FACTORS AFFECTING RESERVOIR AND FILTRATION PROPERTIES OF CARBONATE ROCKS OF THE MAIN DOLOMITE (THE POLISH LOWLAND)

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ABSTRACT:

Pore space parameters (mercury porosimetry) and fracture properties were investigated. Mercury porosimetry shows great space heterogeneity of pore space parameters as well as specific shapes of pore bodies and channels. This was verified by computer analysis of microscopic images. From fractal analysis we distinguished three fracture systems. Analyses of thin sections and polished sections gave estimations of filtration properties of all fracture systems.

In addition reservoir geochemistry researches were done. Pirobitumines were identified in the pore space of the reservoirs rocks. Correlation between oils and source rocks showed migration paths of hydrocarbons and explained continuity of the analysed reservoir.

The next part of our investigations focused on the influence of pirobitumines on wettability. Amott wettability tests were performed. A great part of the analysed rocks showed mixed wettability. Also fractures showed various types of wettability because of residual organic matter mixed with clay minerals lying on fracture surfaces. These results agree with relative permeability investigations which were done as a last part of laboratory investigations. Results of laboratory measurements were compared with well logs and normalized using field test permeability.

INTRODUCTION:

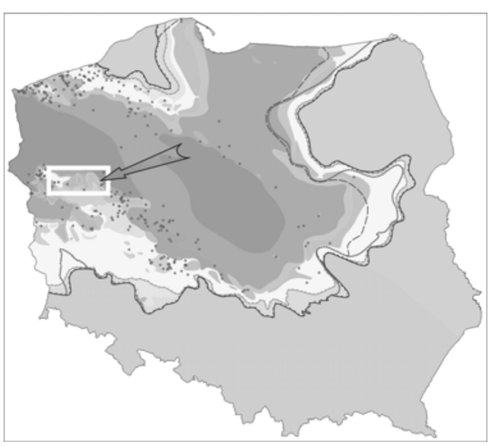

Figure 1. The area of interest

A great part of recently discovered oil fields in Poland is connected with the Zechstein carbonate platforms located in the Polish Lowland. The last discovered oil fields lay on the Gorzow Block (fig.1.) (Wagner &. Kotarba 2004). Changing sedimentary conditions and complicated diagenesis history, as well as the fact that the reservoir rocks were also source rocks affected pore space parameters and wettability. The second factor that affected reservoir properties was tectonic activity. As a result carbonate reservoir rocks from the analysed area share great heterogeneity, mixed wettability and several fracture systems. Special laboratory investigations, containing pore space analyses, fracture analysis and geochemical analyses were performed. The base question with respect to the rock analyses is to characterize the filtration and reservoir properties of the rocks and to distinguish all factors affecting these properties.

LABORATORY INVESTIGATIONS

Porosity and permeability to air measurements performed in trade laboratories were available during our correlation studies. The results show good porosity and very poor permeability of the investigated rocks. Average values of porosity for investigated boreholes varies from 8 % to 22 % while average values of permeability are generally low (<15 mD). Only in one borehole a 2 meter thick high permeable bed was found. It increased average values of permeability for this well to 40 mD.

Pore Space Analyses

A mercury injection capillary pressure apparatus was applied to investigate pore space parameters. 241 samples from 6 boreholes were examined. Four classes of similarity were distinguished (Such 2002) using porosity, values of threshold diameter and fractal dimension as parameters (tab.1.) No correlation between permeability and threshold diameter was observed. So, additional mercury injection measurements were performed. Rock material from plug samples used in permeability measurements was applied. Two analyses from all samples chosen for additional measurements were performed. This series of investigations was done for the samples that showed greatest the inconsistency for the air permeability.
Typical results of such investigations are presented in fig.2.

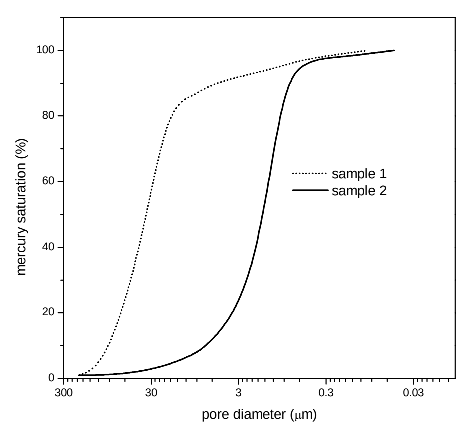

Figure 2. Differences in pore diameter between samples from the same plug

Table 1. Pore space parameters for distinguished classes of similarity

Type	Porosity [%]	Threshold diameter (um)	Fractal dimension
I	>15	30 – 90	>2.98
II	>8	15-30	2.96-2.98
III	7-14	3-10	2.95-2.9
IV	0-10	<3	<2.9

Fracture Investigations

The fracture investigation set consists of: detailed description of cores (distinguishing of fracture intervals, directions of fractures), fractal dimension analyses using polished sections and fracture porosity and permeability using thin and polishing sections (Lesniak & Darlak 1995, Bona et.al. 2003, Gliniak et al. 2002). Two systems of fractures were distinguished during the macroscopic description of the cores. Generally they can be described as horizontal and vertical systems. A fractal approach was applied to the polished section images to verify macroscopic observations (Such, Lesniak 2001, Such 2002). The box definition of fractal (Mandelbrot 1977) dimension was used, separately to horizontal and vertical fractures. Polished section images were multiplied four times. 1 cm, 0.5 cm, and 0.25 cm boxes were used in the calculation of the fractal dimension. It was found that:

- three fracture systems existed in the investigated area. There are large horizontal fractures (thicknesses greater than 0.65 mm), horizontal fractures covering the range of thickness (diameter <0.31 mm) and vertical fractures.
- there are the same systems in the whole analyzed area. Their fractals dimension equals 1.08 for large fractures, 1.35 for smaller horizontal fractures and 1.18 for vertical fractures.

The large fracture system is strongly calcitised and is open only in two wells.

Fracture porosity and permeability measurements performed on thin and polished section show non zero fracture permeability along the whole investigated interval in all wells. Numerical values are presented in table.2.

Table.2. Fracture porosity and permeability

Fracture	Average porosity (%)	Maximum permeability (mD)	Average permability (mD)
Large*	<1	241	only in 2 wells
Horizontal	3.5	60	5-15
Vertical	<3	60	5-15

*- recognized only in 2 wells.

Vertical fractures show similar thickness distribution, so we put for both fracture systems the same values of permeability. Vertical fractures were recognized in all wells but the obtained statistical quality of the measurements was worse than that for measurements of horizontal fractures.

Wettability and Relative Permeability Tests.

It was obvious to us that the wettability of the investigated rocks can be strange, because of large amounts of residual organic matter. Part of this matter, mixed with clay minerals covers pore and fracture walls. Furthermore, pirobitumines were found in the pore space. Amott wettability test were conducted (Tiab, Donaldson 1995). 10 samples were investigated. All of them showed mixed wettability. The volumes of spontaneously displaced oil covered the range from 0.1 cm^3 to 0.5 cm^3 which is 9 to 30 % of total pore volume. The volumes of spontaneously displaced water cover the range from 0.1 cm^3 to 0.4 cm^3. The investigated samples showed Amott wettability indices ranging from - 0.03 (only one sample with index less than 0.0) to 0.12.

A long series of oil-water relative permeability measurements gave more interesting results. 42 analyses were performed. The results covered the range from 0.19 to 0.75 for relative permeability to water and 0.29 to 0.84 for relative permeability to oil. These results shows that all kinds of samples from water wet to oil wet as well as from porous to fractured are present in the investigated area.

11 samples show values of relative permeabilities as well as shapes of relative permeability curves characteristic for pure fracture fluid flow (Chillingarian at all 1992). Correlation between wettability and relative permeability results allow us to divide the analyzed samples into several groups according to their characteristic parameters (tab.3)

Table 3. Wettability characterization

Group of samples	Number of samples	Relative permeability to water
Water wet	5	<0.25
Predominantly water wet	4	0.26-0.33
Mixed wet	27	>0.34
Predominantly oil wet	6	greater than relative permeability to oil

GEOCHEMISTRY INVESTGATION

In addition reservoir geochemistry researches were performed. Samples were analyzed for organic carbon content and level of maturity using Rock-Eval pyrolysis. The maximum temperature of pyrolysis was evaluated for samples after extraction of free hydrocarbons. Most of the analysed samples showed a high level of maturity. Pirobitumines were identified in the pore space of the reservoirs rocks on the basis of a trace of pyrolysis and also using oxidation curves. Several samples from this reservoir show a small S_1 peak, a bimodal S_2 peak and significant amounts of CO and CO_2 released during oxidation at high temperature (near 800^oC) (Fig 3, 4).

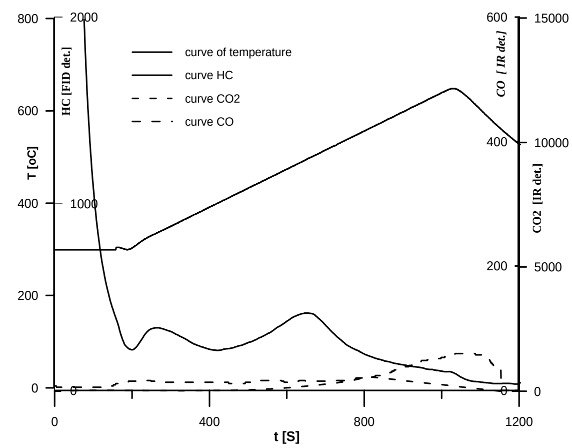

Figure 3. Pyrolysis curves illustrating presence of S_1 peak and double S_2 peak

These peaks were observed in the rock sample after decarbonation. It means that this is not carbonate decomposition of minerals in the rock matrix. These peaks correspond to the combustion of refractory material associated with pyrobitumen in the sample (Lafargue E, Burwood R., 1997). Solid reservoir bitumen occurs in carbonate and siliclastic oil and gas reservoirs in many basins throughout the world (Hwang R.S et all, 1992), Lomando A.J., 1992). This solid bitumen could block the reservoir permeability hence the small differences in molecular composition of examined oils.

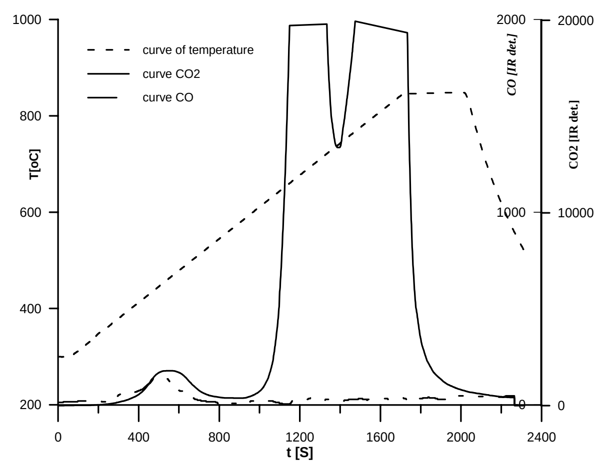

Figure 4. CO_2 and CO oxidation curves produced from oxidation of refractory organic matter

DISCUSSION

Presence of the same fracture systems in the whole area reveals that it is one reservoir with hydrodynamic continuity. Porosity is rather good despite the presence of pirobitumines in parts of the reservoir rocks.

Three reservoir fluid transport systems were described in the analyzed area. Their parameters are shown in tab.4. Laboratory measurements gave a good correlation with well tests. The comparison between laboratory measured and well test permeability is also given in tab.4.

Table 4. Transport system parameters

	Number of wells	Intergranular perm. (mD)	Medium fract. perm. (mD)	Well test perm. (mD)
I	3	<1.5	15	15
II	2	<1.5	15 + large fract.	100
III	1	40	15	55

Three factors determine flow of fluids through reservoir rocks. These are:

- The reservoir rocks are very heterogeneous. This is caused by the reef origin of the reservoir rocks with its specific development and diagenesis (Moore 2001). Heterogeneity reduces intergranular permeability in such degree that in 5 wells its values are practically negligible.
- The presence of a fracture system. Horizontal fractures are responsible for transport of fluids towards boreholes. Permeability can be multiply by large, non calcitised fractures observed in two wells in analysed area.
- Mixed wettability. Special attention must be given to a system of oil-wet vertical fractures recognized in all wells. It is a potential path for formation water.

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