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ANALYSIS OF TECHNOLOGICAL PARAMETERS OF CEMENT SLURRIES USED FOR SEALING CASING IN THE LUBLIN BASIN AREA****

1. INTRODUCTION

Recently a growing interest in the realization of prospecting and opening wellbores in shale formations has been observed in Poland. This type of wellbores requires sticking to very restrictive technological requirements regarding drilling fluids. The most important are the type of the applied sealing slurry and its parameters. The composition and properties of the slurry depend on the geologic-technical conditions in the well where the cements bonds and hardens. This is connected with the type of the drilled geological formations, ultimate depth, dynamic and static temperature, reservoir pressure and fracturing pressure [10, 12]. Accordingly, for the sake of working out a new recipe for a slurry or modifying the existing one, parameters of the slurries previously applied to wells drilled in the same geological structure should be analyzed in detail. This is extremely important because wrongly performed cementing jobs (especially productive horizons) result in complications and huge difficulties with liquidating exhalations and possible escapes of medium from the spaces between casing and beyond casing. It should be also stressed that the cost of sealing up jobs are very high. Therefore the analysis of the technological parameters of sealing slurries previously applied for sealing casing in the perspective area allows the crew to work out a new recipe of a slurry to be used for sealing the annular space.

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2. REQUIREMENTS SET BEFORE CEMENT SLURRIES TO BE USED FOR SEALING PRODUCTION CASING IN THE LUBLIN BASIN AREA

Fresh cement slurries used for cementing annular space in the Lublin Basin area should meet the following conditions:

- Proper pumpability of cement slurry into annular space in a function of time, with a safety margin (time of beginning of thickening in HPHT conditions should be ca. 180 to 300 minutes, depending on the depth of the well).
- They should bond immediately after being injected into the annulus. However the time between the injection of the liquid cement slurry into the annular space and the moment it solidifies, reaching the ability to tightly fill the space, should be as short as possible.
- The Transition Time should be short, from 50 Pa to 250 Pa, during the measurement of the increasing static structural strength (SWS) [3, 6].
- The sealing slurries also should have proper rheological parameters, thanks to which muds and buffer fluid can be efficiently displaced from the well at minimum flow resistance. This type of slurry should also allow for the largest radius of filling of the sealed medium.
- Slurries should be stable as far as sedimentation goes (zero water settlement), and filtration in HPHT conditions should not exceed 50 cm^3/30 min [4, 5, 8, 11].

Hardened cement slurries, bonded in the wellbore should have the following properties:

- Good insulation between zones (after bonding have high adhesiveness with casing and rock formation).
- Lowest possible permeability and porosity).
- High compressive strength in high temperature and high pressure conditions.
- Insulate casing against aggressive activity of drilling fluids, and crushing under the influence of swelling rock formations.
- No shrinking while hardening.
- High resistance to corrosion [1, 2, 7–9].

The recipes of cement slurries for sealing casing columns in the Lublin Basin area, which would meet above requirements could be worked out on the basis of an analysis of technological parameters of slurries already used in that area.

A list of wellbores where production casing has been recently cemented is given in Table 1. The wellbore conditions were described with such parameters as depth of well, downhole temperature and pressure, as well as diameter of sealed casing. The table also gives information about recipes of sealing slurries used for cementing a given casing column in a given wellbore.

3. LABORATORY EXPERIMENTS

A series of analyses of technological parameters of cement slurries used for sealing of casing columns in the Lublin Basin area were performed in a cooperation with the Laboratory of Sealing Slurries, Oil and Gas Institute – National Research Institute and the Faculty of Drilling Oil and Gas, AGH UST. The experiments were made in compliance with the following standards: API Spec 10 and PN-EN 10426-2 Oil and Gas Industry “Cements and materials for cementing jobs in wellbores – part 2”.

The analyses of cement slurries were conducted with the use of high-class measuring apparatuses owned by the Laboratory of Sealing Slurries, Oil and Gas Institute – National Research Institute (Chandler and Ofite, i.e. mixers, Baroid scales, pressure consistometer, filtration press, Fann viscometer, porosimeter, gaseous permeability meter, ultrasound cement analyzer UCA + SGSM for analyzing mechanical and static strength of cementing gets, compressive strength testing machine and devices testing the adhesiveness of cement stone to steel pipes, and other).

The analysis was performed for technological parameters of 7 groups of slurry compositions presented in Table 1: for one sealing 13 3/8" and 5" casing columns and five slurries for sealing 9 5/8" casing column (for which detailed analyses were performed). The obtained results were presented in Table 2. For the sake of distinguishing between the obtained results, the most advantageous values were marked in green, otherwise – in red. The comparison of positive to negative values has been presented in the lower part of the table to indicate the optimum recipe compositions.

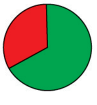
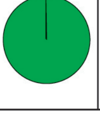
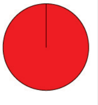
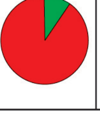
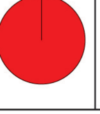
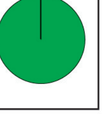
Table 1

Composition of analyzed slurries

WELLBORE		K 1			LK 1	W 1		
Column ["]		13 3/8	9 5/8	9 5/8	9 5/8	9 5/8	9 5/8	5 1/2
Depth [m]		500	2300	2300	2000	1800	1800	3092
Temperature [°C]		30	55	55	60	45	55	90
Pressure [MPa]		7	27	27	25	22	24	38
Denotations: w/c – water/cement ratio, bwow – in relation to working water weight Remaining components are added in relation to the cement weight								
Network water		w/c = 0.49	w/c = 0.60	w/c = 0.50	w/c = 0.50	w/c = 0.75	w/c = 0.52	w/c = 0.44
Bentonite (bwow)		–	1.0%	–	–	1.0%	–	–
KCl (bwow)		–	3.0%	3.0%	–	3.0%	3.0%	–
NaCl		–	–	–	–	–	–	10.0%
Defoaming agent		0.5%	0.5%	0.3%	0.5%	0.5%	0.3%	0.5%
Antifiltration agent		0.2%	0.3%	0.4%	0.8%	0.2%	0.5%	0.2%
Liquefier		0.2%	0.3%	0.4%	0.2%	0.3%	0.3%	0.3%
Liquefier 2		–	–	–	0.5%	–	–	–
Retarder			0.3%	0.2%	–	0.1%	0.2%	0.07%
Latex		10.0%	10.0%	–	–	10.0%	–	10.0%
Latex stabilizer		1.0%	1.0%	–	–	2.0%	–	1.0%
Microcement		20.0%	20.0%	–	–	20.0%	–	20.0%
Microsphere		–	10.0%	–	–	15.0%	–	–
Cement	CEM I 32,5R	100.0%	100.0%	100.0%	–	100.0%	100.0%	–
	CEM G HSR	–	–	–	–	–	–	100.0%
	CEM II B-V 32,5R	–	–	–	100.0%	–	–	–
Swelling agent		0.3%	0.3%	0.3%	–	0.3%	0.3%	0.3%

Table 2

Parameters of analyzed slurries

PARA-METER	COMPO-SITION	K 1			LK 1	W 1		
Denotations of samples for strength calculations		s. 1	s. 2	s. 3	s. 4	s. 5	s. 6	s. 7
Column of pipes ["]		13 3/8	9 5/8	9 5/8	9 5/8	9 5/8	9 5/8	5
Density [kg/m^3]		1800	1600	1820	1810	1460	1820	1900
Spillability [mm]		210	200	200	190	240	220	220
Plastic viscosity [mPa·s]		127.5	72.0	126.0	322.5	57.0	108.0	151.5
Yield point [Pa]		14.6	13.4	17.8	6.0	14.4	6.7	14.2
Filtration [cm^3/30 min]		18.0	66.0	80.0	176.0	50.0	146.0	18.0
Transition time [hrs-min]		1-28	0-52	2-25	1-53	0-53	2-06	1-42
Time of thickening [hrs-min]	30Bc	3-19	5-11	6-26	*7-10 (5Bc)*	4-58	3-36	0-58
	100Bc	5-44	6-02	7-09	–	5-32	4-42	6-35
Permeability (7 days) [mD]		0.091	0.070	0.080	0.098	0.071	0.091	0.064
Compressive strength [MPa]	24 hrs	8.4	12.6	10.4	8.3	12.5	12.6	16.1
	48 hrs	12.3	14.8	12.3	17.8	15.5	15.4	21.3
Adhesiveness to pipes	24 hrs	2.9	2.7	2.8	2.0	3.1	3.0	3.1
	48 hrs	3.6	3.3	3.4	2.4	3.5	3.4	3.5
Porosity		33.15	32.02	34.82	36.3	48.39	38.30	36.69
Per cent of positive to negative values (green to red)								

The rheological parameters determined with the use of Ofite model 900 rotary viscosimeter were analyzed. The dependence between static stress (τi) and shear rate ($\dot{\gamma}$i) was measured. The plastic viscosity and yield point were defined and the obtained results were listed in Table 2.

The slurry filtration values were analyzed with the use of filtration press HPHT, Model 7120 (Chandler), which is used for measuring filtration of cement slurries in dynamic conditions.

Another technological parameter in the analyzed group of slurry recipes was the Static Structural Strength (SSS) and Transition Time (TT) between structural strength value equal to 50 Pa and 250 Pa. The analyses were performed with the use of a Static Gel Strength Measurement device, thanks to which the increasing static structural strength increases while applying gel.

The time of thickening of the analyzed group of sealing slurries was measured with a pressure consistometer OFITE model 130. The changes in the consistency and the time of thickening of the cement slurry could be measured in this way.

All mechanical parameters, i.e. compressive strength, adhesiveness to steel pipes and porosity were analyzed in the hardened cement slurries. Strength tests were performed with a stiff testing machine Chandler model 4207, i.e. static bending tests, compressive tests and adhesiveness of cement stone to different surfaces. The experiments determining the microstructure of hardened sealing slurries were performed with the use of a mercury porosimeter MicroMetrics.

Statistical calculations (Tabs 3 and 4) performed the basis of measurement results were aimed at determining average values of compressive strength and adhesiveness to steel pipes of particular samples and confidence interval (for the assumed confidence interval: $1 - \alpha = 0.95$). The compressive strength of hardened slurry and adhesiveness to steel pipes for three samples were juxtaposed for the analyzed recipes of sealing slurries (in compliance with PN-EN ISO 10426). On this basis the arithmetic mean of analyzed parameters was calculated in MPa. The successive columns of Tables 3 and 4 contain the following calculations:

Standard deviation:

$$\sigma(x) = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n}} \tag{1}$$

Confidence level (*):

$$p_u = t_\alpha \cdot \frac{\sigma(x)}{\sqrt{n-1}} \tag{2}$$

Confidence interval (*):

$$p\left\{\overline{x} - t_\alpha \cdot \frac{\sigma(x)}{\sqrt{n-1}} < x < \overline{x} + t_\alpha \cdot \frac{\sigma(x)}{\sqrt{n-1}}\right\} = 1 - \alpha \tag{3}$$

*) assumed confidence interval $1 - \alpha = 0.95$.

where:

- n – number of samples,
- x_i – results from samples,
- $\overline{x}$ – arithmetic mean from samples,
- t_α – t Student variable from the table of distribution for $n - 1$ degree of freedom,
- p – probability that compressive strength of cement stone equals to $1 - \alpha$ in an interval described with equation (3).

Table 3

Statistical analysis of obtained results of compressive strength tests of hardened cement slurries placed in wellbore-like conditions for 24 hrs and 48 hrs

Sample of hardened cement slurry		Results of compressive strength tests (Ws) for three samples of hardened cement slurry [MPa]			Arithmetic mean Ws [MPa]	Standard deviation	Confidence level (for 1 – α = 0.95)	Confidence level (for 1 – α = 0.95)
Composition No.	Hydration time [h]	Sample						
		1	2	3				
1	24	8.4	8.5	8.3	8.40	0.0816	0.2484	8.1516–8.6484
	48	12.0	12.9	12.0	12.30	0.4243	1.2909	11.0091–13.5909
2	24	12.0	13.0	12.8	12.60	0.4320	1.3146	11.2854–13.9146
	48	14.0	15.0	15.4	14.80	0.5888	1.7915	13.0085–16.5915
3	24	8.0	11.0	12.2	10.40	1.7664	5.3744	5.0256–15.7744
	48	11.0	13.0	12.9	12.30	0.9201	2.7997	9.5003–15.0997
4	24	8.0	8.0	8.9	8.30	0.4243	1.2909	7.0091–9.5909
	48	16.0	19.0	18.4	17.80	1.2961	3.9437	13.8563–21.7437
5	24	12.0	12.0	13.5	12.50	0.7071	2.1515	10.3485–14.6515
	48	13.0	16.0	17.5	15.50	1.8708	5.6923	9.8077–21.1923
6	24	11.0	12.0	11.8	11.60	0.4320	1.3146	10.2854–12.9146
	48	15.0	15.0	16.2	15.40	0.5657	1.7212	13.6788–17.1212
7	24	16.0	16.0	16.3	16.10	0.1414	0.4303	15.6697–16.5303
	48	20.0	21.0	22.9	21.30	1.2028	3.6596	17.6404–24.9596

Table 4

Statistical analysis of obtained results of adhesiveness tests of hardened cement slurries to steel pipes placed in wellbore-like conditions for 24 hrs and 48 hrs

Sample of hardened cement slurry		Results of adhesiveness tests (Pr) for three samples of hardened cement slurry [MPa]			Arithmetic mean Pr [MPa]	Standard deviation	Confidence level (for 1 – α = 0.95)	Confidence level (for 1 – α = 0.95)
Composition No.	Hydration time [h]	Sample						
		1	2	3				
1	24	2.6	2.5	3.6	2.90	0.4967	1.5111	1.3889–4.4111
	48	3.0	3.8	4.0	3.60	0.4320	1.3146	2.2854–4.9146
2	24	2.5	2.5	3.1	2.70	0.2828	0.8606	1.8394–3.5606
	48	3.0	3.0	3.9	3.30	0.4243	1.2909	2.0091–4.5909
3	24	2.3	2.5	3.6	2.80	0.5715	1.7390	1.0610–4.5390
	48	2.8	3.6	3.8	3.40	0.4320	1.3146	2.0854–4.7146

Table 4 cont.

4	24	1.9	2.0	2.1	2.00	0.0816	0.2484	1.7516–2.2484
	48	2.2	2.3	2.7	2.40	0.2160	0.6573	1.7427–3.0573
5	24	3.0	3.0	3.3	3.10	0.1414	0.4303	2.6697–3.5303
	48	3.2	3.4	3.9	3.50	0.2944	0.8957	2.6043–4.3957
6	24	2.8	2.9	3.3	3.00	0.2160	0.6573	2.3427–3.6573
	48	3.1	3.3	3.8	3.40	0.2944	0.8957	2.5043–4.2957
7	24	3.0	3.1	3.2	3.10	0.0816	0.2484	2.8516–3.3484
	48	3.0	3.5	4.0	3.50	0.4082	1.2422	2.2578–4.7422

4. ANALYSIS OF WELLBORE CONDITIONS

The analysis of recipes of slurries used for sealing selected wellbores in the Lublin Basin (Tab. 1 and Fig. 1) revealed that in the case of casing 9 5/8" the slurries were designed for sealing columns placed at a depth of 1800 meters (W1 well) to 2300 meters (K1 well). The temperature and pressure in these wells ranged between 45°C to 55°C and 22 MPa to 27 MPa, respectively. The casing 13 3/8" in K1 well was placed at a depth of 500 meters, where the downhole temperature equaled to 30°C, and pressure to 7 MPa. The 5" column in W1 well was placed at 3092 meters, where the temperature was 90°C and pressure 38 MPa. The depth, temperature and pressure have been presented in Figure 1.

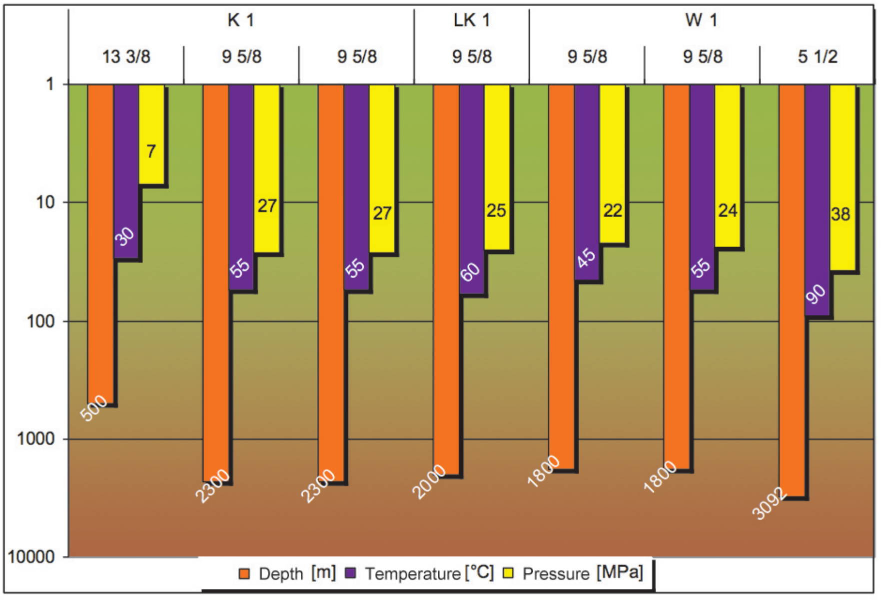


Fig. 1. Comparison of wellbore conditions of analyzed wellbores

5. ANALYSIS OF SLURRY RECIPES

While two sealing 9 5/8" casing, upper – light[1] and lower – regular density sealing slurries were used in K1 and W1 wells. The regular[2] density slurry was applied in LK1 well. Microsphere was added to light slurries to lower their density. Accordingly, these slurries contained bentonite responsible for the formation of a suspension, which counteracted delamination of fractions of different weight. Slurries which were planned to be used for sealing K1 and W1 wells contained 3% of KCl. Moreover the parameters of these recipes were modified with defoamers, antifiltration agent, liquefier and bonding retarder. Light slurries used for sealing K1 and W1 well, which had a microsphere addition (10% and 15%, respectively) also contained 20% microcement, which was used for sealing up the intergrain spaces. Unlike other recipes used for sealing 9 5/8" casing, these ones contained 10% of latex. All slurries to be used for sealing 9 5/8" casing were based on Portland cement CEM I 32,5R, except for the slurry used for sealing 9 5/8" casing in LK1 well, where Portland ash cement CEM II B-V 32,5 was used. All slurries planned to be used for sealing 9 5/8" casing (except for LK1 well) contained a swelling agent to eliminate the shrinking of slurry during the hydration process.

The slurry used for sealing 13 3/8" casing in K1 well has a similar composition, except that it did not contain bonding retarder due to the small depth of deposition of casing and the resulting short time of the cementing job. Additional this slurry contained latex and microcement.

Slurry used for sealing 5" casing in W1 well was based on 10%-NaCl working water. 20% of microcement and 10% of latex were added to seal up the microstructure of the hardened sealing slurry. Drilling cement G HSR was used as a binder. The analyzed slurry recipes have been listed in Table 1.

6. ANALYSIS OF PARAMETERS OF FRESH SLURRIES

The density of slurries used for sealing casing in the Lublin Basin area ranged from 1460 kg/m^3 to 1900 kg/m^3 (Tab. 2, Fig. 2). The slurry of density 1460 kg/m^3 used for sealing 9 5/8" casing in W1 well, and slurry of density 1600 kg/m^3 for 9 5/8” casing in L1 well are lower-density upper slurries.

The spillability of compared slurries equals to 190 mm for a slurry used in LK1 well to 240 mm in the upper slurry for sealing 9 5/8" casing in W1 well (Tab. 2, Fig. 2). The values of the remaining rheological parameters, plastic viscosity of slurries ranged from 57 mPa·s (upper slurry in W1 well) to 322 mPa·s (regular-density slurry used for sealing LK1 well). The yield point values equaled from 6 Pa (W1 well) to 17.8 Pa (K1 well). The list of parameters has been presented in Figure 2, and values in Table. 2. The analysis of above rheological parameters reveals that the most advantageous values were

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[1] Light slurry of density to 1800 kg/m^3
[2] Regular density slurry of ca. 1800 kg/m^3

observed for upper slurry used for sealing 9 5/8" casing in W1 well (spillability 240 mm, plastic viscosity 57 mPa·s). The least favorable values were noted for slurry used for sealing 9 5/8" casing in LK1 well (spillability 190 mm, plastic viscosity 322 mPa·s), despite the lowest yield point value, which was equal to 6 Pa.

The lowest filtration values in the Lublin Basin well were applied in slurries injected to W1 and K1 wells (obtained filtration equaled to 18 cm^3/30 min). The highest values were observed in slurries used for sealing LK1 well (filtration of 176 cm^3/30 min) and lower slurry in W1 well (filtration of 146 cm^3/30 min). The described parameters have been listed in Table 2 and Figure 2.

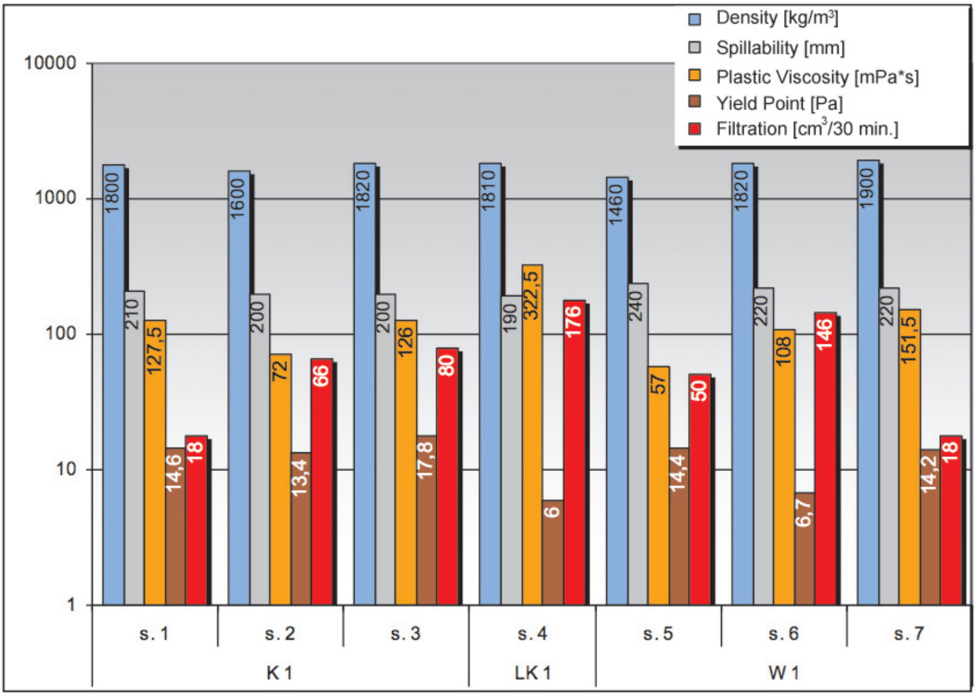

Fig. 2. Comparison of parameters of fresh slurries used in the analyzed group of wellbores

When analyzing the increasing static structural strength of cement slurry and its transition time from 50 Pa to 250 Pa informing about the possibility of stopping potential migration of gas, the lowest value was observed in upper slurries used for sealing 9 5/8" casing. In K1 well time TT equaled to 52 minutes (the course of SSS increase has been plotted in Figure 4). The time TT of slurry used for sealing W1 well equaled to 53 minutes (The SSS increase has been plotted in Figure 5). These slurries have very good parameters stopping gas migration (Table 2, and marked spots in Figure 3). The longest time was observed for the upper slurry used for sealing of 9 5/8" casing in K1 well (time TT = 2 hrs 25 minutes).

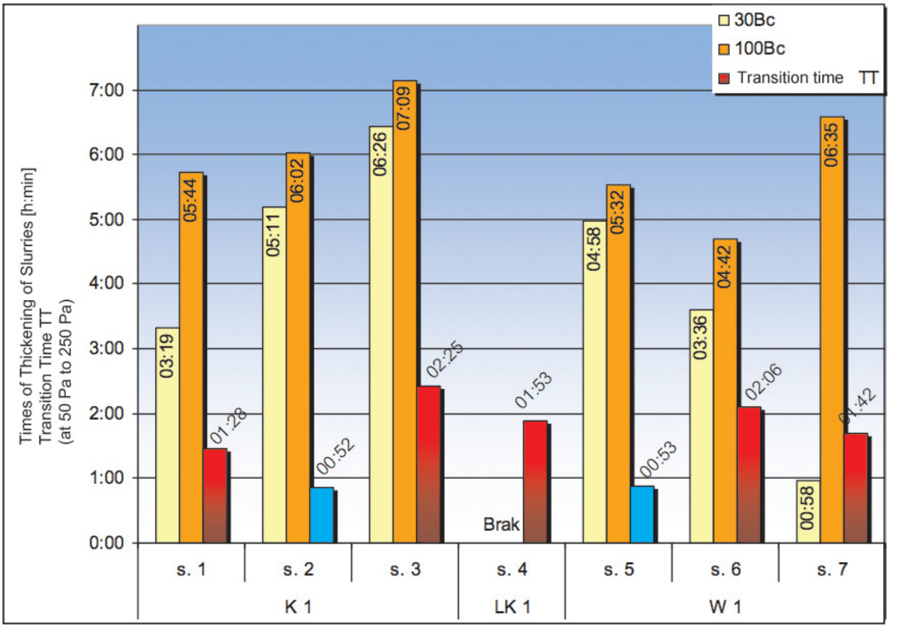

Fig. 3. Comparison of times of thickening and transition time of slurries used in the analyzed group of wellbores

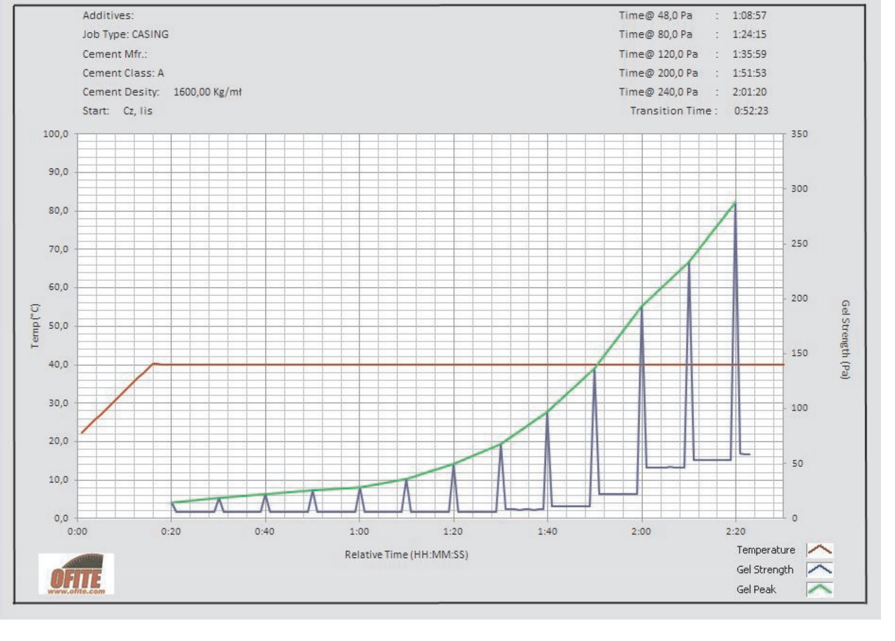

Fig. 4. Static structural strength in a function of transition time for slurry used in K1 well and casing 9 5/8"

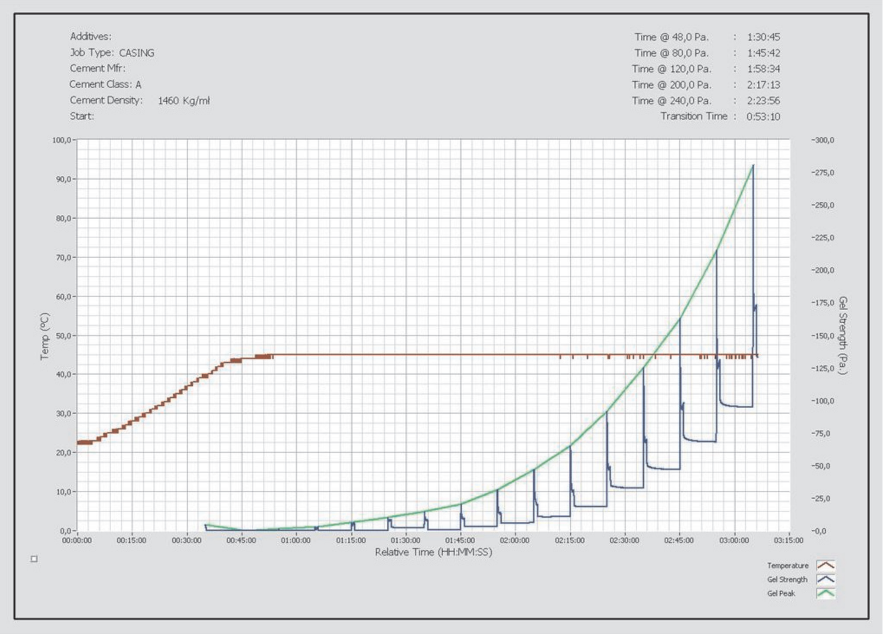

Fig. 5. Static structural strength in a function of transition time used in W1 well casing 9 5/8"

When comparing the time of thickening of the selected group of slurries, the most advantageous values were observed for the upper slurry used for sealing 9 5/8" casing in W1 well, whereas the least favorable parameters were noted for the slurry used in LK1 well (slurry failed to thicken during the test). The graphical representation of the obtained results has been visualized in Figure 3.

7. ANALYSIS OF PARAMETERS OF HARDENED SLURRIES

The analyses of hardened sealing slurries focused mainly on mechanical parameters and porosity, describing the microstructure of hardened cement slurry. When comparing the compressive strength values, the highest values were observed in a sample of slurry used for sealing 5 1/2" casing in W1 well. The average compressive strength value equaled to 16.1 MPa after 24 hrs of hydration 21.3 MPa after 48 hrs of hydration. The obtained value may stem from the fact the sample was placed at highest temperature and hydration pressure. The cement type is also very important. The lowest values of compressive strength were observed in a sample of slurry to be used for sealing LK1 well and a sample of slurry for K1 well. The results have been listed in Tables 2 and 3 and in Figure 6. The analysis of results of adhesiveness tests the highest values were also noted for the slurry used in W1 well (5 1/2" casing column). The results have been presented in Tables 2 and 4 and in Figure 6.

When comparing the porosity of hardened sealing slurries used for sealing the annular space in the Lublin Basin area, the obtained values ranged from the minimum of 32.02% for the upper slurry used for sealing 9 5/8" casing in K1 well to the maximum of 48.39% also for the upper slurry used for sealing 9 5/8" casing in W1 well. The results have been listed in Table 2 and in Figure 6. Such differences between these two samples of light slurries can be attributed to the amount of microsphere, water/cement ratio and hydration pressure.

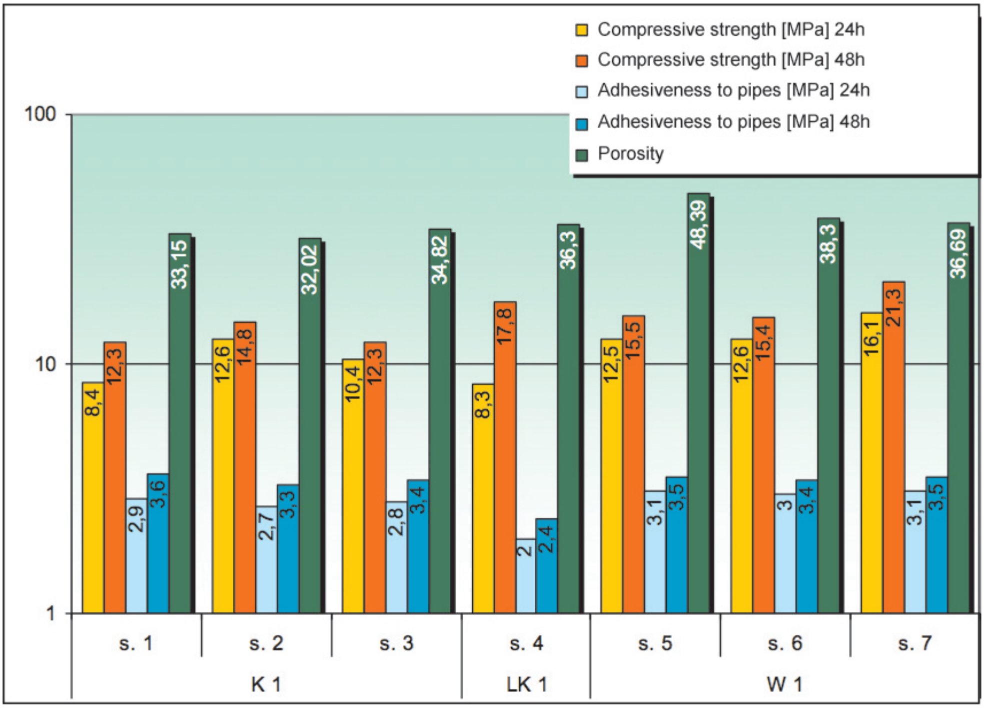

Fig. 6. Comparison of parameters of hardened cement slurries in the analyzed group of wellbores

The analysis of technological parameters of cement slurries shows to a considerable differentiation of particular technological parameters in the geological area despite comparable conditions in the wellbores (slurries used 9 5/8" casing). The technological parameters of sealing slurries previously used in that area have been analyzed for the sake of designing new cement slurries to be used in the Lublin Basin area. In this way the slurries having poorest technological parameters could be spotted and remedies applied, or new recipes worked out to obtain high efficiency of sealing of the annulus.

8. CONCLUSIONS

The following conclusions have been drawn from the analysis of parameters of fresh and hardened slurries used in the Lublin Basin area:

1. Analyzed cement slurries used for sealing annular space in selected wellbores of the Lublin Basin area show considerable differences in their technological parameters which decide about the efficiency of sealing.
2. The analysis of the % ratio of best to poorest parameters of cement slurries (last column in Table 2), the poorest parameters were observed for slurries used for 5/8" casing in LK1 well and the upper slurry for sealing 9 5/8" casing in K1 well. The best parameters were noted for a slurry used for sealing 5" casing in W1 well and lower slurry for sealing 9 5/8" casing in K1 well.
3. The complex analysis of the obtained results reveals that the most favorable conditions were noted for a slurry based on drilling cement G HSR (for sealing of 5" casing in W1 well) and upper slurry based on Portland cement CEM I 32,5R used for sealing 9 5/8" casing in K1 well. The poorest parameters were obtained when using ash cement CEM II B-V 32,5R (sealing of 9 5/8" casing in LK1 well).
4. After introducing suitable modifications, sealing slurries applied for 13 3/8" casing in K1 well and 9 5/8" casing (upper slurry) in W1 well can be also used.
5. The analysis of the obtained results allows for further works aimed at modifying already known recipes of sealing slurries and working out new ones to be used for wellbores drilled in the Lublin Basin area.
6. The modification of the existing recipes of sealing slurries and working out of new ones will contribute to obtaining better technological parameters of fresh and hardened sealing slurries and higher efficiency of sealing casing in wellbores drilled in shale gas formations in the Lublin Basin area.

REFERENCES

[1] Bensted J.: *Cementy wiertnicze* [Oilwell Cements]. Cement Wapno Beton, No. 6/2002.

[2] Bensted J., Smith J.: *Cementy wiertnicze z historycznej perspektywy* [Oilwell Cements. Part 6. A Historic Perspective]. Cement Wapno Beton, No. 3, 2008.

[3] Dębińska E.: *Wyznaczanie statycznej wytrzymałości strukturalnej i wczesnej wytrzymałości mechanicznej zaczynów cementowych.* Nafta-Gaz, No. 2, s. 2013, pp. 134–142.

[4] Gawlik P., Szymczak M.: *Migracje gazowe w przestrzeniach międzyrurowych otworów realizowanych na Przedgórzu Karpat*. Nafta-Gaz, No. 7–8, 2006.

[5] Kremieniewski M., Rzepka M.: *Badania zaczynów cementowych przeznaczonych do uszczelniania otworów wiertniczych*. Wiadomości Naftowe i Gazownicze, No. 4, 2012, pp. 9–13.

[6] Kremieniewski M., Rzepka M., Dębińska E.: *Statyczna wytrzymałość strukturalna zaczynów przeznaczonych do uszczelniania otworów o podwyższonym ryzyku występowania migracji gazu*. Nafta-Gaz, No. 9, 2014, pp. 608–616.

[7] Nelson E.B.: *Cementowanie otworów wiertniczych.* Schlumberger Educational Service, Houston, Texas USA, 1990.

[8] Rzepka M., Kremieniewski M., Dębińska E.: *Zaczyny cementowe przeznaczone do uszczelniania eksploatacyjnych kolumn rur okładzinowych na Niżu Polskim*. Nafta-Gaz, No. 8, 2012, pp. 512–522.

[9] Stryczek S., Gonet A.: *Wymagania odnośnie zaczynów uszczelniających stosowanych w technologiach wiertniczych*. Sympozjum Naukowo-Techniczne, „Cementy w budownictwie, robotach wiertniczych i inżynieryjnych oraz hydrotechnice", Piła-Płotki 2001.

[10] Stryczek S., Małolepszy J., Gonet A., Wiśniowski R., Kotwica Ł.: *Wpływ dodatków mineralnych na kształtowanie się właściwości technologicznych zaczynów uszczelniających stosowanych w wiertnictwie i geoinżynierii.* Wydawnictwo S.C.M.R., Kraków 2011.

[11] Stryczek S., Wiśniowski R., Gonet A., Złotkowski A.: *The influence of time of rheological parameters of fresh cement slurries*. AGH Drilling, Oil, Gas, vol. 31, 2014, pp. 123–133.

[12] Stryczek S., Wiśniowski R., Kotwica Ł., Złotkowski A., Rzepka M., Kremieniewski M., Skrzypaszek K.: *Analysis of technological parameters of cementing slurries for horizontal casing works in Pomeranian Basin*. AGH Drilling, Oil, Gas, vol. 32, 2015, pp. 431–442.