RELATIVE PERMEABILITIES AND TRANSPORT SYSTEM IN MIXED WETTED CARBONATE ROCKS

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ABSTRACT

Two types of mixed wet reservoirs were observed. The first type was built by porous, permeable, organogenic carbonate rocks (bryozoan reefs) of the Main Dolomite, the second represents fractured – porous, low porosity carbonate sediments.

Mixed wettability in the first type of reservoir was discovered during laboratory investigations of relative permeabilities and confirmed by Amott tests. Values of base permeabilities to water and to oil presented bimodal distribution. Additional tests and visualisation of displacement procedure shows mixed-wet character of the investigated rock.

In a second case wettability phenomena in fractured reservoirs were investigated after field tests indicated very low values of permeability (ten times lower than calculated from logs and cores data).This situation led to performance of additional measurements and to reinterpretation of all data. The storage element of the investigated reservoir is microporous rock. Transport of reservoir fluids to boreholes by such rocks is not possible. Values of the threshold diameters are lower than 2 μm.

Fracture systems were recognised using a fractal approach. It was found that three independent fracture systems existed in the field but only one system of fractures transports reservoir fluids. The fractures of this system are connected with organic and clayed interbeddings. Organic or clay-lined walls of fractures make the transport system neutral or weakly oil-wet in otherwise strongly water-wet reservoir rocks. These results were confirmed by relative permeability tests.

INTRODUCTION

Carbonate rocks of the Main Dolomite are the base reservoir rocks in Poland. The Main Dolomite basin shows some properties strongly affecting reservoir characteristics.There are: fracturing, occurrence of bryozoan reefs and surrounding by sealing rocks. Fractures are responsilbe for most of the transport of reservoir fluids, average reservoir rocks are characterized by poor transport properties (microporous pore space). Only in reef facies do good reservoir rocks exist but even in reefs fracture systems improve transport capability [4]. Good sealing of the Main Dolomite sediments ensured that the oil system of the basin is closed and that these sediments are both source and reservoir rocks. In such conditions residual organic matter can be present in reservoir rocks and affect wettability properties.

INVESTIGATIONS

34 samples from 3 boreholes of bryozoan reefs of the Main Dolomite from the Polish Lowland were investigated. Porosity, permeability to nitrogen, capillary pressure tests and relative permeabilities were measured. A mercury injection capillary pressure apparatus was used. Values of threshold diameter, fractal dimension and distribution of pore diameters were calculated to characterise the type of pore space and to estimate parameters of network model of pore space. The relative permeability tests were performed in simulated reservoir conditions with original reservoir fluids using a TEMCO steady-state relative permeability device. Values of base relative permeabilities and residual saturations were measured. Finally, Amott tests and microscopic analyses of thin sections were done.

The same analyses were performed for porous-fractured rocks from 3 boreholes. Fortunately, it was possible to cut several plug samples with fractures and fit the relative permeability tests. Additionally, investigations of fracture system were done including detailed description of whole dimension cores (extraction of fracture intervals, density and directions of fractures) and analyses of fracture system parameters such as thickness distribution, connections, number of fractures and fractal dimension using oriented polished sections [1,3].

RESULTS

The values of base relative permeabilities to water and to oil obtained during tests are presented in Fig. 1 and Fig. 2. In Fig.1. all values of base permeabilities are gathered. White bars represent base permeabilities to oil, black to water for samples from number 1 to 34.

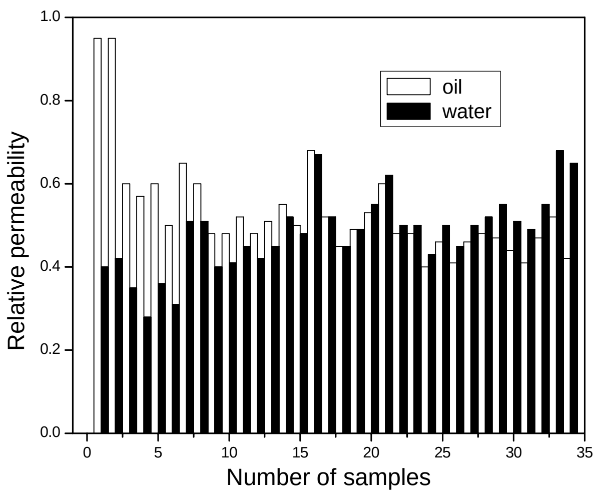

Figure. 1. Obtained values of base permeability to oil and water

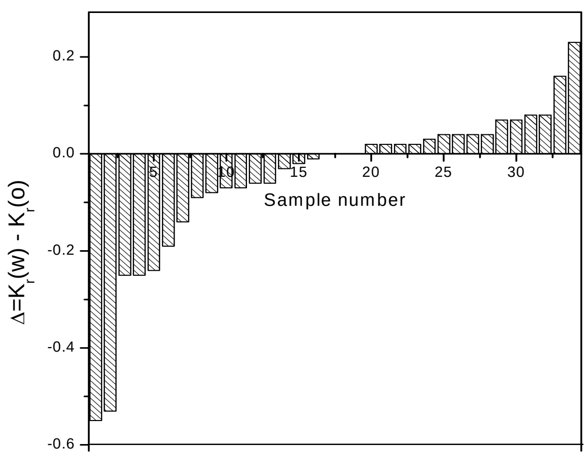

Figure 2.Difference between base permeability to oil and to water

Fig. 2 shows differences between values of base permeabilities for all samples defined as

$$\Delta = K_r\,(w) - K_r\,(o)$$

Analysis of the Δ parameter distribution suggests a wide range of wettability conditions in the investigated samples from typical water-wet rocks (Δ lower than-0.25) through weakly water-wet, and neutral to oil-wet samples. Amott tests were performed to verify the wettability distinguished during relative permeability measurements [2]. The results of Amott test show that only the first 5 samples represent purely water-wet type of rocks. The rest of the whole collection consists of mixed wet sediments and Δ parameter is only a general indicator of predominant tendency. The mass of spontaneously displaced water for these samples varies from 0.2 to 0.8g, for oil this values covered the range respectively from 0.65g to 0.1g. Table 1 shows results of Amott wettability test on two samples: predominantly water-wet and predominantly oil-wet

Table 1. Results of the Amott wettability test on typical cores

Sample/ pore volume (ml)	Displacement by oil		Displacement by water		Amott Wet. Index
	Spontaneous (ml) –V_{sw}	Forced (ml) - V_{fw}	Spontaneous (ml) - V_{so}	Forced (ml) - V_{fo}	
1 / 2.5	0.69	0.96	0.24	1.14	0.24
2 / 1.67	0.2	0.87	0.4	0.59	-0.21

where

$$\text{Amott Wettability Index} = (V_{sw}/(V_{sw}+V_{fw})-V_{so}/(V_{so}-V_{fo}))$$

Investigated samples represent similar types of pore space. The porosity is high (from 15 to 34%), whereas permeability is rather poor (below 80 mD). Analyses of capillary pressure curves and microscopic analyses of thin sections show a small number of macropores and microvugs of diameter equal to 200 – 400 µm that contribute to the storage part of pore space[5] which accounts for about 92-93% of the whole pore space. They are connected by a network of long, relatively narrow channels (threshold diameters from 5 to 20 µm). Fractal dimension are greater than 2.98. An average cumulative curve is shown in Fig 3A. Fig. 3B illustrates schematically the type of pore space.

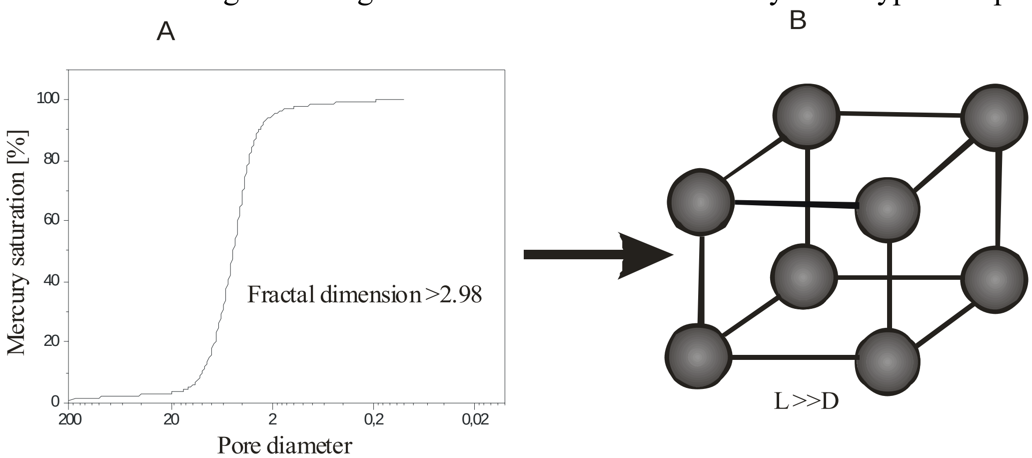

Figure 3. Typical cumulative curve of pore size distribution (A) and connected with it model of pore space (B)

Macropores visible on the surface of samples can be divided into two groups: the black and the bright grey. The black ones form oil-wet paths of transport, the bright grey are water-wet. This effect can be observed during spontaneous displacement of oil. Droplets of oil occur only in bright grey pores. Microscopic investigation of thin sections shows that the black colour of rocks and and pores are connected with the presence of organic matter in rocks and with residual organic matter lying on the surface of pores. The content of organic matter determines the predominant tendency in wettability. In this situation, the colour of rock can be used as an indicator of wettability. Differences of greyscale of predominantly water- and oil-wet samples are shown in Fig.4A. Great heterogeneity of organic matter content is observed in analysed rocks. Fig. 4B presents a sample that is partially water- and oil-wet.

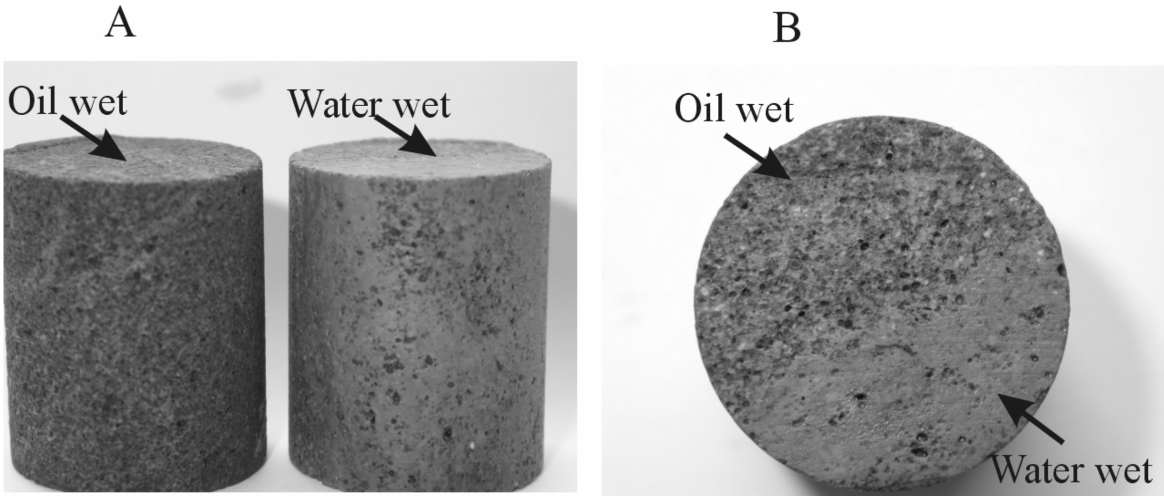

Figure 4. Grey scale distinct oil and water wet rocks:
A – comparison between predominantly oil and water wet samples
B – two in one (demonstration of heterogeneity of rocks)

In the second case, the investigation of fractured porous rocks shows that the storage element of this reservoir was in the microporosity. Measured porosity covers the range 5-14%. Measured values of threshold diameters are lower than 2 μm. Permeability to nitrogen showed values lower than 0.3 mD. The fracture system is solely responsible for transport of reservoir fluids. Directions and intervals occupied by fractures and stylolites were established. The fracture system was recognised using a fractal approach [5,6]. The box definition of fractal dimension was applied to polished thin sections. Finally, it was found that three fracture systems existed in the oil field: a "broad" fracture system, a "white" fracture system and "black" fracture system, each of them characterised by its own fractal dimension. More detailed investigations showed that only "black" fracture system can transport fluids towards boreholes [4]. Fractures of this system have average thickness 0.0025 mm and fractal dimensions vary from 1.24 to 1.31. The distribution of measured values of fractal dimension is shown in Fig. 5A. A typical thickness distribution (random chosen polished section) is presented in Fig. 5B.

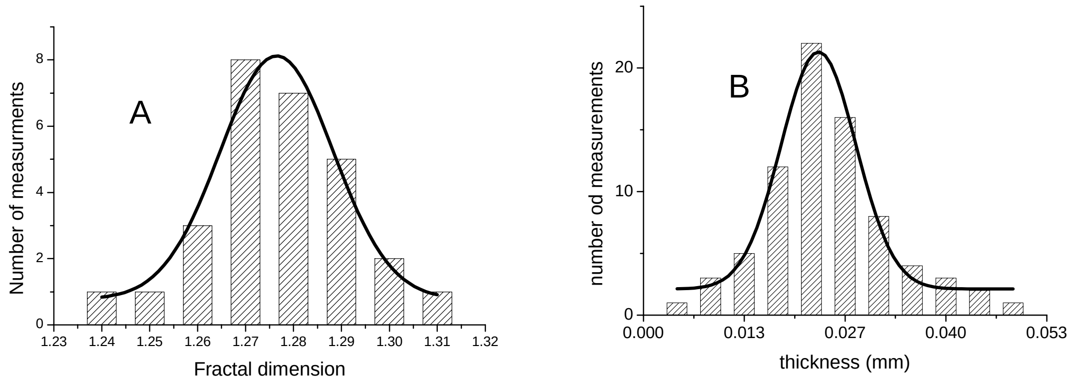

Figure 5. Parameters of black fracture system: A – distribution of fractal dimension, B – thickness distribution for typical sample

This system is connected with thin layers of clay-lined and organic sediments. The fractures run along these layers. Typical runs and connections of a "black" system fracture are presented in Fig. 6.

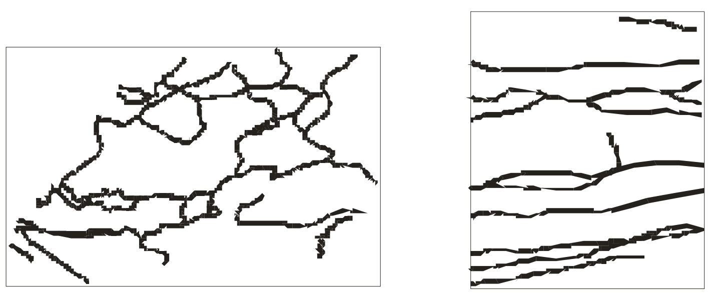

Fig. 6. Sketches of fracture system in real dimension

Relative permeability tests for three samples with "black" fractures show results typical for oil-wet rocks (Δ greater than 0.06) and high values of residual water saturation (greater than 50%). These results confirm earlier measurements. Oil is stored in water-wet reservoir rocks and transported to boreholes by the oil-wet fracture system.

CONCLUSIONS

1. Two types of mixed-wet reservoirs were found in the Main Dolomite sediments. Parameters of a pore space of organogenic carbonate rocks help to demonstrete the mixed-wet character of most of the investigated samples.
2. The first sample type consists of organogenic, porous carbonate rocks. Wettability varies with content of organic matter in the rock and the presence of organic matter or clay minerals mixed with organic matter on the surface of pores and channels. Only a small number of samples for which the parameter Δ is greater than -0.25 showed purely water-wet properties. Investigated rocks show great heterogeneity of wettability properties. Colour of sample is a good indicator of its wettability. This type of samples is common in carbonate rocks of reef facies in the Main Dolomite basin.
3. The second sample type was found in fractured porous reservoirs. Reservoirs rocks are water-wet while the fractures are oil-wet. In this case fractures run along or inside clay interbedding. The transport system in this case may be unique to the Main Dolomite basin

NOMENCLATURE

K_r (w) – base relative permeability to water – value of relative permeability to water obtained for residual saturation of oil
K_r (o) – base relative permeability to oil – value of relative permeability to oil obtained for residual water saturation
L – length of pore channel
D – diameter of pore body

REFERENCES

1. Leśniak G., P. Such, "Complex correlation for characterisation of transport system in fracture rocks ", *Proceed. 12 IOR,* (2003) Kazań 8-10 September, 502-505
2. Bona N., F. Radaelli, A. Ortenzi, A. De Poli, C. Peduzzi, M. Giorgioni, „Integrated Core Analysis for Fractured Reservoirs", *SPE Reservoir Evaluation & Engineering.,*(2003), Vol 6, No 4, 226-234
3. Leśniak G., B. Darłak, "Laboratory investigation of petrophysical properties of fracture and vugged rocks" Proceed. *"Modern Exploration and Improved Oil and Gas Recovery Methods"*(1995) Cracow 12-15 September, P-234
4. Donaldson E.C., D. Tiabb, "*Petrophysics*", Gulf Publishing Co., Houston, Texas (1996), 705
5. Such P., G. Leśniak, "Application of fractal approach and microscopic images in net model of pore space", *Proceed.. 63-rd EAGE Conference Amsterdam*, (2001), P-644
6. Turcotte D.L., "*Fractals and Chaos in Geology and Geophysics*", Cambridge University Press (1997).