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Natural heavy oil reservoirs porosity and saturation coefficients estimation based on wavelet analysis of X-Ray computed tomography histogram

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Abstract. With the development of unconventional resources the standard task of evaluation the porosity and oil saturation needs new approach. Heavy oil and bitumen can act as cement in many sand reservoirs, which excludes the use of standard measuring techniques. A new method for estimating the porosity and oil saturation of heavy oil reservoirs, based on wavelet X-ray computed tomography histogram analysis, was proposed. Its advantages are the ability to work with loose sand reservoirs, for which it is not possible to use standard assessment methods. A comparative analysis of the proposed method with a standard method for estimating porosity based on sample saturation with kerosene showed that the values of the porosity coefficient in the tomography resolution range 5-15 μm differed by 3-7% in the direction of the wavelet analysis method. This effect is due to the presence of transient voxels – mixels.

Keywords: heavy oil, reservoir, porosity, saturation, CT, X-ray computed tomography, histogram, wavelet, mixel.

1. Introduction

With the depletion of light and medium oil reserves, heavy oils and natural bitumen become an important source to meet the growing demand for fuel and petrochemicals [1]. The standard tasks of evaluation the porosity and oil saturation of reservoirs become nontrivial in new circumstances. The central problem is that heavy oil and bitumen can act as cement in many sand reservoirs. Thus, the hydrocarbon extraction of such samples leads to the destruction of the rock and the inability to evaluate the filtration and capacitive properties of reservoir using the standard methods. This paper outlines a new approach for estimation the porosity and oil saturation based on analysis of X-Ray computed tomography histogram.

X-Ray computed tomography (CT) is an established and rapidly evolving technology of proven value for geological investigations [2]. The advantage of tomography over other

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porous media characterization techniques is direct imaging of microstructure, from which we can evaluate statistical and geometrical parameters such as porosity or porous media surface area. Each three-dimensional cell of tomography model (voxel) has the grayscale value of X-Ray attenuation coefficient of material. Standard histogram of X-Ray computed tomography of clean reservoir sample has a form of a double-peaked curve, where the x-ray attenuation coefficient is plotted along the x-axis and the number of voxels with a given grayscale value – along the y-axis. The minimum value of histogram between two peaks usually is a border value between rock matrixes and air in porous media and around the sample (fig. 1a). Heavy oil saturated sample usually has additional little peak after air curve (fig. 1b). The main idea of our approach is using the information from histogram for oil volume classification.

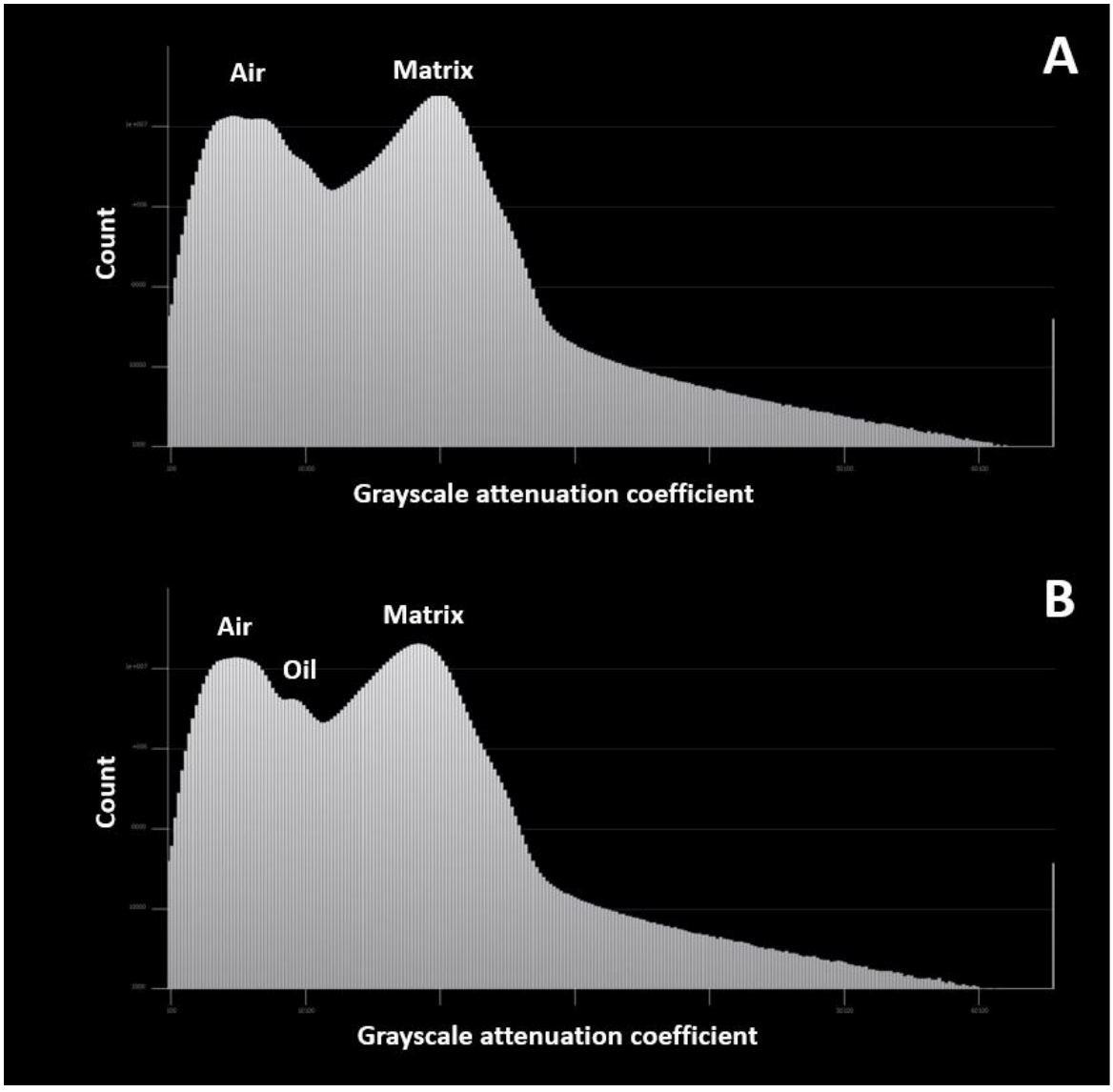

Figure 1. Typical X-Ray computed tomography histogram of the sand reservoir (resolution 36μm): a – after hydrocarbon extraction, b – before hydrocarbon extraction

2. Methodology

We use wavelet analysis to break the main curve to several, which sum of areas is equal to area of main curve. Wavelets are a class of functions used to localize a given function in both space and scaling. The method is based on continuous wavelet transformations with special selected basis in order to solve inverse problem and briefly described in [3].

Data processing starts with cutting the air volume around the sample. This step changes the form of histogram from double picked to one picked curve (fig. 2a). After analysis, the general curve is broken to 5-8 "daughter" wavelets (fig. 2b). Each of them can be interpreted as one material.

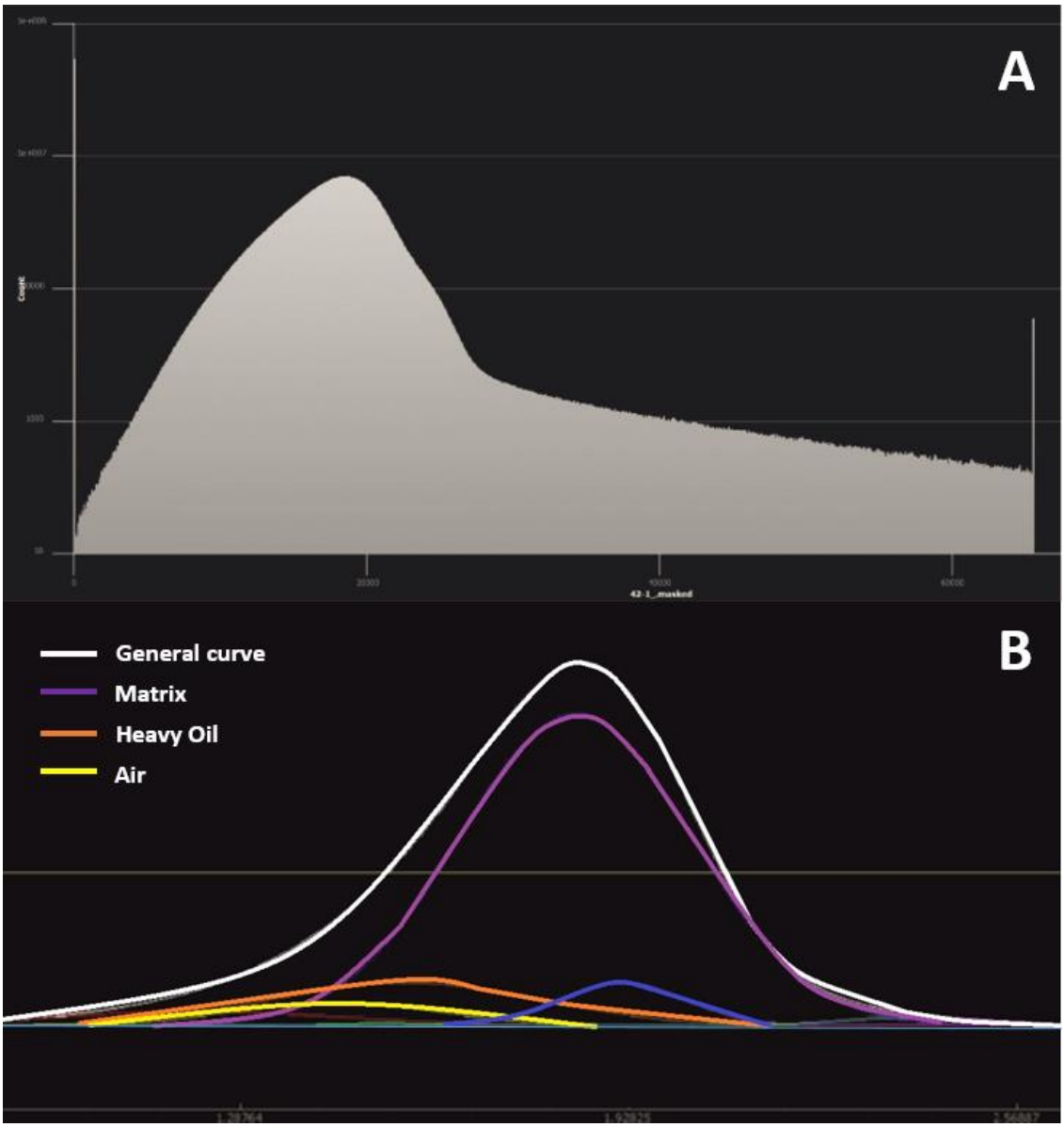

Figure 2. Histogram transformation: a – after cutting the air around the sample, b – after wavelet analysis with defining the materials

3. Results and Discussions

The grayscale values extracted for air and oil from the results of wavelet analysis demonstrate a visual conformity with tomographic slices (fig. 3). Air classified regions correlate with the most black areas and oil classified areas surround them.

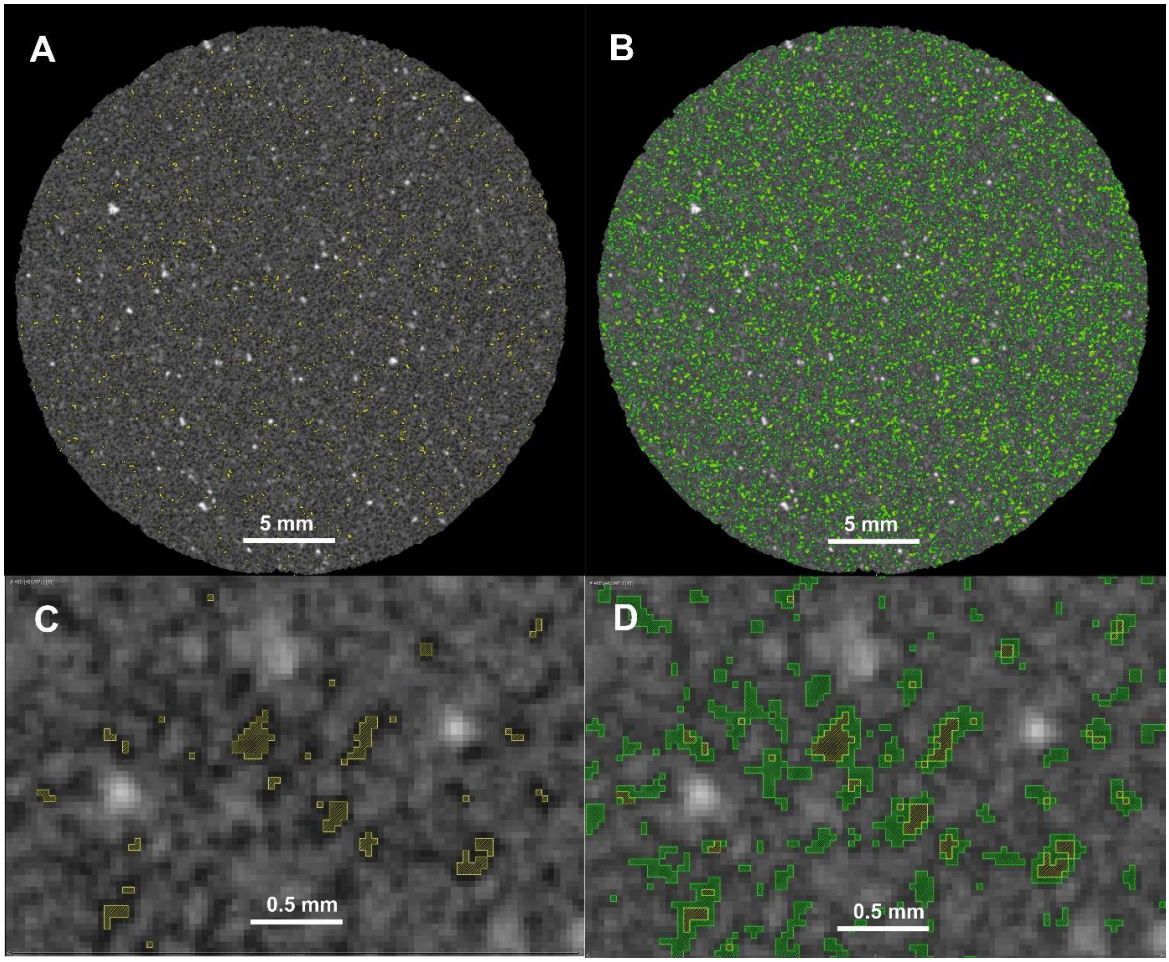

Figure 3. Image classification based on the results of wavelet analysis: yellow – air in pores, green – heavy oil in pores

We compared the porosity coefficients, obtained by standard method of saturating the sample with kerosene and wavelet analysis of tomographic histograms on 7 samples (table 1 and fig. 4). The last one included the sum of porous media filled by air and heavy oil. The results of comparison demonstrate that wavelet analysis data is always higher to 3-7% than standard method in the range of tomography resolution from 5 to 15 μm. This effect takes a place due to wrong classification of the voxels with the same grey value as used for heavy oil. Naturally, this voxels can have transitional gray values between air filled pores and matrix or include voxels with “invisible” pores, which sizes less than tomography resolution [4]. These transitional voxels called “mixels” [5].

Table 1. Comparison between porosities coefficients, obtained by standard method and wavelet analysis for different samples

Sample No.	Tomography resolution, μm	Porosity coefficient, %	
		Standard method*	Wavelet analysis
1	12,696	30,52	33,52
2	5,885	10,73	15,26
3	12,803	24,44	30,11
4	13,303	23,44	29,87
5	12,689	21,28	27,92
6	14,173	22,1	25,62
7	11,578	4,15	8,02

* - standard is method of saturating the sample with kerosene

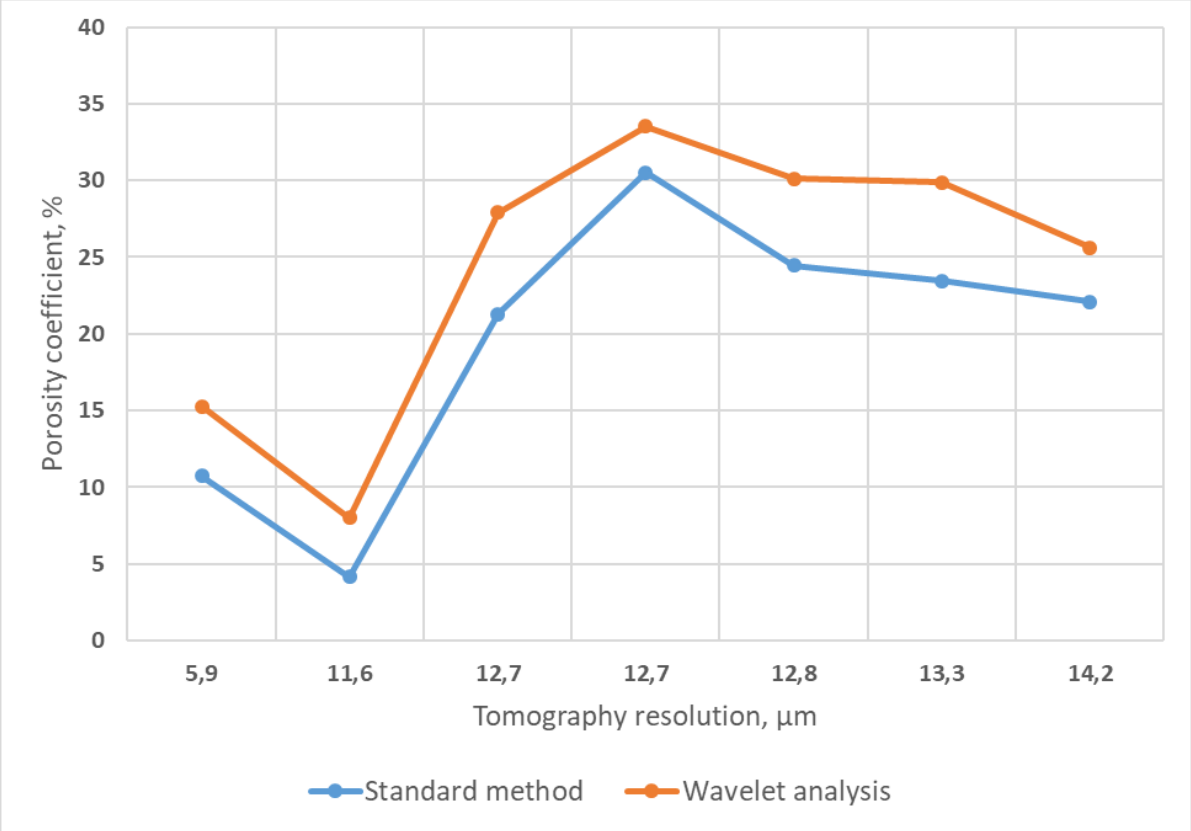

Figure 4. Changing the porosity coefficient versus resolution of sample's tomography

4. Conclusions

Thus, a new method for estimating the porosity and oil saturation of heavy oil reservoirs, based on wavelet X-ray computed tomography histogram analysis, was proposed. Its advantages are the ability to work with loose sand reservoirs, for which it is not possible to use standard assessment methods. A comparative analysis of the proposed method with a

standard method for estimating porosity based on sample saturation with kerosene showed that the values of the porosity coefficient in the tomography resolution range 5-15 μm differed by 3-7% in the direction of the wavelet analysis method. The study of the applicability of this method will be continued.

Acknowledgements

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