REV IDENTIFICATION OF TIGHT SANDSTONE IN SULIGE GAS FIELD IN CHANGQING OILFIELD CHINA USING CT BASED DIGITAL CORE TECHNOLOGY

Ying Gao, Jun Yao, Yongfei Yang, Jianlin Zhao
School of Petroleum Engineering, China University of Petroleum (East China)

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Avignon, France, 8-11 September, 2014

ABSTRACT

The representative elementary volume (REV) of porous media is one essential and necessary parameter when inferring Darcy-scale flow properties from pore-scale studies. Suitable and accurate size of REV has a great influence on the geometric-topology calculation and flow simulation. Generally different types of rock can have different REVs.

In this paper, a micro-CT based digital rock technology is used to characterize the REV of sandstone from the Sulige Gas Field in the Changqing Oilfield in China. Firstly, the digital core of the sample is obtained by micro-CT scanning of rock samples with the resolution of 3.4μm. Secondly, respective pore network models, with the voxel size from $100\times100\times100$ to $600\times600\times600$, are extracted from the processed micro-CT images. Thirdly, single-phase and two-phase oil-water flow simulation are performed on these models to get geometry-topology and flow properties of each model.

According to the data obtained above, porosity, coordination number, average pore radius and throat length are used to identify the REV firstly. In addition, the parameters of the standard deviation and the coefficient of variation are used to evaluate heterogeneity and to confirm the REV. Alternatively, the REV can be determined to the point where one standard deviation is within +/- 5% of the sample mean. By combining the two methods, we finally determined the REV is $1020\times1020\times1020$ μm^3 for tight sandstone in Sulige Gas Field in Changqing Oilfield China, whose corresponding grid size is $300\times300\times300$. Consequently, this result can direct the further study of the tight rock in this reservoir.

INTRODUCTION

The length scale of Digital Rock models and respective sample sizes is one of the key parameters in processing the digital core. The proper choice of the considered sample volume can not only provide the right physical property, but also can use the less calculation process and time. The key step to get an appropriate length is to determine a representative elementary volume. The REV concept has been discussed in the calculation of effective petro physical properties in reservoir evaluation in many publications[1].

The representative elementary volume (REV) is the smallest core unit which still represents continuum porous media properties and on the basis of which macroscopic parameters of the porous medium like porosity and permeability can be analyzed. The size of an REV is different to different kinds of rocks. In most studies[2, 3] the REV is based on porosity, however it is expected that the REV varies for any petro physical and flow property, i.e. that the porosity REV is different than the permeability REV. The underlying reason is that certain features in the pore space like pore throats have much less contribution to porosity but largely control permeability and 2-phase flow, however it has been shown experimentally that a 2-phase REV would be much larger than the single-phase REV[4, 5]. However, these conclusions are achieved by experiments but not simulation.

In this paper the REV for tight sandstone samples in Sulige Gas Field in Changqing Oilfield China is analyzed with respect to porosity, permeability, pore throat diameter and length using pore-network models extracted from micro-CT images. An alternative way to estimate the REV could be to consider the standard deviation and the coefficient of variation of probing volumes of different sizes. Here this approach is compared to the conventional approach to determine REVs.

METHODOLOGY

Tight Sandstone Samples

In tight sandstone, there is a complex relationship between the parameters of pores and throats, such as geometry, size, distribution and connectivity, as the lithological is pretty tight. Multi-scale phenomenon exists in the multiple microstructure. Since tight sandstone gas reservoirs distribute in a wide region in China and the oil reserves are abundant, getting knowing of their physical properties is important for the exploration and production. As a consequence, the REV of the tight sandstone is different in different regions.

One typical tight sandstone sample from Sulige Gas Field in Changqing Oilfield China is prepared and used for imaging and REV analysis. After a series of process such as cleanout and porosity- permeability experimental measurements, the rock is drilled into a column whose diameter is about 3 mm to acquire more accurate CT images.

CT Imaging and 3D Digital Rock Reconstruction

CT has been utilized widely for the micro scale study[6]. Rock core sample is scanned by an Zeiss MCT-400 X-ray computed tomography machine at 140KV and 71μA at a physical resolution of 3.4 μm producing a 3D volume[7] with 1000^3 voxels as displayed in Figure 1.

In order to identify the REV, six kinds of 3D digital cores (Figure 2), whose voxel sizes from $100\times100\times100$ to $600\times600\times600$, are extracted from the whole digital core to do the following analysis, including filter by non-local means method and segmentation by watershed segmentation method.

Pore Network Model Extraction and Analysis

The digital core acquired above is simplified into pore network model which can reflect the authentic rock physical property and improve the calculation time. This pore analysis tools used to extract pore network from 3D digital rock was developed by Jiang et al[8], which is one new thinning method describing an efficient and accurate algorithm for extracting the geometrical/topological network that represents the pore structure of a porous medium.

In order to avoid the randomness as the heterogeneity of the formation existing, we extract six subsamples whose grid size are 100^3 which are not overlapping, four subsamples whose grid size are 200^3 which are not overlapping, four subsamples whose grid size are 300^3 which are not overlapping, three subsamples whose grid size are 400^3 which are not overlapping, two subsamples whose grid size are 500^3 which are not overlapping, and two subsamples whose grid size are 600^3 which are overlapping only one little part. Calculation of subsamples of different grid size below is carried by all of these datasets, and the value is the average value.

The six typical extracted pore network model is shown in Figure 3. And the average connected porosity got from these datasets is shown in Table 1.

Table 1 Basic parameters of the six subsamples

Subsample	**100^3**	**200^3**	**300^3**	**400^3**	**500^3**	**600^3**
Porosity/%	4.63	4.04	2.56	2.52	2.54	2.53
average pore radius/μm	5.61	6.95	6.54	6.46	6.51	6.43
throat length/μm	18.6	21.9	22.7	22.9	23.1	22.8
shape factor	0.0528	0.0504	0.0511	0.0513	0.0515	0.0513
average coordination number	3.43	3.23	3.29	3.29	3.23	3.29
Permeability/10^{-3}μm^2	14.14	15.27	1.30	1.33	1.30	1.32

RESULTS AND DISCUSSIONS

Geometry and Topology Analysis

Geometry and topology properties of one sample are important in analysing the pore network model. Geometry properties include pore radius distribution, shape factor distribution, and throat length distribution and topology properties include mainly coordination number distribution [9]. Figures in Figure 4 illustrate the geometry and topology properties of this tight sandstone sample. In terms of the data and figures, average values of the basic parameters of the subsamples are shown in Table 1.

Flow Analysis

The permeability is estimated from the network permeability performed in the pore network model according to percolation theory[10]. The average absolute permeability data is shown in the Table 1.

Comparing the permeability, porosity, average pore radius and average throat length of the six kinds of subsamples, as shown in Figures 4, the four parameters begin to be independent of the averaging volume from approximate 10^9 μm^3. Thus, the subsample whose grid size is $300\times300\times300$ is the most suitable REV choice, or one cubic whose volume is $1020\times1020\times1020$ μm^3 can reflect the basic petro-physical properties.

Parameters Analysis

Based on the calculated REV, heterogeneity, as one characteristic of tight sandstone in Sulige Gas Field, is evaluated and reflected by the following parameters, so standard deviation and the coefficient of variation is introduced.

The parameters of the standard deviation σ shows how much variation from the average exists. It defines as $\sigma=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i-\mu\right)^2}$, where N is the corresponding number of different subsamples of one voxel size, μ is the average value of corresponding parameter for different subsamples of one voxel size, and x_i is the value of one parameter for different subsamples of one voxel size.

From the Table 2, we can get that the standard deviation varies little when the grid size of subsamples is bigger than 300, and the standard deviation change differently when the size is lower than 200.

Table 2 The standard deviation of porosity and the simulation value of the six subsamples

Subsample	**100^3**	**200^3**	**300^3**	**400^3**	**500^3**	**600^3**
Porosity/%	1.307	1.880	0.111	0.108	0.110	0.095
Permeability/10^{-3}μm^2	7.103	6.288	0.067	0.065	0.065	0.057
average pore radius/μm	0.608	0.488	0.308	0.306	0.312	0.309
average throat length/μm	1.566	1.794	0.125	0.122	0.125	0.123

Compared to the standard deviation, the coefficient of variation is more specific in reflecting the variation as this need not to take the average value into consideration. The parameters of the coefficient of variation c_v is a normalized measure of dispersion of a probability distribution or frequency distribution. It defines as $c_v=\frac{\sigma}{\mu}$, where σ is the standard deviation and μ is the average of these six values of one parameter.

Table 3 The coefficient of variation of the six subsamples

Subsample	**100^3**	**200^3**	**300^3**	**400^3**	**500^3**	**600^3**
Porosity/%	0.282	0.464	0.043	0.043	0.043	0.038
Permeability/10^{-3}μm^2	0.502	0.412	0.050	0.049	0.050	0.043
average pore radius/μm	0.108	0.070	0.047	0.047	0.048	0.048
average throat length/μm	0.084	0.082	0.006	0.005	0.005	0.005

In terms of the Table 3,we find that the variance decreases as the subsample size increases. The REV computation, which is fitted to the line of one standard deviation about the sample mean, is extrapolated to the point where one standard deviation is within +/- 5% of the sample mean[11]. Based on the data above, $300\times300\times300$ is fitted to be the REV of this sample.

CONCLUSION

In this work, based on the CT images and 3D digital core reconstruction, a non-destructive 3D image is obtained. Then, a binary dataset is constructed to do further analysis. The geometry –topology, which is got by the thinning algorithm, and flow properties, which is got by the percolation theory, were compared among the six subsamples. Based on the data obtained, we can get that the REV is $1020\times1020\times1020$ μm^3 for tight sandstone in Sulige Gas Field in Changqing Oilfield China, whose corresponding grid size is $300\times300\times300$. An alternative way to estimate the REV could be to consider the standard deviation and the coefficient of variation of probing volumes of different sizes. Here this approach is compared to the conventional approach to determine REVs.

ACKNOWLEDGEMENTS

We would like to express appreciation to the following financial support: the National Natural Science Foundation of China (No. 51234007，51304232), the Major Programs of Ministry of Education of China (No. 311009), Specialized Research Fund for the Doctoral Program of Higher Education (20120133120017), the National Natural Science Foundation of Shandong Province (No. ZR2011EEQ002), Introducing Talents of Discipline to Universities (B08028), and Self-Dependent Innovation Research Program Project in China University of Petroleum (East China) (No. 14CX06090A). Authors would like to give appreciation to professional suggestions from reviewer Steffen Berg.

REFERENCES

1. Bear J. Dynamics of fluids in porous media[M]. Courier Dover Publications, 2013.
2. Hassanizadeh M., Gray W. G. General conservation equations for multi-phase systems: 1. Averaging procedure[J]. Advances in Water Resources, 1979, 2: 131-144.
3. Hurst A. Sedimentary flow units in hydrocarbon reservoirs: some shortcomings and a case for high-resolution permeability data[J]. The Geological Modelling of Hydrocarbon Reservoirs and Outcrop Analogues, 2009, 37: 191.
4. Georgiadis A., Berg S., Makurat A., et al. Pore-scale micro-computed-tomography imaging: Nonwetting-phase cluster-size distribution during drainage and imbibition[J]. Physical Review E, 2013, 88(3): 033002.
5. Armstrong R. T., Georgiadis A., Ott H., et al. Critical capillary number: Desaturation studied with fast X‐ray computed microtomography[J]. Geophysical Research Letters, 2014, 41(1): 55-60.

6. Arns C. H., Bauget F., Limaye A., et al. Pore-scale characterization of carbonates using X-ray microtomography[J]. SPE JOURNAL-RICHARDSON-, 2005, 10(4): 475.
7. Waters A., Martz H., Logan C., et al. Xradia Performance Summary–Update[J]. Lawrence Livermore National Laboratory, Livermore, CA, UCRL-TR-206565, 2004.
8. Jiang Z., Wu K., Couples G., et al. Efficient extraction of networks from three‐dimensional porous media[J]. Water Resources Research, 2007, 43(12).
9. Jiang Z., Van Dijke M., Wu K., et al. Stochastic pore network generation from 3D rock images[J]. Transport in Porous Media, 2012, 94(2): 571-593.
10. Blunt M. J., Jackson M. D., Piri M., et al. Detailed physics, predictive capabilities and macroscopic consequences for pore-network models of multiphase flow[J]. Advances in Water Resources, 2002, 25(8): 1069-1089.
11. Al Ibrahim M. A., Hurley N. F., Zhao W., et al. An Automated Petrographic Image Analysis System: Capillary Pressure Curves Using Confocal Microscopy[A]. Proceedings of the SPE Annual Technical Conference and Exhibition[C]. Society of Petroleum Engineers, 2012.

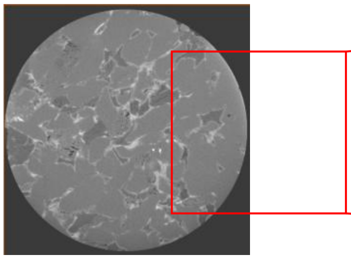


Figure 1 Original image of the sample with the resolution of 3.4 μm.

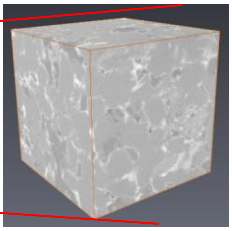


Figure2 One of the six digital cores, and the image is the sample of $600\times600\times600$.

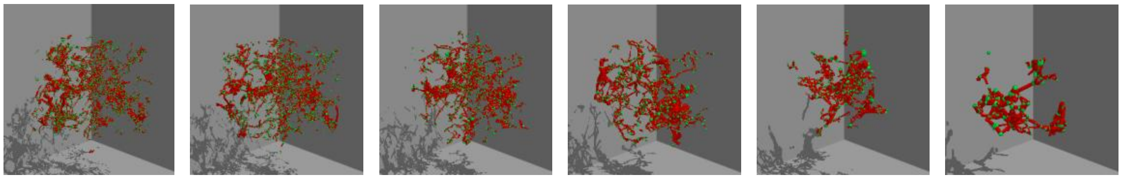
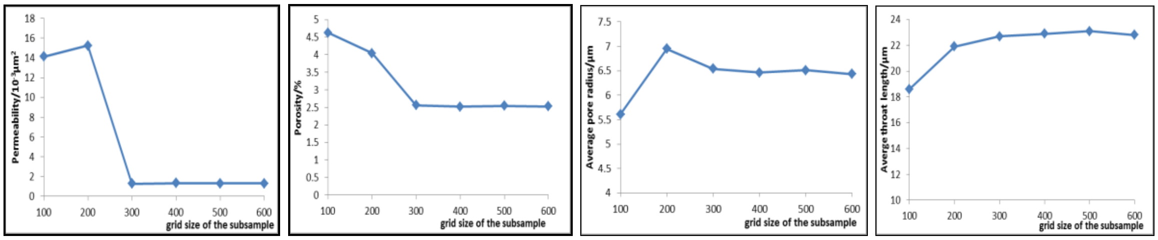


Figure 3 Pore network models of the six subsamples from $600\times600\times600$ to $100\times100\times100$.



(a) (b) (c) (d)

Figure 4 Different parameters at at different size of sub-volumes

(a) Permeability at different size of sub-volumes. (b) Porosity at different size of sub-volumes. (c) Average pore radius at different size of sub-volumes. (d) Average throat length at different size of sub-volumes.