AGH DRILLING, OIL, GAS • Vol. 30 • No. 2 • 2013

http://dx.doi.org/10.7494/drill.2013.30.2.333

**Stanisław Dubiel*, Mirosław Rzyczniak*, Anna Godula*, Michał Maruta***

# ANALYSIS OF DRILL STEM TESTING TECHNOLOGY OF THE MALM CARBONATE ROCKS OF THE CARPATHIAN FOOTHILLS, IN THE ASPECT OF GEOLOGICAL RESEARCH AND EXPLORATION DECISIONS**

## 1. INTRODUCTION

The credibility of drill stem tests results performed with DST tools depends largely on the technology used. The Polish Oil and Gas Company most commonly use double-cycle drill stem tests, which, in the case of inflow to DST tool oil or reservoir water, enable among others the evaluation of [1, 2]:

- changes of permeability of reservoir rocks in closer and more distant parts of the near-wellbore area test with DST,
- change of yield index in the first and in the second sampling cycle,
- relieving the given horizon of reservoir rocks from the repression of the column of the drilling mud.

In the case of natural gas inflow to DST and mud spacer self-acting outflow from DST column, the technology of drill stem test changes from double-cycle to multi-cycle with classical open flow operation. Thanks to open the flow operation, it is possible to remove the mud from bottom hole and declogging the near-wellbore area rocks.

The Baker Inflatable type tool allows us to perform selective reservoir test, mostly in open hole sections of boreholes but also in the case of large caverns in borehole walls [1]. Then the inflow of reservoir fluid is from a predetermined interval of wellbore. This allows to shutoff the inflow of bottom water to the DST tool and reduces forming the water cone.

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

** The work has been done as a part of statutory research in the Department of Oil Engineering and the Department of Drilling and Geoengineering.

## 2. THE SELECTIVE DRILL STEM TEST OF THE MALM SEDIMENTS IN Ł-20 WELL, USING INFLATABLE DRILLSTEM TEST TOOL PRODUCED BY BAKER WITH MUD FLOW FROM THE NEAR-BOREHOLE AREA

**Technology of DST, No. 19** (Tab. 1)

Selective, double-cycle drill stem test DST of the Malm sediments in well Ł-20 was performed using Bakers Inflatable Drillstem Test Tool, with an inflatable packer fastened on the depth 1730 m and 1760 m respectively, in open hole sections above cement plug (Tab. 1, Tab. 2) [2].

Total time of the first and second flow period was 151 min, and the total volume of mud inflow with no signs of hydrocarbons and reservoir water was 0.900 $m^3$.

Analysis of pressure plots (Fig. 1) shows that the packers were fastened tight and only a part of the mud may come from the space between packers (approximately 0.440 $m^3$). This graph shows also that the hydraulic connection with the reservoir was achieved, because the bottom pressure in the first and second cycle rebuilt to the value respectively: 17.31 MPa and 16.65 MPa. It is a large degree of recovery as compared to extrapolated (from the second pressure build-up curve) value of reservoir pressure (17.46 MPa) at a depth 1735 m.

**Table 1**

Summary of the technological parameters of the DST test, No. 19

| | | | | |
|---|---|---|---|---|
| 1 | Stratigraphy and lithology | | Malm | |
| 2 | The depth of the well | | – | m |
| 3 | The depth of the cement plug | | 1850.00 | m |
| 4 | The well diameter | | 0.245 | m |
| 5 | The depth of manometer | | 1735.00 | m |
| 6 | The inside diameter of pipes | | 97.60 | m |
| 7 | The depth of the packer | I | 1760.00 | m |
| | | II | 1730.00 | m |
| 8 | The mud parameters during the DST test | kind | bentonite | |
| | | density | 1130 | $kg/m^3$ |
| | | funnel viscosity | 48.00 | s |
| | | fluid loss | 8.8 | $cm^3$ |
| 9 | The time from drilling to sampling | | 37 | day |
| 10 | The kind of spacer | | water | |
| 11 | The height of the spacer column | | 650.00 | m |
| 12 | Course of testing | time of I inflow | 18.00 | min |
| | | time of II inflow | 133.00 | min |
| | | time of I build-up | 64.00 | min |
| | | time of II build-up | 68.00 | min |
| 13 | Pressures | hydrostatic pressure of the mud on the reservoir level | 19.23 | MPa |
| | | max. depression during testing | 11.20 | MPa |
| | | pressure excess of the mud on the reservoir level | 1.77 | MPa |
| 14 | Type of DST tool | | Baker – Inflatable 5” | |

Significant pressure difference (17.32 – 16.65 = 0.67 MPa) between the first and second build-up test shows the effect of too much mud overpressure (pressure repression) on the vuggy-fracture Malm reservoir rocks (hydrostatic pressure of mud minus pore pressure: 19.23 – 17.46 = 1.77 MPa) (Tab. 2).

**Table 2**

The Malm reservoir parameters determined from laboratory tests and well logging [4]

| | | | |
|---|---|---|---|
| 1 | Effective thickness of the tested horizon | 25 | m |
| 2 | Permeability of the tested horizon | 6 | % |
| 3 | Kind of inflow | mud without signs of hydrocarbons | |
| 5 | Fluid density | 1130 | kg/m$^3$ |
| 6 | Salnity $Cl^-$ | – | g/l |
| 7 | Fluid compressibility coefficient | 0.0005 | 1/MPa |
| 8 | Relative density of gas | – | – |
| 9 | Compressibility of gas | – | – |

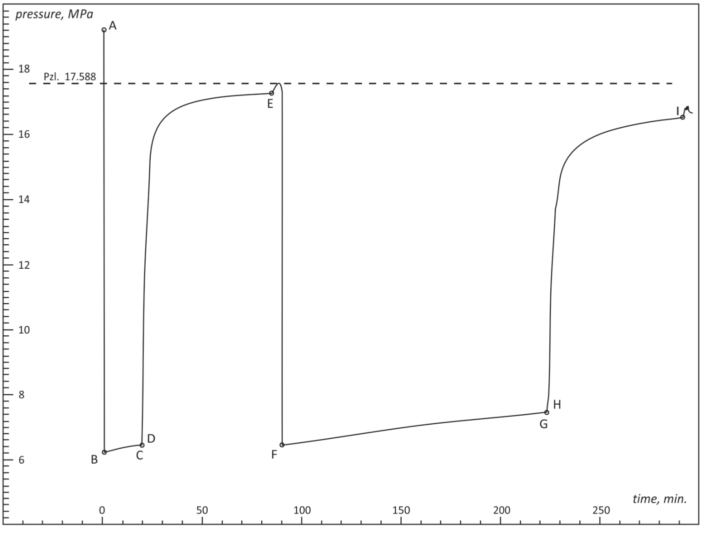


**Fig. 1.** Course of bottom hole pressure registration in the wellbore Ł-20 (Malm 1730–1760 m)

## Geological and prospecting decisions on the background of the obtained results

The results of the drill stem test confirmed the harmful impact of the mud on the vuggy-fracture Malm reservoir rocks during the drilling, as well as during preparing the cement plug at the bottom of the well. The bottom hole pressure build-up graphs reached the various final value, and the difference between them is 0.66 MPa. This demonstrates the detente of tested layer from the mud overpressure formed in the process of drilling through layers of collector rocks. Based on these results, only the value of reservoir pressure was defined (Figs 2, 3) Unfortunately, no information about the type of reservoir fluid was obtained. In such cases, it is recommended to acidize or acid fracture with carbonic acid the carbonate Malm sediments in the Carpathian Foothills.

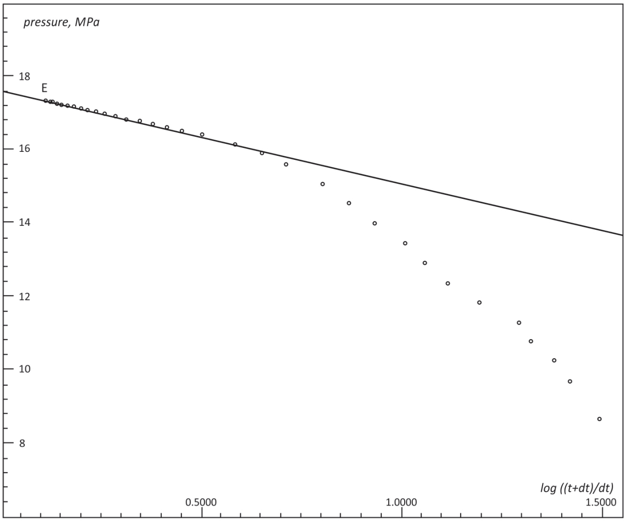


**Fig. 2.** Determination of reservoir pressure with Horner method based on extrapolation and build-up of bottom pressure in the wellbore Ł-20 (Malm 1730–1760 m)

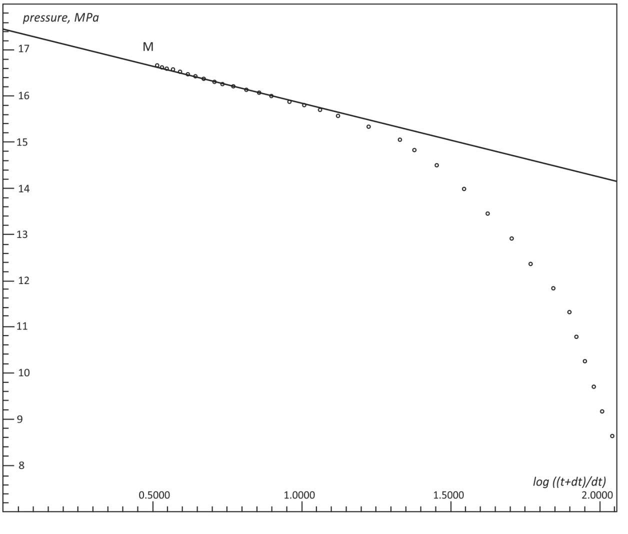


**Fig. 3.** Determination of reservoir pressure with Horner method based on extrapolation II build-up of bottom hole pressure in the well Ł-20 (Malm 1730–1760 m)

## 3. THE DOUBLE-CYCLE DRILL STEM TEST OF THE MALM SEDIMENTS IN THE WELL Ż-42 WITH THE LIGHTLY GASSED RESERVOIR WATER INFLOW TO PROBE

**Technology of DST test, No. 53** (Tab. 3)

The double-cycle drill stem test of Jurassic formation in open hole sections of borehole Ż-42 (1635–1701 m) was made, about 9 days after drilling. During completion the 200 meter height water spacer was used. The initial pressure depression was 12.827 MPa. In the period of the first inflow test, lasting about 30 minutes, the medium outflow of air from the drill string was observed and it fallen progressively. In the period of the second inflow test, lasting about 91 minutes, the poor air outflow with no signs of natural gas was observed. After removing the DST tool, the inflow of about 5 $m^3$ reservoir water to the drill string was observed. The reservoir water was poor gassed with flammable gas. Laboratory tests determined that it is a reservoir water with a salinity 124.2 g/l NaCl. In the time of the first build-up test, lasting about 61 minutes, the bottom hole pressure increased to the value 15.28 MPa. In the time of the second build-up test, lasting about 153 minutes, the bottom hole pressure increased also to the value 15.28 MPa (Fig. 4). Reservoir pressure, determined by log-log method from the second build-up-curve is 15.283 MPa at a depth of 1632 m. Reservoir measurements (Tab. 4) were determined by Horner's method (from the first and second build-up-curve) (Figs 5, 6) and, for comparison, by the log-log method (Tab. 5, Fig. 7) [4], from the second build-up-curve.

**Table 3**

List of parameters of technology DST test, No. 53

| | | | | |
|---|---|---|---|---|
| 1 | Stratigraphy and lithology | | Malm | |
| 2 | The well diameter | | 0.216 | m |
| 3 | The depth of manometer | | 1632 | m |
| 4 | Reservoir parameters | reservoir thickness | 16 | m |
| | | kind of fluid | water | |
| | | fluid flow rate | 0.04167 | $m^3$/min |
| | | fluid density | 1087 | kg/$m^3$ |
| | | fluid viscosity | 0.7495 | cP |
| | | porosity | 0.06 | – |
| | | compressibility coefficient | 0.0004 | 1/MPa |
| | | volume coefficient | 1.0091 | $m^3/m^3$ |
| 5 | The inside diameter of pipes | | 0.88 | m |
| 6 | Course of testing | time of I inflow | 29.8 | min |
| | | time of II inflow | 60.6 | min |
| | | time of I build-up | 90.8 | min |
| | | time of II build-up | 152.5 | min |
| 7 | Initial depression | | 12.827 | MPa |
| 8 | Max. depression during testing | | 13.493 | MPa |
| 9 | Type of DST tool | | Halliburton Standard | |

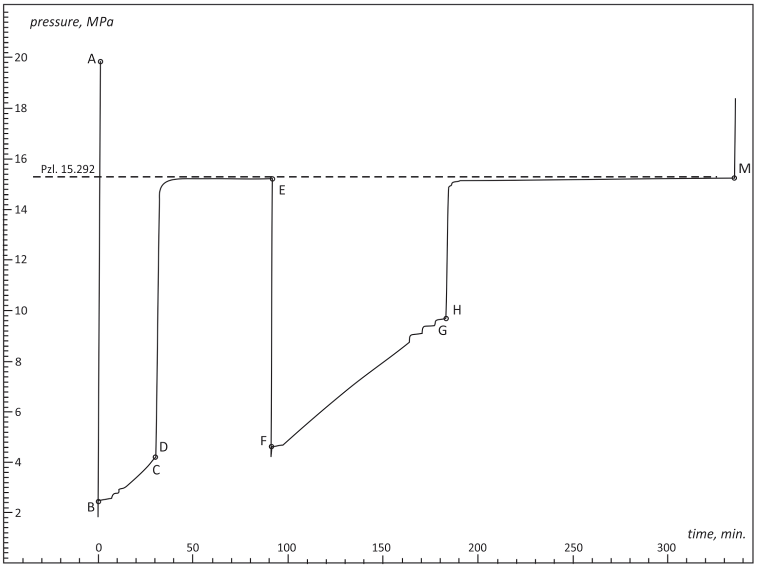


**Fig. 4.** Course of bottom hole pressure registration in the wellbore Ż-42 (Jurassic 1635–1701 m)

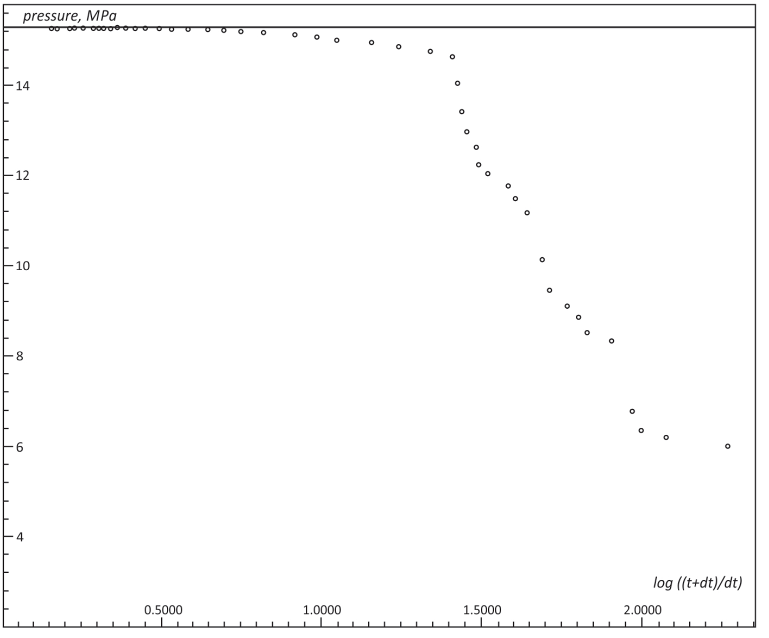


**Fig. 5.** Interpretation of the first build-up of DST test results using Horner's method in the wellbore Ż-42 (Jurassic 1635–1701 m).

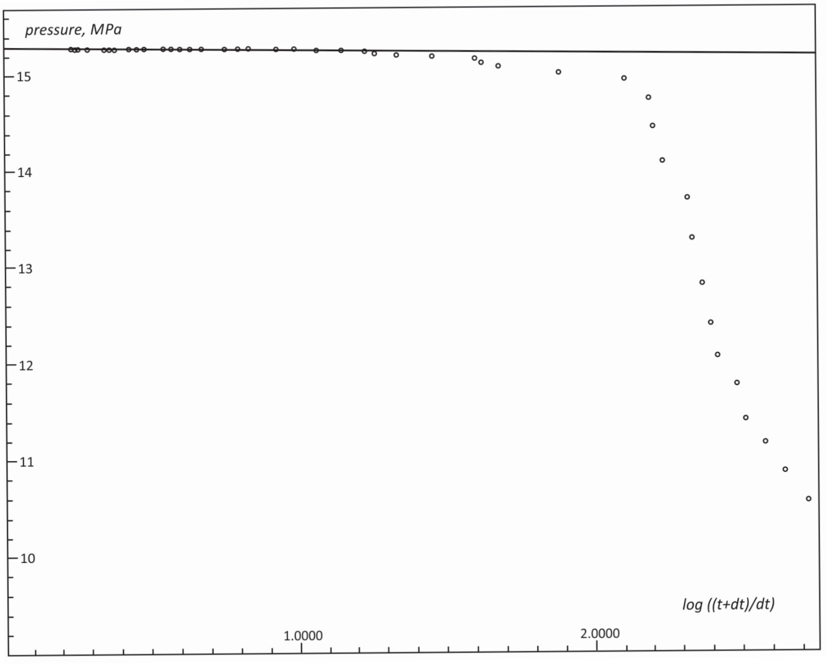


**Fig. 6.** Interpretation of the second build-up of DST test results using Horner's method in the wellbore Ż-42 (Jurassic 1635–1701 m)

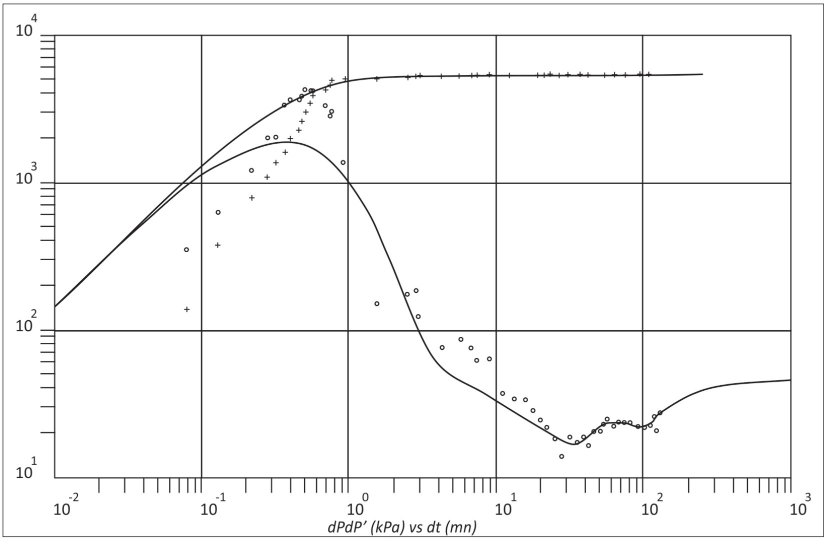


**Fig. 7.** Interpretation of DST test results in the wellbore Ż-42 (Jurassic, 1635–1701 m) in double logarithmic coordinate system (log-log) – Kappa's software "Saphir 202"

**Table 4**

Summary of the results of the measurements and calculations reservoir parameters of Malm using Horner's method – DST test, No. 53

| No. | Parameter | I build-up | | II build-up | |
|---|---|---|---|---|---|
| 1 | Reservoir pressure | 15.29 | MPa | 15.29 | MPa |
| 2 | Reservoir pressure gradient | 0.0094 | MPa/m | 0.0094 | MPa/m |
| 3 | Coefficient *m* | 0.05 | MPa/(cycle·log) | 0.05 | MPa/(cycle·log) |
| 4 | Conductivity $k \cdot h/\mu$ | 2744.553 | $\cdot 10^{-12}$ $m^3/(Pa \cdot s)$ | 2596.023 | $\cdot 10^{-12}$ $m^3/(Pa \cdot s)$ |
| 5 | Rock permability *k* | 128.55659 | mD | 121.59936 | mD |
| 6 | Skin effect | +264.65 | – | 120.45 | – |

**Table 5**

Summary of the results of calculations reservoir parameters of Malm using the log-log method – DST test, No. 53

| No. | Parameter | Build-up | |
|---|---|---|---|
| 1 | Reservoir pressure | 15.283 | MPa |
| 2 | Reservoir pressure gradient | 0.0094 | MPa/m |
| 3 | Hydraulic conductivity $k \cdot h$ | 892.43 | mD·m |
| 4 | Skin effect $S_2$ | +50.362 | – |
| 5 | Wellbore storage coefficient *C* | $2.9082 \cdot 10^{-6}$ | $m^3$/kPa |
| 6 | Dimensionless wellbore storage coefficient *CD* | 114.82 | – |
| 7 | Rate of fracture capacity and matrixfracture system capacity ω | 0.18587 | – |
| 8 | Contrast capacity parameter between the fracture and whole reservoir λ | $5.7838 \cdot 10^{-7}$ | – |
| 9 | Radius of the researching during test $R_{b2}$ | 315.02 | m |

**Reservoir diagnostics based on the results of second DST test, cycle No. 53, according to the "Saphir 202" software from Kappa company:**

- Matched, theoretical model of the reservoir:
  - dual porosity reservoir,
  - semi-steady state flow (2 Phi PSS), corresponding to the vuggy-fracture rock.
- Matched, theoretical model of reservoir-wellbore system:
  - wellbore is characterized by a high coefficient of storage (Tab. 5),
  - near-borehole area is characterized by a high skin effect (Tab. 5).
- Matched, theoretical model of reservoir boundary:
  - unlimited reservoir within a radius of the DST test,
  - radius of the area tested in the second cycle $R_{b2}$ = 315 m.

### Geological and prospecting decisions on the background of the obtained results

Examined water and gas-bearing aquifer has good reservoir properties. This level may be more saturated with hydrocarbons in different part of the examined geological structure that is why the relative permeability of the collector rock for natural gas can be higher. The results, especially the calculated reservoir parameters of the Malm sediments, are valuable geostatistical datas collected and processed for oil prospecting on concerned area [3].

## 4. AN OPEN FLOW OPERATION IN CASED WELLBORE Z-7 THROUGH THE DST TOOL DURING THE TEST NO. 41 OF MALM SEDIMENTS

### Technology of DST test, No. 41 (Tab. 6)

The triple-cycle drill stem test of Malm formations on depth 2628–2645 m was made. Before the test, the 7" casing was perforated and the open flow operation of natural gas from wellbore was conducted (Fig. 8). During completion the 500 meter height water spacer was used. Initial pressure depression was 23.25 MPa.

In the first cycle, in the period of the inflow lasting about 411 minutes, the strong outflow of air from the drill string was observed and after about 18 minutes also spacer. Then, in this period of time, the static and dynamic head pressure was measured several times and the gas open flow operation was conducted several times. In the time of build-up, lasting about 1630 minutes, the bottom hole pressure increased to the value 26.69 MPa. In the second cycle of the drill stem test the bottom hole pressure build-up lasted about 644 minutes. The bottom hole pressure in that time increased to the value 25.67 MPa. In the third cycle of the drill stem test several open flow operations and several measurements of the dynamic head pressure was made. The bottom hole pressure build-up in this cycle lasted about 817 minutes and the pressure reached 25.58 MPa. The value of reservoir pressure, determined by the log-log method from the third build-up-curve is 25.602 MPa at a depth of 2610 m.

**Table 6.**

List of calculations results of Malm reservoir parameters carried out by log-log method, test No. 41

| No. | Parameter | II build-up | |
|---|---|---|---|
| 1 | The estimated flow rate of the gas flow (under standard conditions) | 3000 | $m^3/h$ |
| 2 | Reservoir pressure | 25.602 | MPa |
| 3 | Reservoir pressure gradient | 0.0098 | MPa/m |
| 4 | Hydraulic conductivity $k \cdot h$ | 32.845 | mD·m |
| 5 | Skin effect $S_2$ | +20.143 | – |
| 6 | Wellbore storage coefficient $C$ | $2.1948 \cdot 10^{-4}$ | $m^3/kPa$ |
| 7 | Dimensionless wellbore storage coefficient $CD$ | 257.13 | – |
| 8 | Rock permeability $k$ | 1.9068 | mD |
| 9 | Rate of fracture capacity and matrixfracture system capacity ω | 0.053514 | – |
| 10 | Contrast capacity parameter between the fracture and whole reservoir λ | $6.5004 \cdot 10^{-7}$ | – |
| 11 | Radius of the researching during test $R_{b2}$ | 109.08 | m |

Gas rate was estimated on the basis of the first curve of inflow, taking into account the chemical composition of the gas and the conditions in the bottom of the borehole during the test. Reservoir measurements were determined by the log-log method, from the third build--up-curve of bottom hole pressure (Fig. 9, Tab. 6).

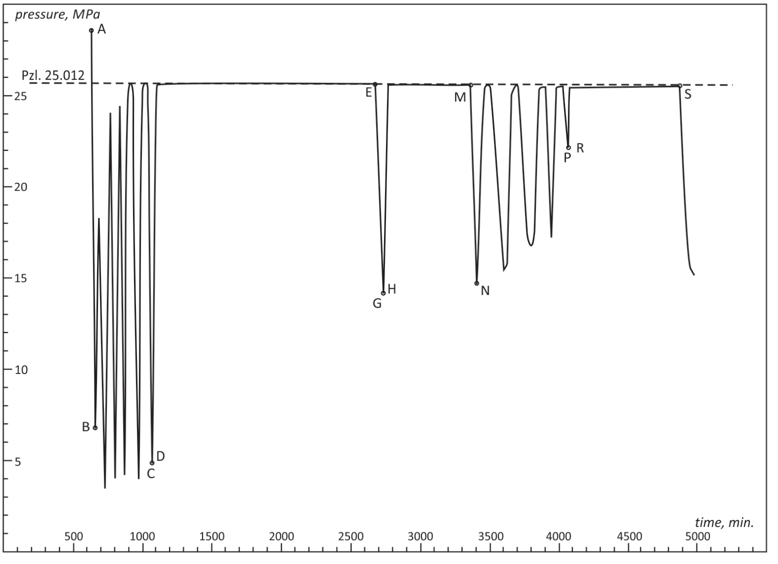


**Fig. 8.** Course of the bottom hole pressure registration in the wellbore Z-7 (Malm 2628–2645m)

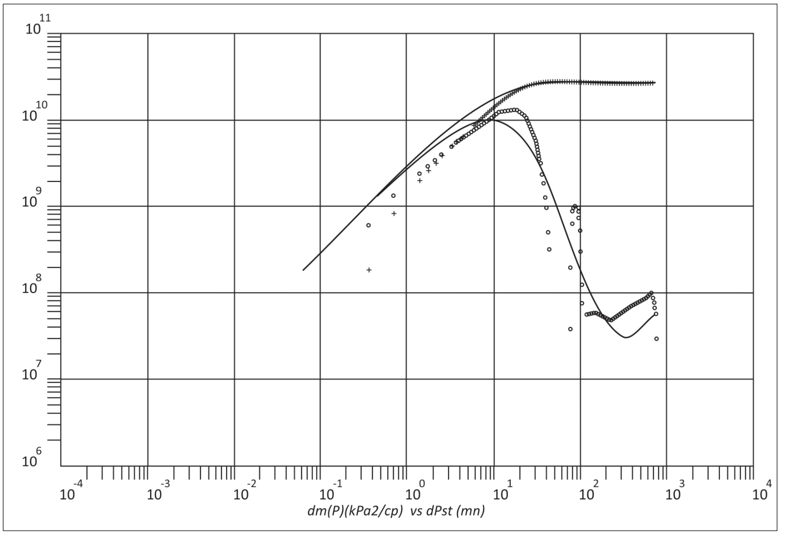


**Fig. 9.** Interpretation of the second build-up test by the log-log method in the wellbore Z-7 (Malm 2628–2645 m)

**Reservoir diagnostics based on the results of the second DST test, cycle No. 41, according to the "Saphir 202" software from Kappa company:**

- Matched, theoretical model of the reservoir:
  - dual porosity reservoir,
  - semi-steady state flow (2 Phi PSS), corresponding to the vuggy-fracture rock.
- Matched, theoretical model of the reservoir-wellbore system:
  - wellbore is characterized by a high coefficient of storage, $C = 2.1948 \cdot 10^{-4}$ m$^3$/MPa,
  - near-borehole area is characterized by a high skin effect, $S_2 = 20.143$.
- Matched, theoretical model of the reservoir boundary:
  - reservoir limited by one fault with a constant pressure located about 67 m from the borehole,
  - radius of the area tested in the second cycle $R_{b2} = 315$ m.

**Geological and prospecting decisions on the background of the obtained results**

Examined gas-bearing layer has medium reservoir properties. The best curve fit to the actual theoretical curve was obtained for the reservoir model with dual reservoir porosity (vuggy-fracture rock). The reservoir boundary may occur within a radius of the drill stem test ($R_{b2} = 100$ m), approximately 70 m from the wellbore. The examined gas-bearing layer has a commercial value, so before putting it into exploitation, it is advisable to perform a reservoir stimulation of natural gas production [5].

## 5. CONCLUSIONS

1. Analysis of the results obtained from the three selected DST tests show that the applied technologies provide ample opportunities for making geological and exploration decisions about the further use of the tested Malm horizon in the wellbore.
2. The results of test No. 19 may provide a basis for decisions about the necessity of hydraulic fracturing of the Malm sediments, because there was no inflow of reservoir water to the DST tool and the recorded graphs indicate the presence of good filtration properties of the reservoir and the normal reservoir pressure gradient.
3. Results obtained from test No. 53 are a valuable collection of information on reservoir parameters and can also be used in geostatistical analysis.
4. The results obtained on the basis of test No. 41 confirmed the presence of natural gas deposits having a commercial value in the Malm layer and the necessity of hydraulic fracturing before putting the well into production.
5. The results of two DST tests (test No. 53 and test No. 41) interpreted in a double logarithmic system show that:
   - the Malm sediments of the Carpathian Foothills characterized by a dual porosity (porosity of cracks and porosity of the rock matrix);
   - coefficient ω, characterizing the relation between gaps capacity and a total capacity of rocks, is: 0.053514 (test No. 41) and 0.18587 (test No. 53);

- coefficient λ, characterizing the flow between the pores, is: $6.5004 \cdot 10^{-7}$ (test No. 41) and $5.7838 \cdot 10^{-7}$ (test No. 53);
- identified large values of $S_2$ are: 20.143 (test No. 41) and 50.362 (test No. 53) mean damage to the permeability of this type of collector rocks and form the basis of the decision to stimulate the extracting operation before putting wells into production.

## REFERENCES

[1] Dubiel S., Chrząszcz W., Rzyczniak M.: *Problemy opróbowania warstw perspektywicznych rurowymi próbnikami złoża*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2003.

[2] Dubiel S., Rzyczniak M., Chrząszcz W., Miska W., Wójtowicz T., Kułaga T., Nowakowski Z., Rogowski E.: *Analiza i interpretacja wyników badań rurowymi próbnikami złoża warstw perspektywicznych w rejonie Przedgórza Karpat w celu oceny właściwości zbiornikowych skał i parametrów złożowych poszczególnych poziomów*. WWNiG AGH, Kraków 1994.

[3] Dubiel S., Uliasz-Misiak B.: *Analiza statystyczna parametrów zbiornikowych utworów jury górnej-kredy dolnej zapadliska przedkarpackiego uzyskanych z testów RPZ i pomiarów geofizycznych* [Statistical analysis of reservoir parameters of the Upper Jurassic-Lower Cretaceous formation in the Carpathian Foredeep obtained from DST tests and geophysical surveys]. Gospodarka Surowcami Mineralnymi, t. 29, z. 2, 2013, pp. 119–134.

[4] Dubiel S., Zubrzycki A., Maruta M.: *Analiza właściwości zbiornikowych skał węglanowych na podstawie wyników testów RPZ i pomiarów geofizyki wiertniczej* [Analysis of carbonate reservoir rock properties on the basis of DST and well logging]. AGH Drilling, Oil, Gas, vol. 29, no. 1, 2012, pp. 127–134.

[5] Dubiel S., Zubrzycki A., Maruta M.: *Decision system model for HC exploration on the basis of DST test results*. AGH Drilling, Oil, Gas, vol. 30, no. 1, 2013, pp. 51–56.

[6] Dubiel S., Zubrzycki A., Rybicki C., Maruta M.: *Application of DST interpretation results by log-log method in the pore space type estimation for the upper jurassic carbonate reservoir rocks of the carpathian foredeep basement*. Archives of Mining Sciences, vol. 57, no. 2, 2012, pp. 413–424.

[7] *Kappa Engineering. Eeltest interpretation. Course booklet. Version 1.20. September 1973.*