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ANALYSIS OF DRILL STEM TEST (DST) RESULTS AT OSOBNICA OIL FIELD, IN TERMS OF SAMPLING OF SELECTED TECHNOLOGY PARAMETERS**

Nomenclature

DST – Drill Stem Test,
n.o. – barefoot segment of the well,
S – skin-effect [±],
$\bar{p}$ – average pressure [MPa],
x_f – half the length of fracture [m],
k – effective permeability of matrix + fracture system [mD],
h – thickness [m],
p^* – initial pressure [MPa],
R_b – radius of the investigation during test [m],
L – distance from the well to boundary [m],
t_1, t_2 – time of first and second period of the inflow [min],
Δt_1, Δt_2 – time of first and second build-up of the bottom pressure [min],
ε – hydraulic conductivity [$(m^3/Pa) \cdot s \cdot 10^{-12}$],
W_f – actual productivity [$(m^3/h)/MPa \cdot 10^{-7}$].

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1. INTRODUCTION

Polish Outer Carpathians are still prospective zone of hydrocarbon exploration, where Istebna Sandstones and three horizons of Ciężkowice Sandstones are important and form anticlinal traps for hydrocarbons. In these horizons many oil and gas fields have been discovered in the second half of the twentieth century, i.e., Osobnica oil and gas field. Both already discovered accumulations of hydrocarbons, as well as the newly drilled Paleocene sandstone intervals in the late twentieth century, typed by well-logging to DST tests, are perspective horizons of favorable reservoir parameters. Reservoir tests of these strata made by tube sampler (DST) at the end of the twentieth century provided many reliable information reservoir on which the important decisions in the field of geological exploration and production have been made. The credibility of DST depends largely on used technology. Finally, based on the results of DST there can be estimated commercial value of these horizons. In addition, analysis of the interpretation of DST, especially, charts of the reconstruction of the bottom pressure by traditional Horner method (semi-logarithmic system) and modern "log-log" method (double logarithmic system) allows, according to the authors, demonstrate not only the relationship between obtained test curves shapes with occurring conditions resource properties, but also with the technological parameters.

In the Polish Oil and Gas Company most commonly two-cycled DST are used, which in the case of high gas, oil or reservoir water inflow, allow an assessment of:

- the value of relaxation effect of tested horizon to the repression of head pressure of the mud in the hole.
- changes in reservoir parameters defined by Horner method based on the results of I and II cycle of DST;
- changes in the permeability of reservoir rocks in the near and further zone of the well in the area of research within the probe;
- reservoir conditions and the number and shape of the boundaries of the reservoir, using the log-log method.

This paper presents the results of analysis and reinterpretation of data from the three tests deposit DST: 1/98; 2/98 and 4/98, made in two wells O-139 and O-141, characterized by varying degrees of credibility.

2. GEOLOGICAL SETTING OF OSOBNICA OIL FIELD

The Osobnica oil field was discovered in 1953 [10] and it's accumulated within the Bóbrka-Osobnica Fold and which is localized in Silesian Nappe of Polish Outer Carpathians (Fig. 1). The Osobnica structure is a sliced brachyantycline, whis is cut into blocks by some disclocations. Oil is accumulated mostly in the southern limb of anticline, whereas the northern one is reduced. The Osobnica structure is composed of the Istebna (Czarnorzeki) Beds and three horizons of the Ciężkowice Sandstones separated by Mottled Shales. Most productive is Horizon III of Ciężkowice Sandstone, then Upper Cretaceous Istebna Sandstone and Horizon II of Ciężkowice Sandstone. The lithological seal is made by the Istebna Shales and three layers of Eocene Mottled Shales [7, 8].

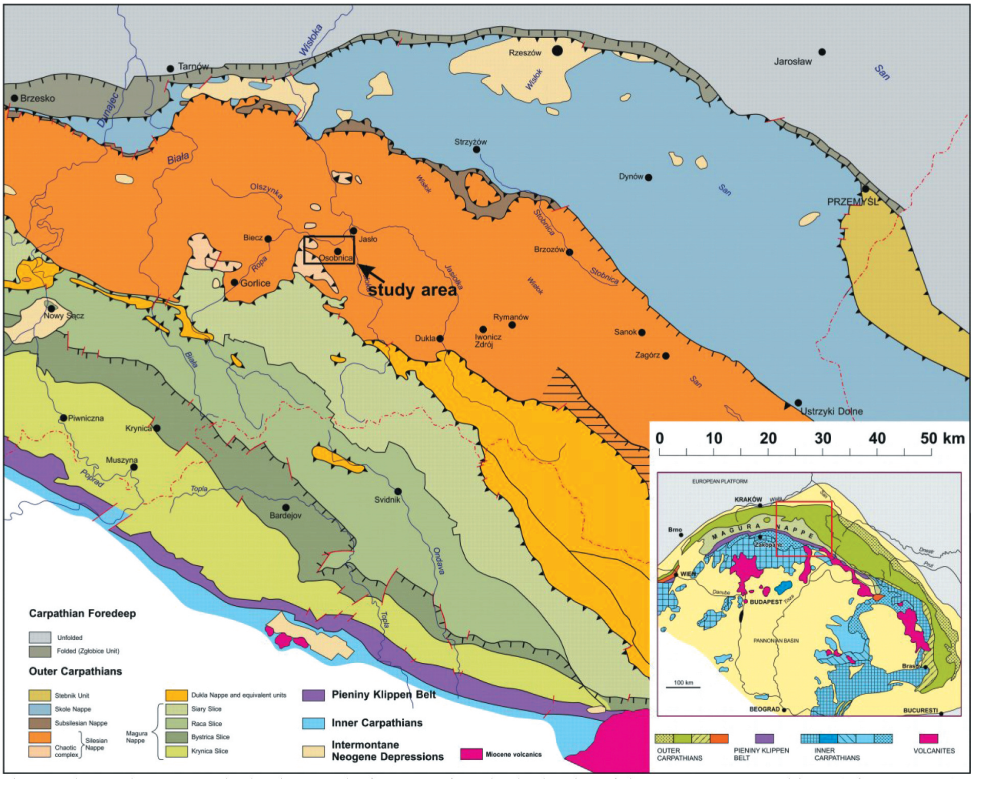

Fig. 1. The study area on the background of a map of geological units of the Western Carpathians (after [11, 12]), a study area marked by black rectangle

3. ANALYSIS OF DST CHARTS FOR THE EFFECT OF RELIEVING THE STUDIED RESERVOIR HORIZONS

Pressure charts during the DST (Figs 2, 3 and 4) have been recorded using mechanical pressure gauges type AK-1 and K-3 manufactured by Kuster, installed in sets of probing made by Halliburton, model Standard 5". During the drilling of analyzed reservoir horizons, high pressures of hydrostatic mud column were used, due to applying too high density of a drilling fluid in comparison to the reservoir pressure gradient (Tab. 1).

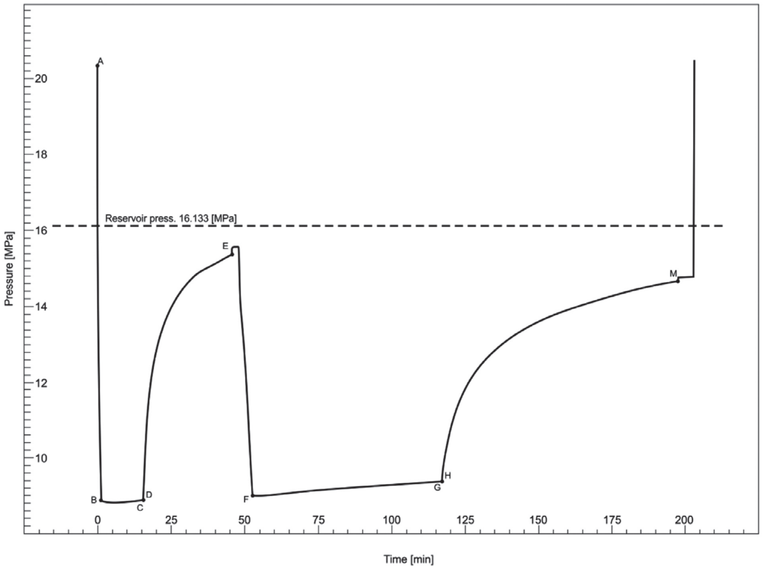

Fig. 2. Pressure chart registered during the test no. 1/98 of Paleocene strata (1621–1673 m) in the well O-139. A – drilling mud hydrostatic pressure in the well; A-B – run in hole, B-C – I inflow period, D-E – I build-up period, F-G – II inflow period, H-M – II build-up period

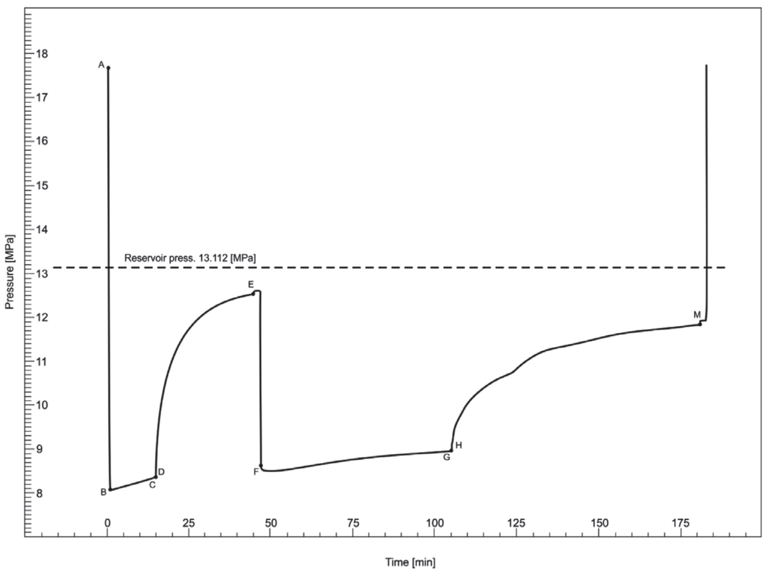

Fig. 3. Pressure chart registered during the test no. 2/98 of Istebna beds (1385–1428 m) in the well O-139. A – drilling mud hydrostatic pressure in the well; A-B – run in hole, B-C – I inflow period, D-E – I build-up period, F-G – II inflow period, H-M – II build-up period

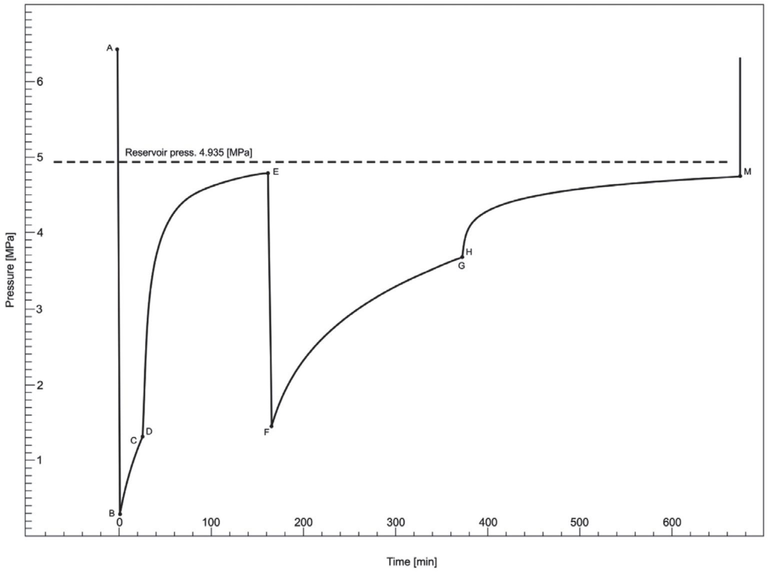

Fig. 4. Pressure chart registered during the test no. 4/98 of Eocene strata (III Ciężkowice sandstone) (602–620 m) in the well O-141. A – drilling mud hydrostatic pressure in the well; A-B – run in hole, B-C – I inflow period, D-E – I build-up period, F-G – II inflow period, H-M – II build-up period

It should be noted, that under dynamic conditions (mud circulation in a wellbore, drilling, plunging drilling pipes) the bottom hole pressure increase by about 10% [1, 2].

The pressure difference (pE – pM) between points E and M at build-up pressure charts I and II (Figs 2, 3 and 4, and Tab. 1) can be an estimated measure of the effect of relieving of the horizon and mud pressure. The Table 1 indicates that the pressure differences from the tests 1/98 and 2/98 have a relatively large value, therefore more reliable reservoir parameters are obtained based on the results of the second cycle of analyzed DST.

Calculations show (Tab. 1), that the most favorable technological conditions for drilling of reservoir rocks and their sampling occurred in the well O-141, Test No. 4/98:

– minimum build-up pressure difference (less than 0.01 MPa);
– a preferred value of the depression to repression pressure ratio (greater than 3).

Much worse technological conditions occurred in the well O-139 (1/98 and 2/98):

– very large build-up pressure difference (greater than 0.1 MPa);
– a very unfavorable value of the depression to repression pressure ratio (much less than 3).

These technological conditions could significantly affect to the too little flow of reservoir fluid to the sampling probe.

By analyzing the ratios of sampling times (Tab. 1) it is clear that they point to provide very good conditions for the registration of easily interpreted pressure charts in a semi-log and log-log systems.

Table 1

Data list of technical and technological parameters from DST tests in wells O-139 and O-141

	Well No., Test No.		**O-139, 1/98**	**O-139, 2/98**	**O-141, 4/98**
1	Stratigraphy		Paleocene	Paleocene	Eocene
2	Sampled interval [m]		1 673–1 620 n.o.	1 385–1 428 n.o.	602–620 n.o.
3	Well dimension [m]		0.216	0.216	0.216
4	Gauge depth [m]		1 615	2 805	580
5	The density of the drilling mud during drilling of reservoir rocks [kg/m^3]		1 300	1 292	1 125
6	The time from drilling to testing [day]		30	33	1
7	The height of the water wads column [m]		904	806	20
8	DST time	Time of I inflow test [min]	14.3	14.0	25
		Time of II inflow test [min]	64.2	57.9	207.3
		t_2/t_1 [1]	4.48	4.13	8.29
		Time of I build-up test [min]	30.1	29.5	136.7
		Time of II build-up test [min]	80.4	75.9	302.7
		$\Delta t_2/\Delta t_1$ [1]	2.67	2.57	2.21
9	Pressure values	hydrostatic pressure of the drilling mud on the reservoir horizon [MPa]	20.34	17.65	6.40
		Repression of pressure on the reservoir horizon [MPa]	4.21	4.54	1.47
		$p\mathrm{E} - p\mathrm{M}$ [MPa]	0.68	0.73	0.05
		The initial pressure depression during sampling [MPa]	7.26	5.05	4.645
		the ratio of pressure depression and repression [1]	1.72	1.11	3.16

4. RATING OF COMMERCIAL OF EXAMINED LEVELS BASED ON THE RESULTS OF I AND II CYCLE OF DST

In order to assess of commercial of tested horizons, the reservoir parameters were determined by the Horner method based on the data from cycle I and II (Tab. 2). It was observed, that:

Test 1/98 – flow of mud gasified by gas to probe is ambiguous result (Tab. 1), but is the basis for a decision to intensify the flow of reservoir fluid, especially in the case of high variability skin-effect and normal reservoir pressure gradient (Tab. 2) [6].

Test 2/98 – hydraulic conductivity values ε_1 and $\varepsilon_2 > 10\cdot10^{-12}$m^3/Pa·s and permeability k_1 and $k_2 > 1$ mD, and the ratio of actual productivity W_{f1} and $W_{f2} > 10^{-1}$ (m^3/h)/MPa (Tab. 2) demonstrate the commercial value of examined oil-bearing horizon [5]. In addition, during DST of I and II, another fall in the value of skin-effect $S_1 > S_2$ shows declogging of reservoir rocks studied by probe $R_{b2} = 6{,}6$ m [3].

Test 4/98 – the flow of 1.5 m^3 of drilling mud slightly gasified by combustible gas with traces of oil and the fact that in a sample of fluid, there was not reservoir water [4], is the basis for decisions about necessity of treatment of flow intensification of fluid reservoir. In addition, changes in the skin-effect and hydraulic conductivity, permeability and productivity, determined on the basis of the interpretation of the results of DST cycles I and II (Tab. 2) demonstrate declogging of reservoir rocks in the zone studied by probe with a significant radius of about $R_{b2} = 47$ m. Thus, the sandstone horizon in the well O-141 should be considered as perspective.

The conditions of the tested reservoir horizons, the number and shape of the boundaries of horizons were evaluated using the log-log (Figs 5 and 6) method by Saphir 202B program [4, 9], with the following results:

Well O-139, test No. 2/98:

- homogeneous structure of reservoir horizon;
- well connected with unlimited conductivity fracture (1/2 length $X_f = 6.43$ m);
- in the area of reservoir horizon there is no fault (boundary).

Well O-141, test No. 4/98:

- homogeneous structure of reservoir horizon;
- well connected with unlimited conductivity fracture (1/2 length $X_f = 8.93$ m);
- in the zone of reservoir horizon tested by probe has been identified one rectilinear sealed fault in distance $L = 40$ m from the well.

Table 2

List of calculated reservoir parameters in wells O-139 and O-141 based on DST tests results

	Well No., Test No.	O-139, 1/98	O-139, 2/98	O-141, 4/98
1	Reservoir fluid	Gasified drilling mud without water	oil	Gasified drilling mud with oil sign
2	Average flow rate [m^3/h]	0.5	1.17	0.39
3	Reservoir pressure (from II build-up) [MPa]	16.13	12.41	4.94
4	Reservoir pressure gradient [MPa/m]	0.0102	0.0089	0.0085
5	$\varepsilon = (k \cdot h/\mu)$ $[(m^3/Pa) \cdot s \cdot 10^{-12}]$	$\varepsilon_1,\ \varepsilon_2 < 1$	$\varepsilon_1 = 18.91$ $\varepsilon_2 = 30.508$	$\varepsilon_1 = 5.99$ $\varepsilon_2 = 24.789$
6	k [mD]	$k_1, k_2 < 0.1$	$k_1 = 1.58$ $k_2 = 2.54$	$k_1 = 0.39$ $k_2 = 1.62$
7	W_f $[(m^3/s)/MPa]$	$W_f < 0.1$	$W_{f1} = 0.245$ $W_{f2} = 0.334$	$W_{f1} = 0.105$ $W_{f2} = 0.306$
8	S_1, S_2 [±]	$S_1, S_2 < 0$ $S_2 < S_1$	$S_1 = -1.25$ $S_2 = -2.03$	$S_1 = -2.69$ $S_2 = -3.98$
9	R_b [m]	$R_{b1} < R_{b2} < 1$	$R_{b1} = 2.3$ $R_{b2} = 6.6$	$R_{b1} = 7.6$ $R_{b2} = 47.3$

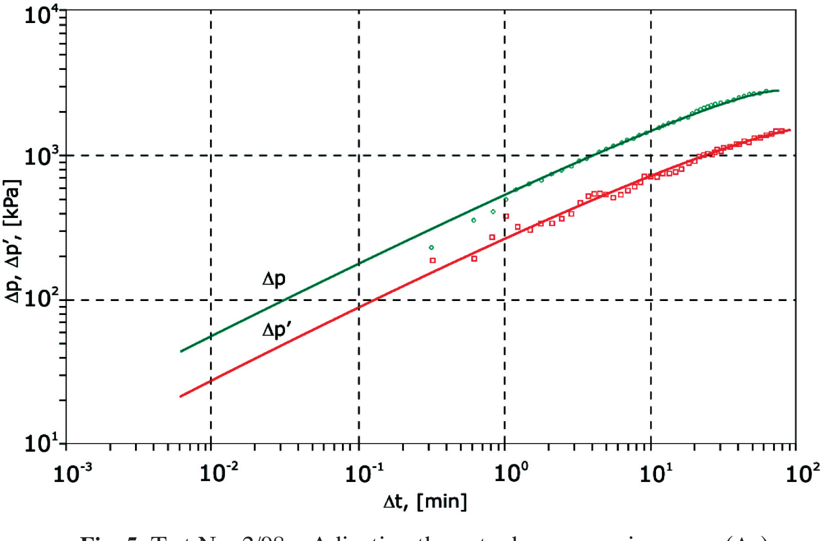

Fig. 5. Test No. 2/98 – Adjusting the actual pressure rise curve (Δp) and the first derivative of pressure increase ($\Delta p'$) as a function of time (Δt) to model curves (log-log method)

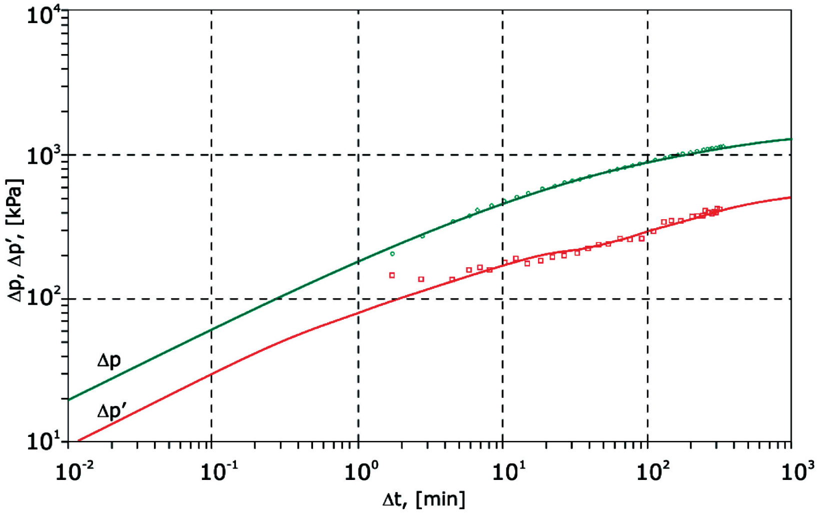

Fig. 6. Test No. 4/98 – Adjusting the actual pressure rise curve (Δp) and the first derivative of pressure increase ($\Delta p'$) as a function of time (Δt) to model curves (log-log method)

5. CONCLUSIONS

1. Based on analysis and reinterpretation of the results from three DST in reservoir horizons at Osobnica oil reservoir it was found that the results are characterized by varying degrees of reservoir recognition.
2. The test No. 2/98 in Paleocene sandstone horizon in the O-139 well shows explicitly that this horizon is oil-bearing and has low comercial value. The occurence of fracture in this horizon, which connects it with a well, faciliated the occurence of self declogging during DST. This may favor the hydraulic fracturing of Paleocene sandstones and achieving a significant increase in oil production due to the stated fracture.
3. The test No. 4/98 of III Ciężkowice sandstone found the rock self-declogging effect in the zone with a radius of about 47 meters, thanks to the fracture, connecting the tested horizon with well O-141. Gas content of this level and the presence of oil signs (without signs of reservoir water) indicate a high chance of getting significant productivity from this horizon after hydraulic fracturing treatment.
4. The test No. 1/98 of Paleocene sandstone in well O-139 gave ambiguous information about the gas-bearing and oil-bearing of this horizon. Despite this, the horizon can be considered as perspective and its productivity can be assessed after the treatment of the hydraulic fracturing of sandstone.

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