HYBRID SUBCONVENTIONAL HYDROCARBON SYSTEM OF THE CARPATHIAN FOREDEEP (SE POLAND)

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Introduction

The Miocene Foredeep Basin (MFB) of the Outer Carpathians is a part of the North Carpathian petroleum province. The MFB contains numerous dry gas fields in the Miocene clastic reservoirs, as well as oil and gas fields in the Mesozoic and Palaeozoic sedimentary basement of the MFB. High quality biogenic gas is produced in the basin since 40'ties of XX century. Due to low burial depth, resulting with low drilling costs, gas production is economically highly prolific.

However, the province is a mature one, and both gas production and gas reserves/resources are recently declining. Current gas production in the Polish part of the MFB is at a level of roughly 1.3 Bcm/y, and during last decade declined by 35 %. Gas contingent resources are currently equal to 28.8 Bcm, being 17.5 % of initial contingent resources, and decreased by ~20 % during the last decade. Gas reserves, equal to 7.5 Bcm, declined during the same time period by ~50 %.

Taking onto account the above observations, as well as presence of roughly 4000 gas and oil related wells drilled so far in the MFB, a potential for further discoveries of significant scale conventional fields could be regarded as limited. However, new subconventional and unconventional exploration concepts allows to redefine petroleum potential of the basin.

Methods

In the current study the subconventional and unconventional petroleum plays of the Polish part of the MFB were analysed. Lithology of the mudstone dominated heterolithic reservoirs, as well as their depositional model, were determined based on core samples and wire log data. Mineralogical composition was examined with XRD method, supplemented with interpretation of wire logs, while heterolithic reservoir porosity and permeability was determined with MICP tool. Analysis of hydrocarbon kitchen quality were based on RockEval TOC content measurements. Initial reservoir pressure and reservoir temperature, as well as distribution of gas fields and gas reserves with depth, were studied based on legacy data. Sorption capacity was determined based on analogue data. Commercial potential of the subconventional and unconventional petroleum plays was analysed with use of published Initial Production (IP) rates for new exploration wells.

Results

The MFB is filled with mainly fine-grained sediments, while conventional sandstone reservoir are not common. However, currently a new exploration approach is applied in the basin, which regards mudstone-dominated heterolithic sediments at low burial depth as a reservoir rock. The mudstone is commonly silt-laminated and occasionally contains low thickness sandstone or siltstone beds.

The mudstone component of the reservoir interval is characterized by MICP porosity being in a range of 9-12 %, domination of nanopores, and low unconventional permeability equal to roughly 0.05-0.15 mD (Machowski et al., 2017). It could be, therefore, regarded as an unconventional tight reservoir or subconventional reservoir. The siltstone or fine-grained sandstone laminas or low thickness beds acts, however, as a conventional component of the reservoir. It is characterized by MICP porosity being in a range of 8-21 %, domination of macropores and mesopores, as well as permeability in a range of 3-30 mD (Machowski et al., 2017). The siltstone and sandstone component increases cumulative lateral permeability of the reservoir complex, allowing therefore for relatively high IPs of productions wells.

The heterolithic reservoir is characterized by high clay content, mostly 30-60 %, and moderate quartz and carbonate content, comparable to US clay-rich mudstone reservoir. Nonetheless, low burial, typically equal to 1500-2000 m, implies low consolidation of the reservoir, and thus hydraulic fracturing cannot be effective. The subconventional reservoir is exploited without stimulation, however, with use of long pipe intervals (100-200 m) perforated on surface.

In the southern part of the basin, the Miocene reservoir is buried beneath Carpathian overthrust to higher depth, exceeding 3000-4000 m. In that zone a reservoir sandstone and mudstone become consolidated. This allows for hydraulic fracturing of the reservoir, which increases gas flow by one order of magnitude with compare to conventional production test. Such a play might be, therefore, classified as a tight gas one.

There is no conventional source rock in the MFB. Organic mater content is typically lower than 1 %, average equal to 0.6-0.7 %. However, such a lean organic matter content characterizes pile of sediments being several hundred meters thick. Cumulative amount of organic matter is, therefore, large, allowing for generation of significant amount of biogenic gas. Gas reserves/contingent resources are not distributed equally across vertical section of the basin. Their highest amount is observed for the depth intervals of 500-1400 m and 1600-1800 m, corresponding to temperature intervals (25-75 °C) suitable for high methanogen bacteria activity levels.

The MFB is characterized by low primary reservoir pressure – hydrostatic pressure is observed down to the depths of roughly 2000-3000 m, while below 3000 m overpressures are locally documented. The basin is characterized also by a low to moderate geothermal gradient, equal to roughly 22-35 °C/km. The above mentioned reservoir pressure and temperature characteristics have major control on sorption capacity in the basin. Moreover, significant amount of organic matter, as well as high clay content, in particular high content of smectite and montmorillonite, results with relatively high gas sorption capacity, determined here for roughly 0.3 to 0.7 m^3 gas/ton rock. The maximum sorption capacity is observed for the depth interval of 7 to 12 hundred meters, and it decreases upwards and downwards. Specifics of the MFB is that clay sorption capacity exceeds one of the organic matter.

Exploration of both subconventional and unconventional gas plays in the MFB gave so far mostly commercial gas flows. Among 32 wells drilled, 27 were positive from commercial point of view, and only 5 were sub-commercial. IP from individual wells were usually at the level of 40-80 Mcm/d, with the best wells reaching 80-140 Mcm/d. The new subconventional and unconventional plays in the MFB has broad regional extend. Their contingent gas resources are preliminary estimated for at least 450 Bcm.

Conclusions

Two new plays are defined in the Carpathian Foredeep Basin in Poland. The first one is a subconventional, hybride play with mudstone dominated heterolithic reservoir. Cumulative lateral permeability of the reservoir is controlled mainly by its siltstone and fine-grained sandstone component. Low consolidation of the reservoir, buried to the depth of 1500-2000 m only, does not allow to apply hydraulic stimulation. The second play is deeper buried (3000-4000 m) tight reservoir, suitable for hydraulic fracturing. Cumulative contingent gas resources of both the plays are estimated for at least 450 Bcm. IPs of exploration wells drilled so far on subconventional and unconventional targets in the MFB indicate commercial gas flows.

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