The effect of pressure depression on the water inflow volume to wells which cover carbonate rocks in the Carpathian Foredeep basement, SE Poland

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Abstract

This paper presents an analysis of well testing data, performed with a Drill stem test (DST). The carbonate levels of Mesozoic reservoir rocks were investigated in the research area of the Carpathian Foredeep. Based on the results of 17 two-cycle DST reservoir tests, the dependence of the volume of the reservoir water flow rate from the Mesozoic carbonate reservoirs (Upper Jurassic, Lower Cretaceous) to the wells as a function of the mean depression of bottom pressure was researched in the selected oil exploration area in the Carpathian Foredeep basement, SE Poland. Using methods of statistical analysis, a satisfactory correlation between variables for power and the exponential model was found, and a weak correlation for the linear model was found. A decrease in the value of the reservoir water flow rate along with an increase in pressure depression was found for the Mesozoic carbonate reservoirs, which may indicate the occurrence of fractures and micro-fractures shortening under extreme pressure depression and blockage phenomena of fractures and cavernous pores in the perimeter area by solid particles (cuttings, salt, polymers, etc.).

Keywords:
Carpathian Foredeep; Mesozoic; DST test; statistics, water flow volume.

1. Introduction

Since the Second World War, intensive geological and exploration works were carried out for oil and gas reservoirs in the Polish part of the Carpathian Foredeep and its basement **(i.e. Cisek and Czernicki, 1965; Karnkowski, 1994; Karnkowski and Ozimkowski, 1998; Borys et al., 2000; Myśliwiec et al., 2006)**; in the 1990s especially in the area between Rzeszów and Bochnia (see **Figure 1**) **(i.e. Czernicki and Moryc, 1990; Heflik, 1992; Kotarba et al., 1998)**.

This research was carried out, inter alia, in Mesozoic carbonate reservoir rocks (upper Jurassic, Lower Cretaceous) separated by well logging, in the profiles of wells **(Maksym et al., 2000; Gutowski et al., 2007; Krajewski et al. 2011)**. Testing the field is one of the most important stages of work in the process of exploring crude oil and natural gas. The results of the trial depend on the further development of the exploration work. One of the methods of testing the drilled levels of reservoir rocks is to use samplers placed into the hole. The use of DST technology allows for quick determination of the value concerning the productivity of the tested level of reservoir rocks. Data from the tests are the basis for the correction of drilling technology, and also help to avoid the unnecessary positioning of a casing column into an un-

productive hole. Tests of reservoir rocks with the use of tubular samplers include: placing the sampler into a well at the appropriate depth, isolating the tested productive level from the pressure of the mud column and connecting it to the inner space of the mud pipes in order to induce a flow, obtaining a pressure increase curve, and collecting reservoir samples.

On the basis of the results obtained from the samples, it is possible to determine the formation pressure, well performance, hydrodynamic coefficient, rock permeability, rock permeability damage index of the near-well zone, and the range radius of the production level examination from the well. Prospective horizons were subjected to reservoir tests with tubular reservoir samplers (DST) to assess their productivity. DST tests were most often performed in open-hole sections, and less-hole sections, after previous perforation of the well. US standard Halliburton type and Baker type Inflatable samplers were used. The samplers used for the tests were two-cycle samplers. During the DST reservoir tests of the Mesozoic reservoirs, in about 90% of cases, two-cycle technology was used, i.e. two tests of inflow of reservoir water to the sampler and two tests of bottom-pressure build-up **(Dubiel et al., 1998)**.

The standard Halliburton type is used for testing the prospective layers of reservoir rocks made available by perforations for a hydrodynamic assessment, as well as for technical tests, e.g., for testing the tightness of a ce-

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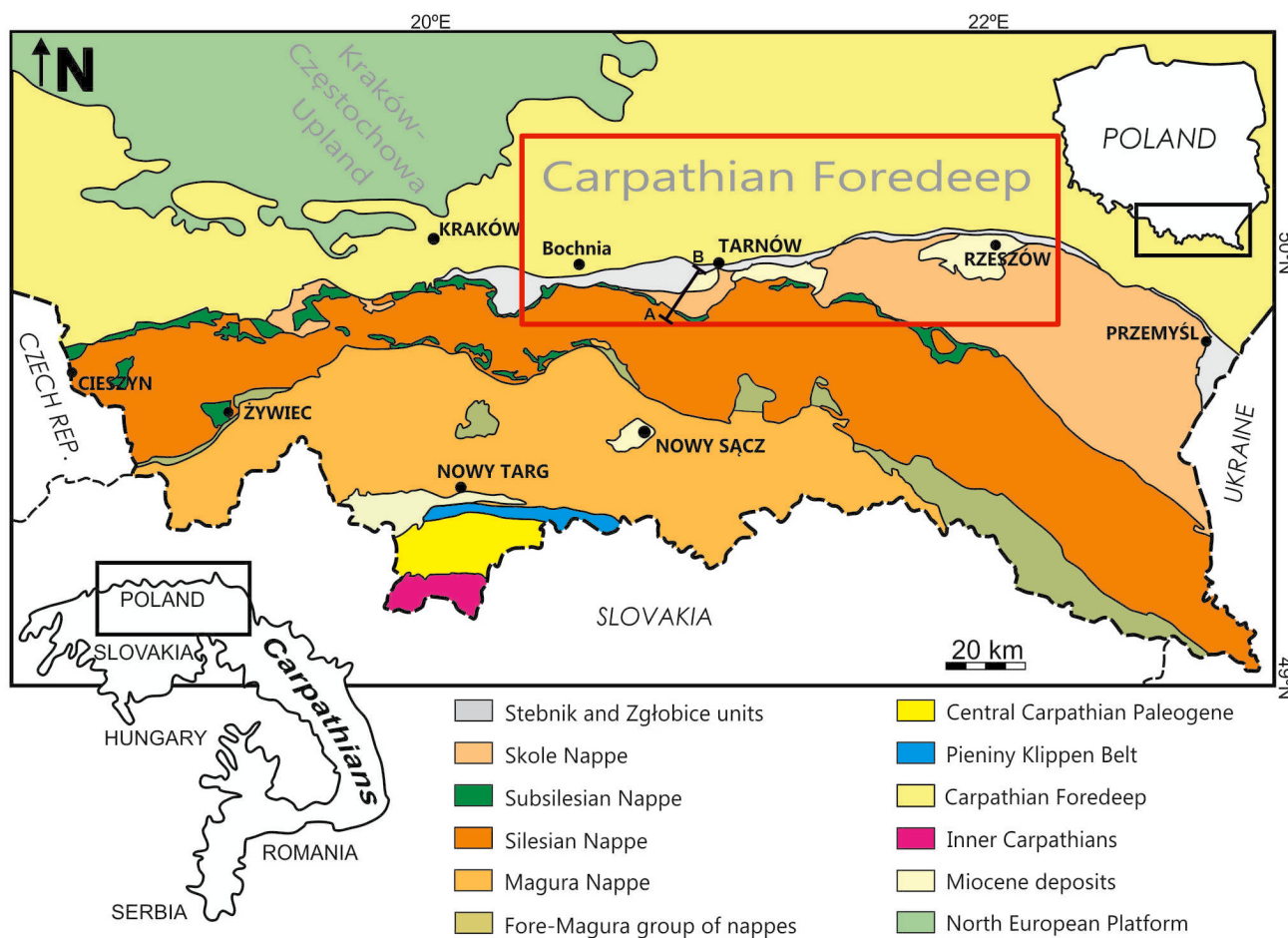
Figure 1. Position of the research area against the tectonic map of the Polish Carpathians and their foreland (map after **Żytko et al., 1989; Cieszkowski et al., 2009; Kowal-Kasprzyk et al., 2020; modified**)

ment plug or casing pipes. It is especially recommended to use such a set in those cases where the distance from the shoe of the casing column to the non-tubular layer is small (several dozen metres), and the wall of the borehole above this layer is vaulted or when XYZ profiling has not been performed.

The inflatable type is intended for the testing of the prospective layers of reservoir rocks in boreholes with a vaulted wall and in poorly compacted rocks, i.e., in geological conditions that do not allow for sealing with mechanical seals fastened under the action of axial pressure. The advantage of these samplers is the good sealing properties of pumped packers. They make it possible to selectively test several of perspective layers of reservoir rocks in a borehole at once. This method shortens the testing time and minimizes testing costs **(Dubiel et al., 1998)**.

Based on the analysis of well testing data, it was concluded that the inflow of reservoir water during DST tests in exploratory wells after oil and gas reservoirs constitutes a significant percentage of sampling cases of prospective levels determined by well-logging. The interpretation results of data from such tests are now used to design further works in the field of oil exploration as well as to use water-bearing horizons in geothermal energy and to obtain salts (e.g. bromine or iodine).

2. Geological setting of research area

The Carpathian Foredeep is part of the large sedimentary basin (the Paratethys Basin) formed in the foreland of the Carpathian Mountains, which slopes to the north. It is a typical pre-mountain trench filled with syn- and postorogenic sediments, the formation of which was related to the Miocene evolution of the orogenic arc of the Outer Carpathians **(Krzywiec, 2006)**. In the west, the Foredeep connects with the Alpine Molasse Basin, and in the east with the pre-mountain basin of the Balkans. It is the youngest alpine unit occurring in Poland, where it extends for a length of about 300 km and a width of up to 100 km. The basin is filled with Lower and Middle Miocene molasse deposits up to 3 km thick in Poland and up to 5 km in the Ukraine **(Kovac et al., 1998; Oszczypko, 2006)**. In terms of lithology, petrography and especially facies, the Miocene reservoir rocks are very diverse. The basement of the Carpathian Foredeep is composed of rocks of the Epivarisian platform and its Permian-Mesozoic cover. The depth of the platform sub-
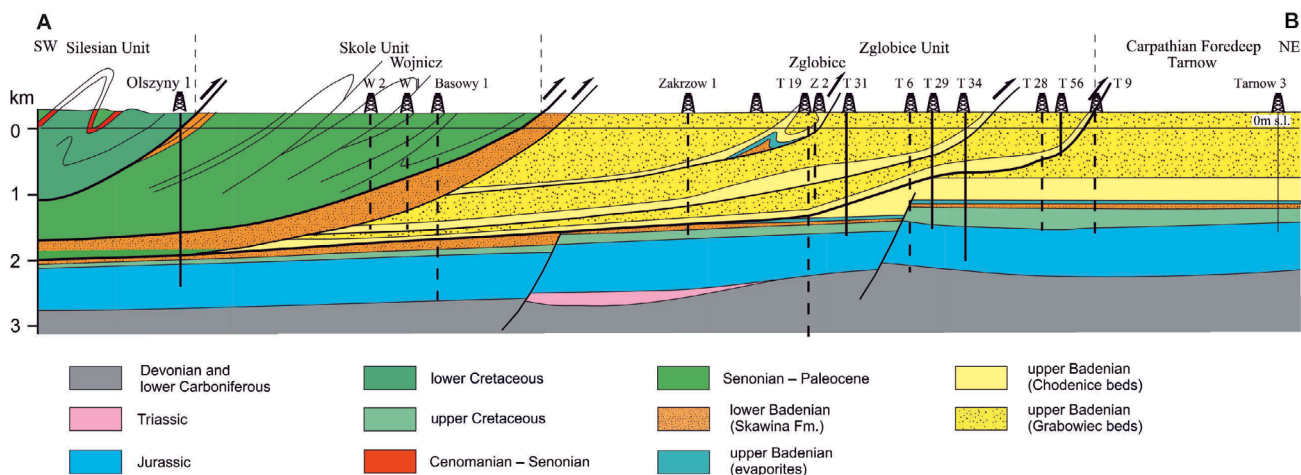
Figure 2. Geological cross-section AB (shown in Figure 1) through the marginal part of the Polish Carpathians and Carpathian Foredeep west of Tarnów (after **Oszczypko, 1998; Oszczypko et al., 2006**)

strate in the Foredeep ranges from several hundred metres to 3500 m **(Oszczypko et al., 2006)**. In the west, under the Miocene of the Carpathian Foredeep, there are rocks of the Upper Silesian Trough, in the central part - rocks of the Miechów Trough, and in the east - of the lower San Basin **(Stupnicka and Stempień-Sałek, 2016)**. The northern boundary of the Foredeep is erosive, while the southern boundary is tectonic **(Mizerski, 2020)**. It is delineated by the front of the Outer Carpathians, which are completely flat over the Miocene sediments of the Carpathian Foredeep **(Oszczypko et al., 2006)**.

In the Carpathian Foredeep, the outer part, located north of the Carpathians, and the inner part hidden under the overhung Carpathians are distinguished **(Oszczypko 1998)**. The outer zone, covering the area of the present Foredeep, is filled with middle Miocene marine sediments (Badenian and Sarmatian). Its width on the territory of Poland ranges from 30-40 km in the west to 90 km in the east. The inner part of the Foredeep, located under the Carpathian nappes (Skole and Zgłobice Units), is filled with early Miocene land sediments and mid-Miocene sediments from the marine environment (see **Figure 2**) **(Oszczypko and Slaczka, 1989; Oszczypko 1998, 2006; Oszczypko et al., 2006; Głuszyński and Aleksandrowski, 2016)**.

The formation of the Carpathian Basin is associated with the end of flysch sedimentation, the uplift and folding of the Outer Carpathians, which was the result of the collision between the European plate and the terranes of Alcapa and Tisza-Dacia with the end of the Burdigalian **(Tomek and Hall, 1993)**.

The Paleozoic–Mesozoic and Neogene strata of the Carpathian Foredeep are oil and gas productive **(Karnkowski, 1999; Myśliwiec, 2004; Oszczypko et al., 2006; Szuflicki et al., 2020)**. The Upper Jurassic series is widespread across the western part of the Carpathian Foredeep (towards the west from Rzeszów). It includes sediment strata from the Oxfordian to Kimmeridgian.

The Oxfordian deposits start from marls, massive limestones with cherts, and cavernous dolomites. The upper Oxfordian consists of organogenic limestones, which pass upward to oolitic limestones. The organogenic rocks were deposited in different facies as bioherms, reef mounds, table-shaped reefs, patch reefs, and deposits of the reef talus. The effective thickness of the reservoir hydrocarbon resources of the Polish Carpathian Foredeep is 12.7 m, the porosity is about 2%, and the permeability ranges from 0 to $184.55 \cdot 10^{-15}$ m^2 (0 to 187 mD). The traps are a structural-stratigraphic type of the uplifted block erosional-tectonic origin. The thick cover of the Miocene deposits seals hydrocarbons. Besides the organogenic limestones, the dolomites are also the primary Upper Jurassic reservoir. The results of the laboratory analysis of core data suggest that the dolomites of the Carpathian Foredeep are formed by alternations of limestone rocks. The dolomites are most commonly late diagenetic and epigenetic **(Myśliwiec et al., 2006).**

3. Materials and methods

Well testing data **(Dubiel et al., 1998)** were used for analyses and calculations, including reservoir tests of the Mesozoic reservoirs in the water-bearing zones of the studied geological structures of the Carpathian Foredeep.

A measure of the productivity of the tested aquifers is usually the average value of the volume flow of the reservoir water inflow (q_{wsr}) to the sampler (see **Table 1**), during a two-cycle DST test. Statistical analyses were made taking into account the results of the DST technology tests made in accordance with individually selected parameters for each test. However, in determining this basic reservoir parameter, pressure depression is not taken into account, as an important parameter of the DST test technology. So in this publication, the unitless production (WW_j) index, taking into account the mean value of pressure depression, was used to assess the pro-

Table 1. Summary of data and results of calculations of the average value of pressure depression and unit extraction index of reservoir water from the Mesozoic strata during DST tests

No.	No. of well; No. of DST	Stratigraphy	Interval from - to, (m)	$q_{wśr}$ $\left(\dfrac{m^3}{h}\right)$	p_z (MPa)	p_{p1} (MPa)	p_{k2} (MPa)	$\Delta p_{śr}$ (MPa)	WW_j $\left(\dfrac{m^3}{h \cdot MPa}\right)$
1	Z-5; 8/96	Upper Jurassic - Cretaceous	1178-1230	4.0	11.34	2.01	3.51	8.58	0.466
2	Z-8; 47/96	Upper Jurassic	1280-1299	1.75	11.8	0.7	5.4	8.75	0.200
3	T-1; 77/96	Upper Jurassic	2692-2710	1.71	27.82	5.4	27.8	11.22	0.152
4	J-3; 89/96	Upper Jurassic	1494-1525	1.5	15.13	5.6	6.7	8.98	0.167
5	K-4; 114/96	Upper Jurassic	657-702	2.8	6.51	1.1	3.9	4.01	0.698
6	R-3; 118/96	Jurassic - Cretaceous	1409-1441	1.275	13.47	1.6	2.5	11.42	0.112
7	R-1; 3/97	Jurassic	2340-2424	0.392	23.8	2.7	21.41	11.75	0.033
8	Z-7; 26/97	Jurassic	2980-3015	0.858	29.52	12.88	14.27	15.95	0.054
9	Ż-42; 49/97	Jurassic	1483-1492	1.08	14.67	2.21	5.16	10.99	0.098
10	W-16; 52/97	Upper Jurassic	1868-1904	2.0	18.52	3.96	7.36	12.86	0.156
11	Ż-42; 53//97	Jurassic	1635-1701	2.5	15.283	2.46	9.77	9.17	0.273
12	W-3; 56/97	Upper Jurassic - Cretaceous	1338-1356	3.6	12.46	3.54	11.14	5.12	0.703
13	W-3; 64/97	Upper Jurassic	1446-1498	21.0	13.57	8.8	13.4	2.47	8.502
14	O-3; 70/97	Jurassic	1574-1577	6.6	15.29	1.36	15.07	7.08	0.933
15	P-2; 73/97	Jurassic	1708-1728	9.0	16.95	4.9	16.86	6.07	1.483
16	Ł-20; 12/98	Upper Jurassic	1503-1542	9.0	14.71	3.13	12.66	6.82	1.321
17	Ł-20; 13/98	Jurassic	2155-2173	0.36	21.403	6.26	7.55	14.50	0.025

ductivity of the examined aquifers (see **Table 1**) and was calculated from the formula **(Dubiel et al., 2003)**:

$$WW_j = \frac{q_{wśr}}{\Delta p_{śr}} \qquad (1)$$

where:

WW_j – reservoir water unit extraction rate, $\left(\dfrac{m^3}{h \cdot MPa}\right)$,

q_{wsr} – average value of the stream of the reservoir water inflow to the sampler during the two-cycle DST reservoir test, $\left(\dfrac{m^3}{h}\right)$,

$\Delta p_{śr}$ – mean value of pressure depression during the first and second cycle of flow test, (MPa).

The average pressure depression for the first and second cycle of inflow test was calculated using the formula:

$$\Delta p_{śr} = p_z - \frac{(p_{p1} - p_{k2})}{2} \qquad (2)$$

where:

p_z – reservoir pressure determined from the extrapolation of the second bottom pressure buildup curve, (MPa);

p_{p1} – pressure recorded at the beginning point of the first curve of water flow to the probe, (MPa);

p_{k2} – pressure recorded at the end point of the second curve of water flow to the probe, (MPa).

Data for calculations and results of calculations are presented in **Table 1**.

4. Results and discussion

In assessing the productivity of aquifers, important information on the rational technological conditions of water extraction can be obtained **(Dubiel et al., 2003)** on the basis of statistical analysis of the results of DST reservoir tests performed in the selected area. For this purpose, the dependence of the flow rate of the reservoir water inflow to the reservoir sampler on pressure depression exerted on the tested aquifer is examined.

Using methods of statistical analysis, based on a scatterplot of measurement points, for dependence: $q_{wśr} = f(\Delta p_{śr})$ the following three models were selected:

a) Linear model $y = ax + b$,
b) Power model $y = ax^n$,
c) Exponential model $y = e^{nx}$.

where:

x – independent variable, (*MPa*), in linear, power, exponential models,

y – dependent variable, $\left(\dfrac{m^3}{h}\right)$ in linear, power, exponential models,

a – the slope factor, in linear and power models,

b – the factor determines the point of intersection of the function graph with the Y axis, in linear model,

n – function exponent, in power and exponential models.

R^2 – coefficient of determination, [-], **(Kukuła, 2006; Jóźwiak and Podgórski, 2012)**.

Table 2. List of selected statistics parameters for the determined dependency models: $q_{wśr} = f\left(\Delta p_{śr}\right)$

No.	Regression model	No. of measurements	Coefficient of determination R^2	Measurement range for $q_{wśr}$, $\left(\dfrac{m^3}{h}\right)$	Measurement range for $\Delta p_{śr}$ (*MPa*)	Regression equation
1	linear	17	0.4953	0.36 ÷ 21.0	2.47 ÷ 14.5	$y = -0.981x + 13.147$
2	power	17	0.6438	0.36 ÷ 21.0	2.47 ÷ 14.5	$y = 109.2x^{-1.813}$
3	exponential	17	0.6715	0.36 ÷ 21.0	2.47 ÷ 14.5	$y = 21.942e^{-0.244x}$
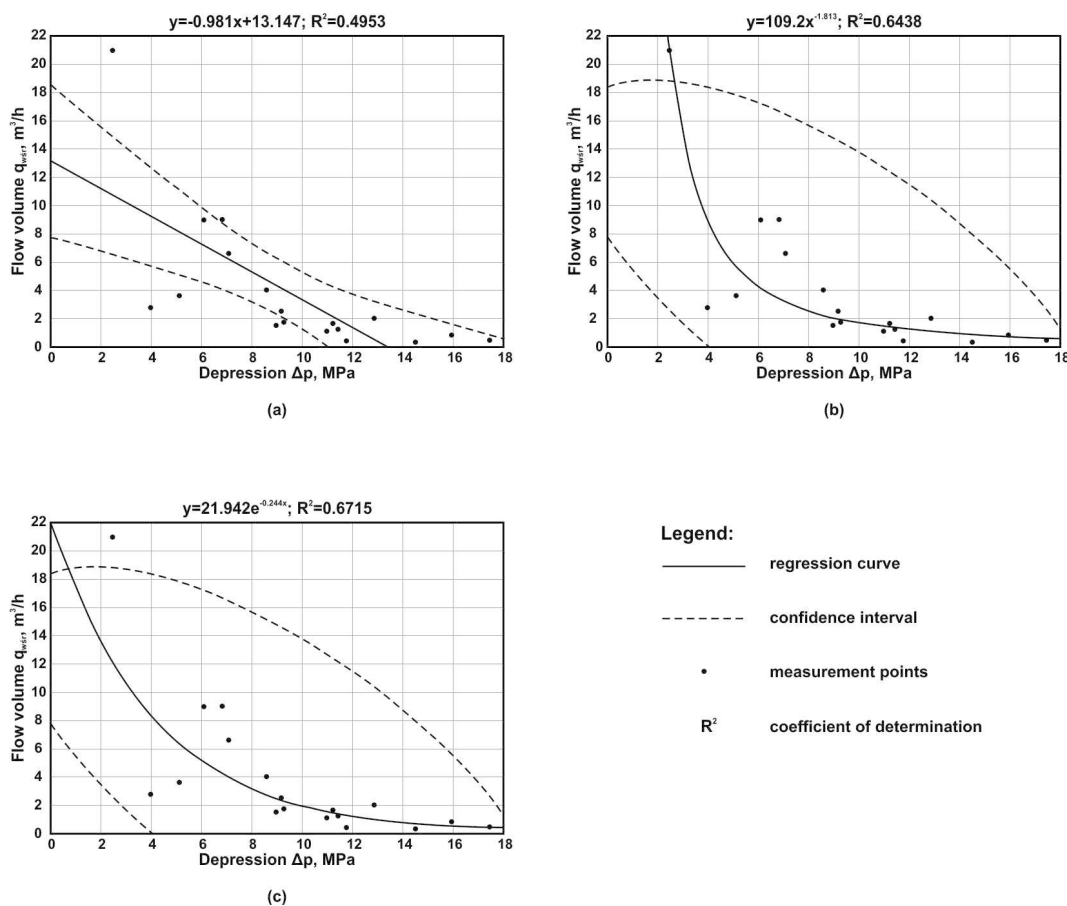
Figure 3. The approximation of the distribution of the measurement points of the dependence $q_{wśr} = f\left(\Delta p_{śr}\right)$ (a) based on the linear model, (b) based on the power model, (c) based on the exponential model.

The determined regression equations and statistical parameters are presented in **Table 2**.

As a result of the analysis, it was found that the worst correlation between variables was obtained for the linear model ($R^2 = 0.4953$) (see **Figure 3a**), then for the power model ($R^2 = 0.6438$) (see **Figure 3b**), and the best for the exponential model ($R^2 = 0.6715$) (see **Figure 3c**). From these graphs, a very significant conclusion can be drawn that in the case of DST testing of carbonate, fractured-reservoir rocks, as the depression of pressure increases, the flow rate of the reservoir water flowing into the wellbore decreases. On the basis of this observation, it can be concluded that in the Mesozoic fractured reservoir rocks, in the studied area of the Carpathian Foredeep, in cases

of extreme pressure depressions, there are changes in the permeability of reservoir rocks in the perimeter zone. The reason for these changes may be the shortening of fractures and microfractures, as well as the movement of mobile solid particles towards the well (salt, rust, polymers, cuttings, clayey particles and others) sticking fractures, microfractures, as well as channels connecting large cavities. Another reason could also be reservoir deliverability or the aquifer volume. As it was concluded, a bigger Δp means less flow through the sampler **(Dubiel et al., 2003; Dubiel and Uliasz-Misiak, 2012)**.

Not all of the determined regression equations are suitable for predicting the expected value of the water volume stream (y) for the designed mean depression (x),

Table 3. List of values of water volume flows predicted using regression equations determined for the three considered models

No.	Regression model	Regression equation	x = 5 (MPa) $y, \left(\dfrac{m^3}{h}\right)$	x = 7.5 (MPa)	x = 10 (MPa)
1	linear	$y = -0.981x + 13.147$	8.217	5.752	3.287
2	power	$y = 109.2x^{-1.813}$	5.902	2.830	1.680
3	exponential	$y = 21.942e^{-0.244x}$	6.478	3.520	1.912

because the coefficients of determination have different values. For example, the predicted values of the reservoir water volume for the given mean pressure depression values (5, 7.5 and 10 MPa), for the three analyzed models, are summarized in **Table 3**. As can be seen in **Table 3**, the predicted values of the water flow rate differ too much between each other. On this basis, the linear model was rejected due to the low value of the determination coefficient and large differences in the predicted values of the volume flow of the reservoir water inflow in comparison with the power and exponential models (see **Table 3**).

Table 3 shows, that in the case of the assumed pressure depression of 5 *MPa*, the linear model inflates the forecast of the water flow volume by about 39% in relation to the power model and about 27% in relation to the exponential model. However, in the case of pressure depression of 10 *MPa*, the deviations of the predicted values of the flow rate of water flow are as much as about 96% and 72%, respectively.

Large errors in forecasting the flow rate of the reservoir water flow to the sampler at a given bottom pressure depression of up to 96% (see **Table 3**) may result from:

– the considerable heterogeneity of the pore-fracture space of the Mesozoic carbonate strata (**Dubiel et al., 2012**),
– the different degree of gasification of the reservoir water with natural gas (no taken into account in the industry when determining the value $(q_{wśr})$ (**Dubiel et al., 1998**),
– too few analyzed measurement data, hardly available in industry.

A good measure of the productivity of the tested aquifer is the unit extraction rate (WW_j). It allows for the assessment of reservoir parameters with regard to the technological parameters used.

Using methods of statistical analysis, based on the scatterplot of measurement points, for the dependence: $WW_{jśr} = f\left(\Delta p_{śr}\right)$, were chosen, as before, the following three models: the linear model (see **Figure 4a**), the power model (see **Figure 4b**) and the exponential model (see **Figure 4c**). The determined regression equations and statistical parameters are summarized in **Table 4.**

Based on the results summarized in **Table 4**, it can be concluded that the linear regression equation is not suitable for predicting the value (y) at the design value (x), due to its too low coefficient of determination. On the other hand, power and exponential models have much higher determination coefficients than a linear model (see **Table 4**), so the regression equations determined for these models are suitable for forecasting.

The predicted values of unit extraction rates, for given average values of pressure depression (5, 7.5 and 10 *MPa*), for the three analyzed models, are presented in **Table 5**.

Analyzing the predicted WW_j values summarized in **Table 5**, it can be concluded that the power and exponential regression equations are suitable for predicting the measured value, wherein the difference between the predicted values decreases with the increase in pressure depression, especially in the range 7.5-10 *MPa* (see **Table 5**). This is an important observation due to the widespread use of pressure depression in the industry, in the above-mentioned range. Correlation dependencies and regression equations (see **Figures 3-4**) were determined using measurement points with confidence intervals with a confidence value of 0.95.

Based on the histogram of the values of unit production rates of WW_j (see **Figure 5**), the following statistical parameters were determined: the average of the distribution series is $0.8544 \dfrac{m^3}{h \cdot MPa}$; the median is $0.189 \dfrac{m^3}{h \cdot MPa}$; the standard deviation is $1.8122 \dfrac{m^3}{h \cdot MPa}$. The high standard deviation value is due to the open character of the WW_j distribution series. The median value of $0.189 \dfrac{m^3}{h \cdot MPa}$ (as the central value of the measurement data set) is usually a good practical measure of the analyzed value. In the analyzed case, this value indicates a low commercial value of the analyzed water-bearing horizons of the Mesozoic strata in the considered area. However, due to occurrence of the Mesozoic carbonate reservoir rocks, it is possible to apply acidizing to increase the extraction of reservoir water (**Falkowicz et al., 2012)**.

Table 4. List of selected statistics parameters, for determined dependency models $WW_j = f\left(\Delta p_{\acute{s}r}\right)$

No.	Regression model	No. of measurements	Coefficient of determination R^2	Measurement range for WW_j $\left(\dfrac{m^3}{h \cdot MPa}\right)$	Measurement range for $\Delta p_{\acute{s}r}$ (MPa)	Regression equation
1	linear	17	0.3871	0.025 ÷ 7.664	2.47 ÷ 14.5	$y = -0.3076x + 3.681$
2	power	17	0.8087	0.025 ÷ 7.664	2.47 ÷ 14.5	$y = 100.81x^{-2.778}$
3	exponential	17	0.8148	0.025 ÷ 7.664	2.47 ÷ 14.5	$y = 8.1244e^{-0.368x}$
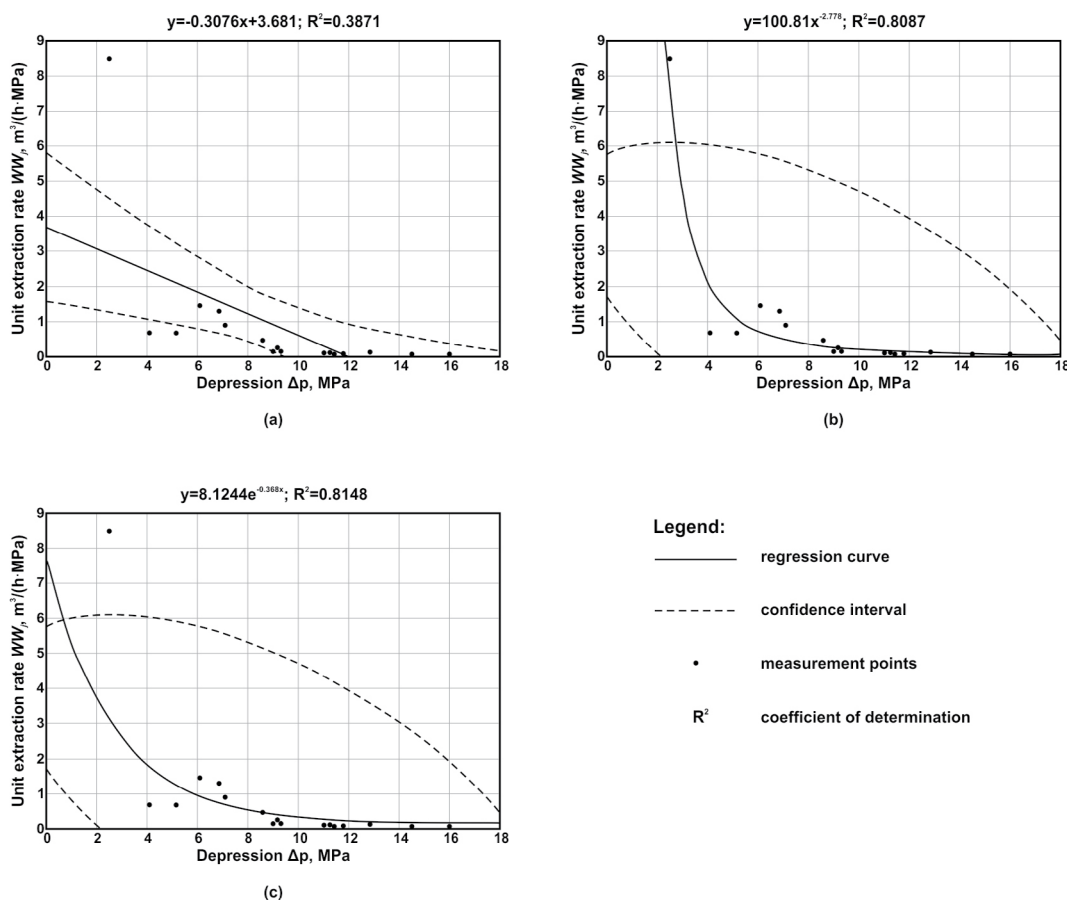
Figure 4. The approximation of the distribution of the measurement points of the dependence $WW_j = f\left(\Delta p_{\acute{s}r}\right)$ (a) based on the linear model, (b) based on the power model, (c) based on the exponential model

Table 5. Comparison of the values of unitary reservoir water production indices predicted using regression equations determined for the three considered models

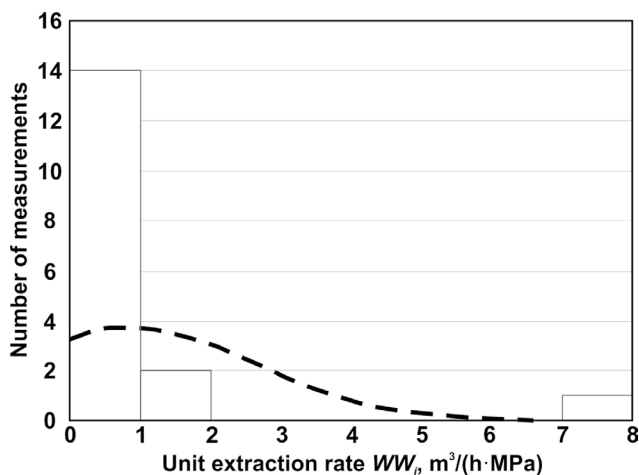| No.	Regression model	Regression equation	x = 5 (MPa)	x = 7.5 (MPa)	x = 10 (MPa)
			$y, \left(\dfrac{m^3}{h}\right)$		
1	linear	$y = -0.3076x + 3.681$	2.143	1.374	0.605
2	power	$y = 100.81x^{-2.778}$	1.153	0.374	0.168
3	exponential	$y = 8.1244e^{-0.368x}$	1.290	0.514	0.205

Figure 5. Histogram of the value
of unit extraction rate WW_j

5. Conclusions

In the case of the DST testing of carbonate, fractured carbonate reservoir rocks of the Mesozoic in the selected region of the Carpathian Foredeep, as the depression of pressure increases, the value of the stream volume of the reservoir water flowing into the well decreases. This observation should be considered when designing DST test technology parameters.

The aim of the statistical analyses was to obtain the highest possible values of the determination coefficient, which proved the best possible adjustment of the regression curve to the measurement points.

Based on a statistical analysis of industrial data from 17 two-cycle DST tests of water-bearing Mesozoic horizons, it was found, inter alia:

> satisfactory correlation of the water flow $q_{wśr}$ as a function of the average pressure depression $\Delta p_{śr}$; however, from the three models studied (linear, power and exponential), the best correlation was obtained for the exponential ($R^2 = 0.6715$) and power ($R^2 = 0.6438$) model, while for the linear ($R^2 = 0.4953$) model, a weak correlation was obtained, therefore it was considered unsuitable for forecasting the water outflow at a given depression (see **Table 2**),

> regression equations determined for exponential and power models are suitable for forecasting the water flow volume for the projected average pressure depression, however with different accuracy; namely: as the depression increases, the difference between the forecasting results decreases.

Differences in the predicted values of streams of reservoir water flow to the sampler at a given bottom pressure depression may result from:

• a small number of analyzed measurement data,
• from high variability of reservoir water flow conditions in a pore-fracture,

• fracture-pore and cavernous Mesozoic carbonate rocks in the studied area of the Carpathian Foredeep, as well as from the different content of natural gas in the reservoir water.

The median value of the WW_j parameter (0.189 $\dfrac{m^3}{h \cdot MPa}$) indicates a low commercial value of the tested aquifers built of Mesozoic carbonate rocks. However, this assessment should consider the fact that the acidizing of these rocks, with suitably selected technology, can significantly increase the rate of extraction of reservoir water, as a result of re-opening rocks of the perimeter zone.

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SAŽETAK

Utjecaj depresije na pritok vode u bušotine u karbonatnim podinama Karpatskoga predgorja na jugoistoku Poljske

U radu je prikazana analiza rezultata testiranja bušotina metodom DST-a (engl. skr. od *Drill Stem Testing*). Istraživanjem su obuhvaćene razine karbonata u stijenama mezozojskih ležišta u Karpatskome predgorju. Na temelju sedamnaest testova ispitivanja ležišta metodom DST-a, provođenih u dvama ciklusima, istražena je ovisnost volumena protoka vode iz mezozojskih karbonatnih ležišta (gornja jura i donja kreda) u bušotine, a kao funkcija prosječne depresije zbog tlaka na dnu bušotine. Kao objekti istraživanja odabrani su oni smješteni upravo u naftnoj zoni Karpatskoga predgorja, na jugoistoku Poljske. Na temelju statističke analize uočena je zadovoljavajuća korelacija između varijabli potencijskoga i eksponencijalnoga modela te slaba korelacija kod linearnoga modela. Smanjenje pritoka ležišne vode iz mezozojskih karbonatnih ležišta, uz povećanje depresije, potencijalno upućuje na pojavu smanjivanja pukotina i mikropukotina uslijed prevelike depresije te na začepljivanje fraktura i šupljina nastalih otapanjem, do čega dolazi zbog krutih čestica poput krhotina, soli, polimera itd.

Ključne riječi:
Karpatsko predgorje; mezozoik; iskušavanje stijena metodom DST-a; statistika; volumni protok vode

Author's contribution

Mirosław Rzyczniak (Ph.D. in Petroleum Engineering) and **Dagmara Zeljaś** (Ph.D. in Environmental Engineering) performed statistical analysis along with the interpretation and discussion. **Marek L. Solecki** (M. Sc. in Petroleum Geology and Ph.D. Candidate) described the geological setting of the research area. **Stanisław J. Dubiel** (Professor Emeritus in Petroleum Engineering) participated in writing the introduction, conclusions and the interpretation of the results.