Estimation of unconsolidated sand porosity from texture parameters

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Abstract

The knowledge of unconsolidated sand porosity is of great importance to many areas of petroleum geology and exploration geophysics. To estimate the unconsolidated sand porosity, we study the relations between the unconsolidated sand porosity and the texture parameters (including sorting coefficient, mean grain size, and roundness) through the experiments on the quartz sand and glass bead samples in this work, based on which the unconsolidated sand porosity can be estimated from the texture parameters. The results show that the unconsolidated sand porosity decreases with the sorting coefficient and it changes periodically with the mean grain size with a decreasing trend. Furthermore, the increase of roundness also decreases the porosity, which is significant under the small sorting coefficient. Based on the experimental data, the empirical formula linking the texture parameters to the unconsolidated sand porosity is built, which predicts the experimental data well.

Introduction

The study of sandstone porosity evolution is of great importance in many areas of petroleum geology and exploration geophysics, such as geomechanics, diagenesis analysis, and formation pressure predictions, among many others. The unconsolidated sand porosity is the starting point of the sandstone porosity evolution. Hence, an accurate estimation of the unconsolidated sand porosity is crucial for the study of sandstone porosity evolution.

Several experimental studies have been performed to investigate the unconsolidated sand porosity. Pryor (1971) measured and analysed the porosities of the unconsolidated sand for various depositional environments. Beard and Weyl (1973) carried out the experiments on the artificially and naturally packed unconsolidated sand samples. The sample porosities were measured and their relations with texture parameters (primarily with the sorting coefficient) were studied. Based on this study, the empirical formula for unconsolidated sand porosity estimation from the sorting coefficient was given by Scherer (1987).

To estimate the unconsolidated sand porosities, the empirical formula given by Scherer (1987) is often used. However, this formula only links the unconsolidated sand porosity to the sand sorting coefficient. The effects of the other texture parameters, such as the sand grain sizes and roundness, are ignored. Hence, to obtain a more accurate estimation of the unconsolidated sand porosity, we will carry out the experiments on the artificially packed quartz sand and glass bead samples in this paper. The relations between the sand texture parameters, including sorting coefficient, mean grain size, and roundness, with the unconsolidated sand porosity will be studied comprehensively, based on which the new empirical formula for estimating unconsolidated sand porosity from texture parameters will be given.

Experiments

We mix the standard quartz sands with different grain sizes to obtain the sand mixture with the deserved mean grain size and sorting coefficient. The sand mixture is then poured into the volumetric cylinder and compacted using the glass rod. The compacted sand mixture is the unconsolidated sand sample we need, whose porosity can be calculated through its total volume and grain volume as follows:

$$\phi_0 = \frac{V_1 - V_2}{V_1} , \qquad (1)$$

where V_1 is the total volume of the sample, which can be measured using the volumetric cylinder; V_2 is the grain volume that can be calculated from the grain weight and density.

To investigate the influences of the mean grain size and sorting coefficient on the unconsolidated sand porosities, we make six sets of quartz sand samples following the procedure described above. For every set of samples, the mean grain sizes range from 0.18 mm to 0.62 mm while the sorting coefficient keeps constant. The sorting coefficients vary between different sets of samples, which are in the range from extremely well sorted (1.20) to poorly sorted (2.41). Furthermore, in order to study the effects of roundness on the unconsolidated sand porosities, we also make another three sets of glass bead samples following the same procedure as that of the quartz sand samples. These glass bead samples have the same mean grain sizes and sorting coefficients with the quartz sand samples, but have much better roundness than the quartz sand samples. Hence, by comparing the porosities of the quartz sand and glass bead samples, the effects of roundness can be studied.

Results and discussions

Effects of sorting coefficient

By measuring the porosities of the unconsolidated sand samples, the influences of the sorting coefficients on the unconsolidated sand porosities are shown in Figure 1. It is found that the unconsolidated sand porosities decrease with the sorting coefficient. The reason for this is that, for the samples with large sorting coefficients, the size of the large grains is obviously larger than that of the small grains. Hence, it will be much easier for the small grains to fill into the pore spaces between the large grains compared to the samples with small sorting coefficients. This will cause the smaller porosities for the samples with large sorting coefficients. It can also be observed that the relations between the sorting coefficients and the unconsolidated sand porosities are influenced by the mean grain sizes of the samples. It can be seen that this influence of the sample mean grain size is complicated and hence needs to be studied.

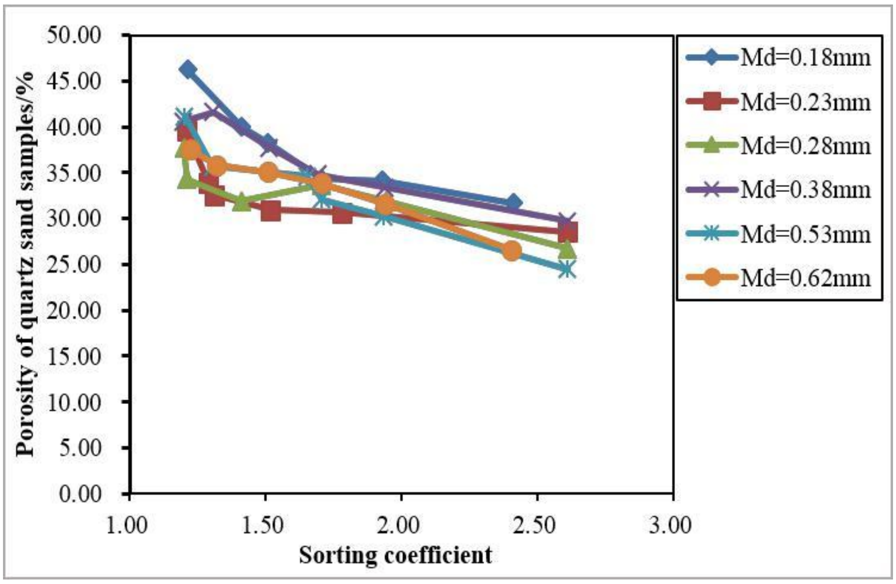


Figure 1 *Influences of the sorting coefficients on the porosities of quartz sand samples under different mean grain sizes.*

Effects of mean grain sizes

The influences of the mean grain size on the unconsolidated sand porosities are shown in Figure 2. It can be found that the influences of the mean grain sizes on the unconsolidated sand porosities are significant and complicated. The unconsolidated sand porosities will decrease and increase with the mean grain size periodically, especially for the samples with small sorting coefficients. This implies that the packing efficiency of the grains varies periodically with the mean grain sizes, which is more obvious for the samples with small sorting coefficients. As the grain packing efficiency depends critically on the frictions between the grains, the periodic variations of the porosity with the mean grain sizes indicates that the frictions between the sand grains vary with the mean grain sizes periodically. However, it can be noted that, on the whole, there is a decreasing trend for the porosities with the increase of the mean grain size. This indicates that while the friction between the grains varies periodically with the mean grain sizes, the general trend for the friction between the grains with the mean grain size is decreasing. It is supported by the experiments carried out by Zhang et al. (2002) on the densely and randomly packed coal particle samples.

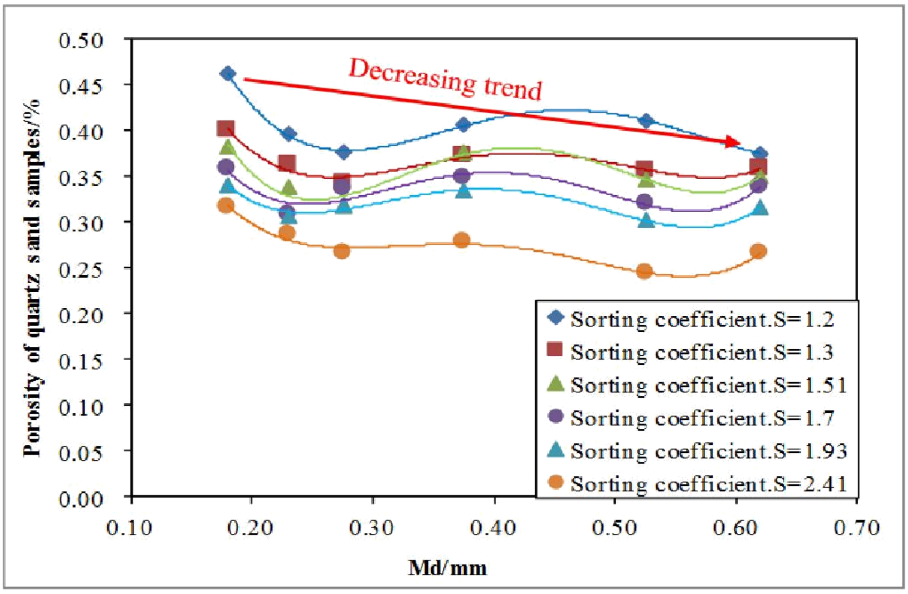


Figure 2 *Influences of the mean grain size on the porosities of the quartz sand samples under different sorting coefficients.*

Effects of roundness

To analyze the influences of roundness, we measured the porosities of the glass bead samples, which have the same sorting coefficients and mean grain sizes with the quartz sand samples but much better roundness than these quartz sand samples. Hence, we can compare the porosities of glass bead and quartz sand samples to analyze the influences of the roundness, as shown in Figure 3. It can be seen that the increase of the roundness will decrease the unconsolidated sand porosities, which is significant under the small sorting coefficients. However, this influence under the large sorting coefficients is much smaller. This is due to the fact that the good roundness will significantly decrease the friction between the grains under the small sorting coefficients which can greatly increase the grain packing efficiency and hence decrease the sand porosities, whereas this effect of roundness is much smaller under the large sorting coefficients and hence the porosities only decrease slightly.

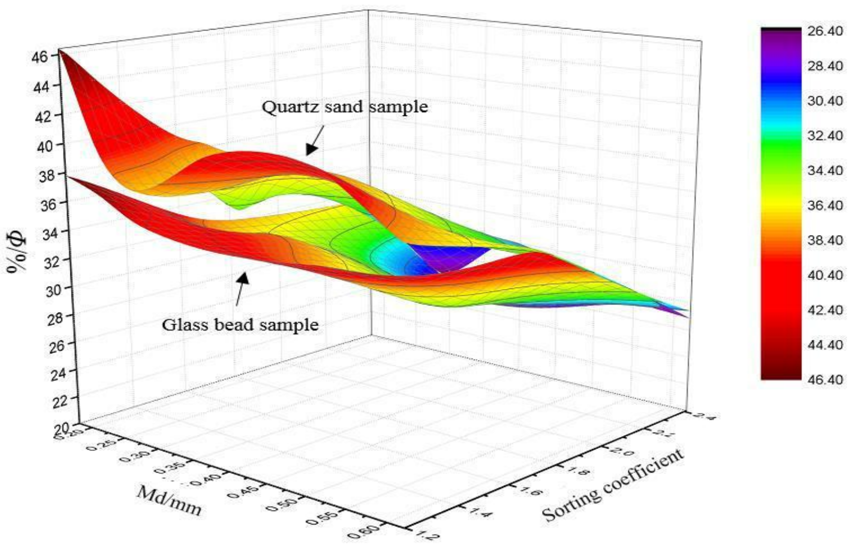


Figure 3 *Influences of roundness on the porosities of the unconsolidated sand.*

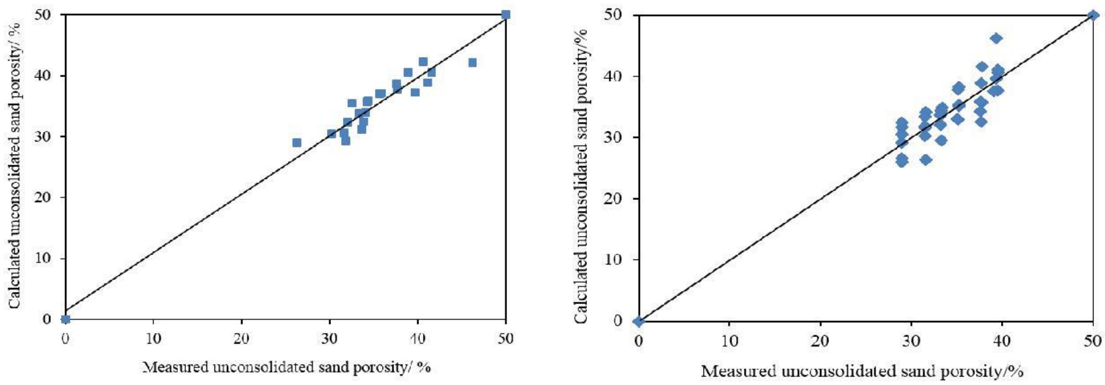
Empirical formula

Based on the experimental data of quartz sand samples, we can build the empirical formula to link the unconsolidated sand porosities with the texture parameters:

$$\phi_0 = 54.16 M_d^4 - 99.18 M_d^3 + 59.06 M_d^2 - 14.65 M_d + 0.25 / S + 1.454 , \tag{2}$$

where M_d is the mean grain size and S is the sorting coefficient.

The prediction results for quartz sand samples are shown in Figure 4a, which match the experimental data very well with a high correlation coefficient of 0.9. If the porosity is only correlated to the sorting coefficient (Scherer, 1987), the correlation coefficient will decrease to 0.7 (Figure 4b). Hence, it is important to consider the effects of the mean grain size. The effects of roundness are not considered currently due to the difficulty to quantify the grain roundness in practice. This makes the current formula only applicable for the sands having similar roundness with the sands measured in this work.



(a) (b)

Figure 4 *Prediction results of porosities with and without considering effects of mean grain size.*

Conclusions

In this work, we investigate the effects of texture parameters on the unconsolidated sand porosities through experiments. The results show that the porosity decreases with the sorting coefficient and it changes periodically with the mean grain size with a decreasing trend. The roundness also decreases the porosity, which is significant under the small sorting coefficient. Based on the experimental data, the empirical formula linking the sorting coefficient and mean grain size to the porosity is built, which predicts the experimental data well. In the future, the method of quantifying grain roundness can be developed, which will enable the consideration of roundness effects in the empirical formula.

Acknowledgements

We would like to thank the financial support from National Natural Science Foundation of China, Contract U1562108.

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