlap degree > reference overlap degree
                    rejecting deposition coordinate
                    retry to find another coordinate
                    IF rejected coordinate = maximum iteration limit
                         END while
                    END if
               ELSE
                    accepting position
               END if
          CALL create grain based on radius and center position
          depositing grain
     END while
SAVE model
```

The next algorithm is as follows:

```
SET model size, grain radius (maximum and minimum limits), reference
overlap degree, and target porosity.
     WHILE model porosity < target porosity
          RANDOMIZE deposition coordinate, grain radius
          calculating overlap degree with previously deposited grains
               IF overlap degree > reference overlap degree
                    rejecting deposition coordinate, find another
                    coordinate
               ELSE
                    accepting position
               END if
          CALL create grain based on radius and center position
          depositing grain
     END while
SAVE model
```

Rock models with almost exact value of porosity and a certain level of overlap degree can be generated based on the last algorithm. The generated rock models are processed and analyzed using *SKYSCAN "CT-analyzer"* or *CTan* software to calculate the object surface, fractal dimension, Euler number, and connectivity. These characteristics are calculated as a quantitative measure of the complexity of the rock model. Object surface is the surface area of all solid objects within the VOI (Volume of Interest). For example, in the context of fluid flow in a pipe having a circular cross-section with a certain radius and length as illustrated in figure 2, specific surface area *S* is expressed as [9]

$$\boldsymbol{S = \frac{2\phi}{R}}. \tag{2}$$

In this model, higher porosity leads to larger surface area which implies that the model has higher complexity level.

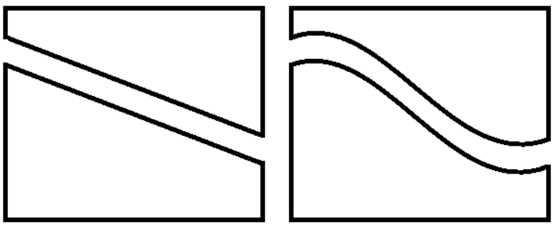


Figure 2. Comparation between two different porous medium model with different surface area, resulting in a difference in complexity.

Fractal dimension value represents complexity from self-similarity of the rock model. One of the efficient and accurate method of calculating fractal dimension of an image is box-counting approach [10] which is used in *CTAn* software. Euler number or Euler-Poincare number along with Connectivity Number is an indicator of connectedness of the grains within the rock model. To generate three-dimensional representation of the model, *CTVox* software is utilized because of its capability in generating 3D visualization from the cross sections of the model. Modelling parameters of the rock models for each algorithm are summarized in table 1.

Table 1. Values of modelling parameters for the implementation of algorithm 1 and 2.

No.	O variations	Porosity limit	Grain coordinate search iteration limit	Grain radius (px)	Model dimension (px ^{3})
1	0 – 30.00% ΔO = 5.000%	-	256×256×256	28 – 32	256×256×256
2	20.00 – 100.00% ΔO = 10.00%	0.3000			

3. Results and discussion

Three-dimensional reconstruction and a cross section sample of the first algorithm implementation are displayed in figure 3. It could be observed qualitatively that the algorithm with lower overlap degree produces more empty space and the overlap value is high. Quantitative validation of the observation is shown in figure 4. It is shown that higher overlap percentage produces lower porosity value and facilitates more space for grain deposition at the same time.

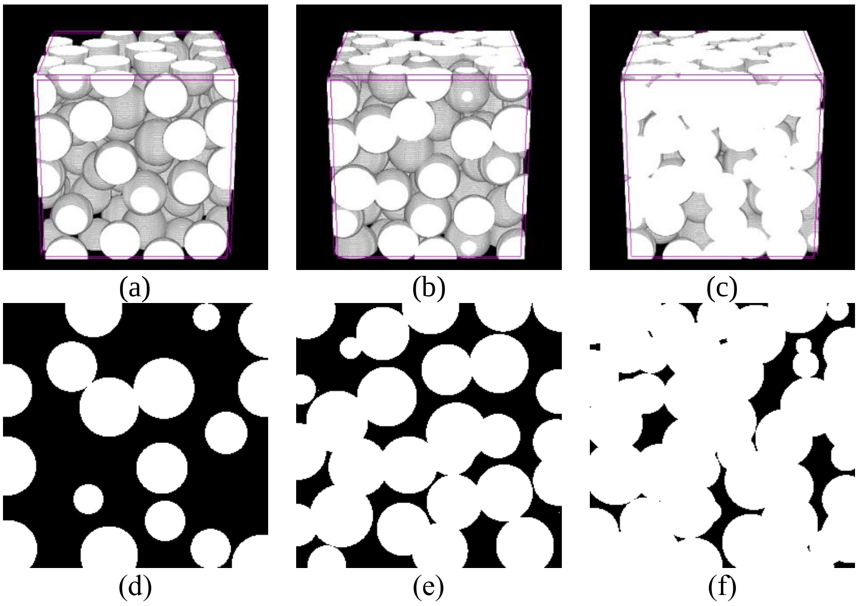
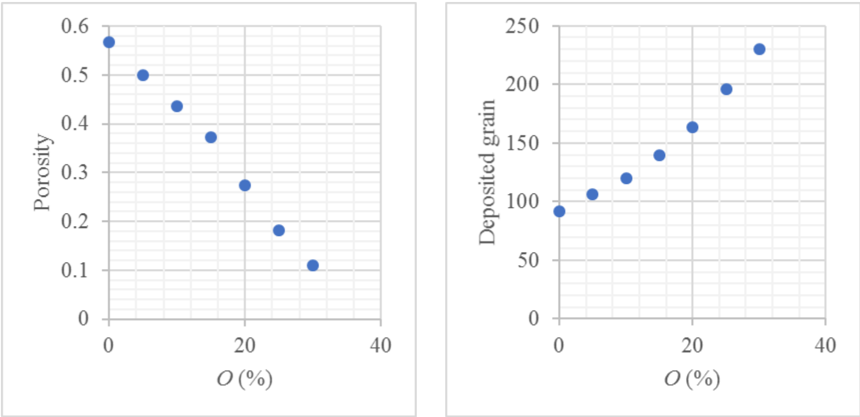


Figure 3. Image results from the first algorithm. (a), (b), and (c) is the three-dimensional representation and (d), (e), and (f) is a sample cross section of the rock model with reference overlap degree of 0, 15, and 30%, respectively.

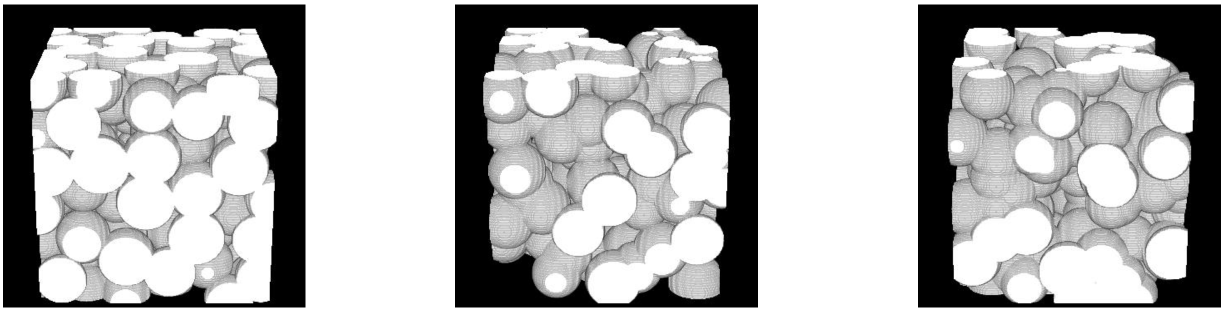
IOP Conf. Series: Earth and Environmental Science **311** (2019) 012042 doi:10.1088/1755-1315/311/1/012042



(a) (b)

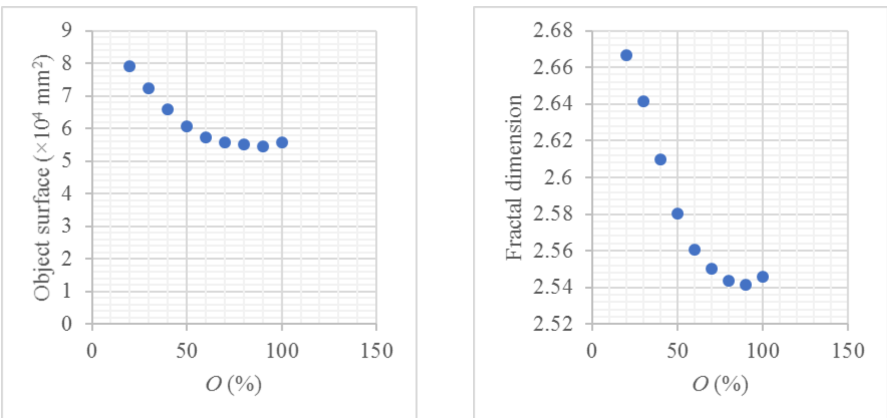
Figure 4. The relation of overlap degree with (a) porosity and (b) number of deposited grains.

Second algorithm image results are shown in figure 5. It is rather difficult to analyze the models qualitatively but by utilizing *CTAn* software, object surface area, fractal dimension, Euler number, and connectivity could be calculated, and the results are displayed in figure 6. It is observed that *random-penetrable* model (O = 100%) statistically have lower surface area, fractal dimension, and connectivity than the results when overlap degree is implemented at lower levels even when porosity level of the models is similar. At the same time, Euler number of *random-penetrable* model is statistically higher. These results imply that quantitatively, models which are not *random-penetrable* have a higher level of complexity based on the values of surface area, fractal dimension, connectivity, and Euler number.



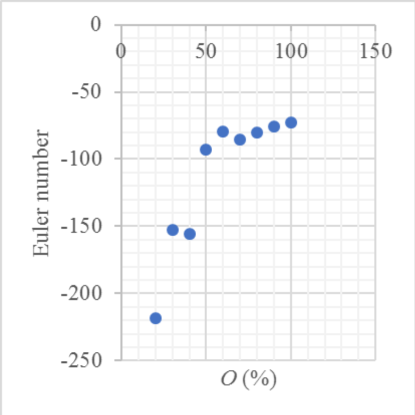
(a) (b) (c)

Figure 5. Three-dimensional image reconstruction of second algorithm model with the same value of porosity. (a), (b), and (c) has reference overlap limit of 20, 60, and 100% (*random-penetrable*), respectively.

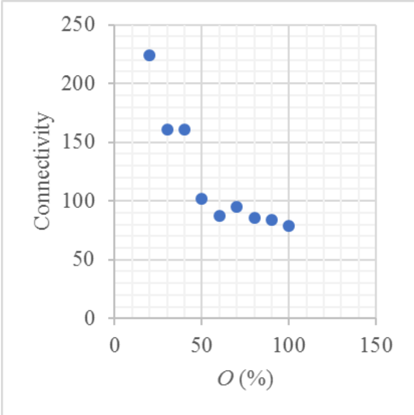


(a) (b)

Figure 6. Results from *CTAn* processing of the results from second algorithm



(c)



(d)

4. Conclusion

The first algorithm successfully produces rock models with a certain level of overlap degree. The result agrees with concepts of compaction that is seen from the relation between reference overlap value and porosity as well as number of deposited grains. Higher overlap value means higher level of compaction which leads to a lower value of porosity. The impact of implementing overlap degree is analyzed from generating models with the same level of porosity but have different values of reference overlap degree. Models with higher level of overlap degree tend to have lower values of surface area, fractal dimension, and connectivity, but higher value of Euler number. These results show that rock models with lower overlap degree have higher level of complexity.

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