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RECIPES OF CEMENT SLURRIES FOR SEALING CASING IN DEEP WELLBORES***

1. INTRODUCTION

The requirements relating to the efficiency of sealing annular space in wellbores have increased over years. They are mainly connected with the columns of production pipes in wellbores drilled on oil and gas deposits [1, 2]. This stems from high costs of additional sealing and big problems with the removal of exhalations and outflows of formation medium from the annular space or beyond them. This is a result of badly performed cementing jobs, especially in the zone of productive horizons. For this reason it is extremely important to correctly cement the annulus as this should provide a long life of the borehole and allow for a higher production over a number of years.

In a majority of wellbores drilled in the Polish Lowland the main problems encountered during drilling and cementing jobs are related with geologic conditions in the Zechstein strata [3, 4]. Among the most important problems observed at a depth exceeding 3 meters are:

– Anomalously high gradients of reservoir pressure and fracturing pressure (e.g. in the Dolomite the gradient of reservoir pressure equals to about 0.017–0.022 MPa/m, and gradient of fracturing pressure is about 0.020–0.024 MPa/m). These gradients necessitate applying considerable specific weights of fluids (mud, buffering fluid, cement slurry).
– High temperatures at the bottom of the wellbore of about 100–120°C.
– Active red or grey saline clays, necessitating application of saline mud and cement slurry.

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– Possible flux of brines (reservoir waters) of abnormally high pressure.
– High hydrogen sulfide concentration in reservoir fluids (H_2S content may reach even 15% of gas volume).
– High magnesium and potassium salts content in drilling fluids – highly corrosive.

Additional problems are related to the formation of unwanted curvatures in the wellbore, cavities or indentions or miscentered position of the column of pipes during drilling, mainly at the end section of the wellbore.

All these geologic-technical difficulties impose special requirements on the designer and performer of the cementing job as far as the equipment and detailed qualitative control of the cement slurry during the job and after hardening are concerned.

Production horizons in deep wellbores are mainly opened when drilling for 7" casing. Cementing with overlap is frequently performed (the overlap is about 200 to 300 m long) in the 9 5/8" casing located in the top of the Zechstein at a depth of about 2600–2700 meters. In certain situations 7" liners are tripped and cemented, and suspended on a column of casing 9 5/8" with a hanger [4].

Selected deep wellbores, where the 7" production casing has been recently cemented, are presented in Table 1 [11].

Table 1
Selected wellbores in the Polish Lowland, where 7" casing was cemented in the years 2013–2015

Symbol of the well (month and year of cementing 7" pipes)	Depth of tripping 7" production casing [m]	Density of cement slurry [kg/m^3]	Variable temperature at the bottom of borehole [°C]	Pressure at which cement slurry was analyzed [MPa]
L-2K (XI-2013)	3690	2420	120	84
D-31K (III-2014)	3285	2100	90	67
SG-11K (XII-2014)	3525	2160	110	76
L-13K (XII-2014)	3455	2100	110	76
L-11H (V-2015)	3620	2150	110	76
B-22K (VIII-2015)	3310	2160	120	70

2. COMPOSITION OF SEALING SLURRIES FOR CEMENTING CASING IN DEEP WELLBORES

Apart from technical aspects, the properties of the cement slurry play a crucial role in the process of correct sealing. Both the composition and properties of the sealing slurry are so selected as to match the geologic-technical conditions in the wellbore, where the slurry undergoes binding and hardening processes, and also type of drilled rocks, final depth of the wellbore, variable and average temperature, reservoir pressure and fracturing pressure.

Cement slurries used in such extreme conditions should have the following properties:

- Maintain yield point so that flow fate is appropriate and cement slurry can be injected into the annular space. The time should be extended by a safety margin (time of the beginning of thickening at a high temperature and high pressure should be about 180 to 300 min, depending on the wellbore depth).
- The time of bonding is relatively fast after the slurry has been injected into the annulus.
- The strength increases quickly after injecting cement slurry to the annular space, and so the hardening processes are fast.
- Exhibit rheological properties thanks to which mud and buffering fluid can be displaced from the wellbore in the lowest possible flow friction conditions and the largest radius of the sealed medium.
- Allow for density regulation (2000–2350 kg/m^3) thanks to the added weighing media.
- Preserve stable settlement properties (zero water settlement) and filtration at high temperature and high pressure at a level of less than 50 cm^3/30 min.

Moreover the hardened cement slurry in the wellbore should have the following properties [1, 2, 5, 8]:

- Provide good insulation between zones (after hardening should have a high adhesiveness index on hardened cement slurry/casing and hardened cement slurry/rock interfaces. Additionally the cement sheath should have a zero or minimum permeability and lowest possible porosity.
- High compressive strength at increased temperature and pressure conditions.
- Protect casing against aggressive drilling fluids or compression by swelling rock formations.
- No shrinking while hardening.
- Resistant to chemical corrosion (especially sulphate and magnesium), high temperature and pressure.

In view of these requirements, a special type of cement and modifying additives are selected. The columns of production pipes in deep wellbores are commonly cemented with G type HSR drilling cement of increased resistance to sulphates. The composition of G type HSR cement, in line with standard [9, 10] is presented in Table 2.

G type drilling cement (analyzed in line with API Spec. 10 and PN-EN ISO 10426-1 for water/cement ratio w/c = 0.44 should meet the following physical and production requirements, as in Table 3.

Table 2

Required composition of G type drilling cement

G type DRILLING CEMENT Highly resistant to sulphates (HSR)	
Magnesium oxide (MgO), at most, [%]	6.0
Sulfur trioxide (SO_3), at most, [%]	3.0
Baking loss, at most, [%]	3.0
Undissolved residue, at most, [%]	0.75
Tricalcium silicate (C_3S) at most, [%]	65
at least, [%]	48
Tricalcium aluminate (C_3A), at most, [%]	3
Calcium aluminuferrite (C_4AF) plus twice tricalcium aluminate (C_3A), at most, [%]	24
Total content of alkalies expressed as sodium monoxide (Na_2O) equivalent, at most, [%]	0.75

Table 3

Conditions to be met by G type cement

No.	Analyzed parameter	Required value
1.	Specific weight established on Baroid scales	About 1900 kg/m^3
2.	Free water (water settlement) defined in a volumetric flask	After 2 hours max. 5.9%
3.	Time of thickening defined in pressure consistometer (temperature 52°C, pressure 36.5 MPa)	The highest admissible consistency after 15 to 30 min equals to 30 Bc. Consistency 100 Bc should be reached after 90 to 120 min.
4.	Compressive strength defined while compressing cubes 2 × 2 × 2 inch	After 8 hours of hardening: At temperature = 38°C minimum 2.1 MPa At temperature = 60°C minimum 10.3 MPa

For deep wellbore applications, sealing slurries should contain a number of components. Apart from using proper drilling cement, the slurry to be used for sealing production pipes should be based on 10% of brine NaCl (bwow – in relation to mass of working water). This is related with the presence saline formations in the wellbore profile. High depth at which the production pipes are driven into the wellbore (usually down to

3000–3500 meters), high temperature and pressure at the bottom of the wellbore cause that a number of modifying agents have to be added to the sealing slurries [4–7, 12].

These are, e.g.:

- Defoaming agents (reducing quantity of air in the slurry).
- Liquefiers, i.e. agents which lower viscosity of the slurry (regulate rheological-structural parameters).
- Agents lowering filtration and water settling (protecting slurry against the loss of water).
- Agents elongating the time of initial thickening (retarding the bonding process).

Apart from these additives, also latex is added to the slurry (prevents gas exhalation), microsilica (silica powder) which increases thermal resistance of hardened slurry at high temperature and weighing material (providing appropriate density of the cement slurry). The tightness of the rock matrix is improved by introducing microcement (fine ground Portland cement), Figure 1.

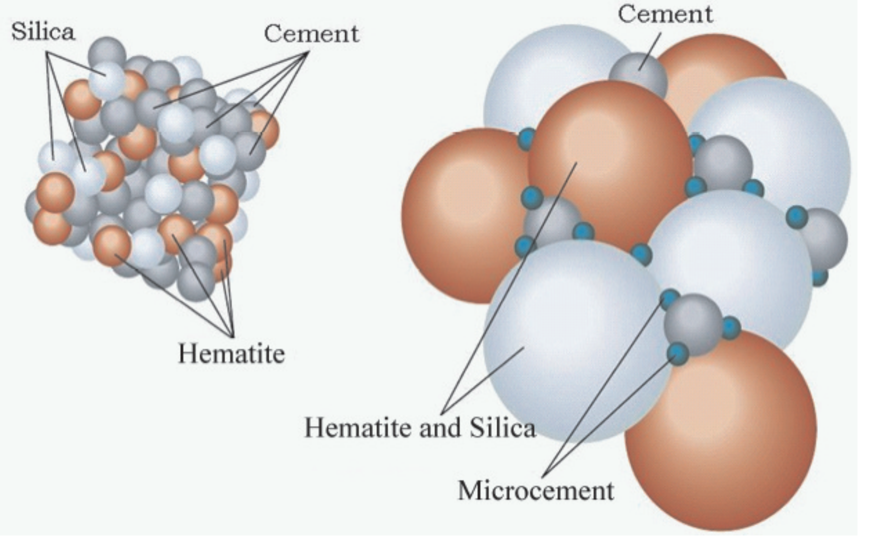

Fig. 1. Schematic of location of particular components in weighted cement slurry [12]

Latex blocks the formation of gaseous canals during bonding by connecting microckacks in the hardening cement slurry. Latex, which is a water dispersion of butadiene-styrene-amide copolymer with modifiers, is used as a suspension of very fine polymeric spherical particles. This reduces the permeability and shrinkage, and increases elasticity of the hardened cement slurry. In cement systems modified with latex its particles form a plastic diaphragm surrounding CSH phase. Besides latex-modified slurries have low filtration, very good rheological parameters, low porosity and low permeability for gas.

Silica powder (silica, microsilica) of ca. 15 μm improves the resistance of hardened cement slurry to high temperatures (added to cement slurries at a temperature of 90°C and higher). Ground hematite is used for increasing density of cement slurries. The weighing material used in the tests had the following physicochemical parameters:

- Chemical composition: Fe_2O_3 – 93.1%, SiO_2 – 2.3%, FeO – 1.4%, Al_2O_3 – 0.9%, CaO – 0.6%, other – trace.
- Physical properties: average density 4980 kg/m^3, bulk density 2800 kg/m^3, granulation under 0.075 mm.

The porosity of hardened cement slurry can be lowered (minimum permeability of the cement matrix) can be obtained by using fine material, which packs into the spaces between hydrating klinker grains and fills the voids between grains. This can be microcement, i.e. milled cement (specific surface of microcement is about 1200 m^2/kg, fractions of < 2 μm ca. 8%, 2–16 μm ca. 82%, >16 μm ca. 10%).

3. LABORATORY EXPERIMENTS

Sealing Slurry Laboratory (Oil and Gas Institute) in cooperation with EXALO Cement Services – the main performer of cementing jobs – worked out a number of recipes of weighing cement-latex slurries of regulated density for deep wellbores. The units performed experiments and exchanged experiences, as a consequence of which suitable types and quantities of liquefiers, retarders and filtration-regulators could be selected. The tests were performed in line with standard PN-EN ISO 10426-2 "Oil and gas industry – Cements and materials for cementing boreholes – part 2: Analysis of cement slurries".

In the years 2000–2014 the OGI and Cement Services in Wołomin (now EXALO) tested various types of modifiers, e.g. a group of most advantageous additives to be used in cement slurries at great depths. On this basis OGI prepared a number of recipes for temperatures 90 to 120°C and pressures 60–70 MPa [6, 7]. The slurries were based on water with sodium chloride 10% bwow (in relation to the mass of working water). The defoamer, liquefier, antifiltration agent and binding retarder were added to the working water. Imported latex, resistant to a temperature of 121°C, was admixed in 18–25% bwoc (in relation to the mass of dry cement). Microsilica and hematite were mixed with G type drilling cement (with microcement in some experiments). Thus prepared mixture of dry components was added to the prepared working water.

The prepared liquid cement slurry was analyzed for its rhelogical parameters (plastic viscosity, yield point), and also density and spillability. The cement slurries were regulated with the use of special liquefiers. Water settlement was determined in a measuring cup set an angle of 90°. The filtration and thickening time of the slurry at high temperatures and high reservoir pressure were also determined. The observed consistency equaled to 30 Bc (beginning of thickening) and 100 Bc (end of thickening).

While working out recipes of slurries attention was paid to the requirements to be met by the cement-latex slurry of increased density to provide efficient cementing and sealing of production casing in deep wellbores. Importantly the slurry should not be too viscous, its seettlement should be zero, filtration lower than 50 cm^3/30 min and thickening time fitting the wellbore conditions, with short transition time between consistency 30 Bc and 100 Bc. The beginning of thickening was so selected that it exceeded the planned time of the cementing job by the safety margin of at least 30–60 minutes.

A list of recipes can be found in Table 4, whereas the results of analyses of cement slurries for various conditions while cementing casing in deep wellbores are given in Table 5.

Table 4

Composition of cement slurries for temperatures 90 to 120°C and pressures 60 to 70 MPa

Composition of slurry	Temperature Pressure	w/c	Defoamer [%]	Liquefier [%]*	Antifiltration agent [%]	Retarder [%] **	Foreign latex [%]	NaCl bwow [%]***	Silica powder [%]	Hematite [%]	Microcement [%]	G type cement [%]
No. 1	**90°C 60 MPa**	0.34	0.5	0.5^A	0.15	0.3^C	20.0	10	10	30	–	100
No. 2		0.36	0.5	0.5^A	0.15	0.3^C	20.0	10	10	40	10	100
No. 3		0.37	0.5	0.5^A	0.15	0.3^C	20.0	10	10	50	–	100
No. 4	**95°C 60 MPa**	0.35	0.4	1.0^B	–	0.4^C	18.0	10	20	40	–	100
No. 5		0.38	0.5	0.3^B	0.3	0.5^C	20.0	10	20	30	10	100
No. 6	**110°C 70 MPa**	0.40	0.5	0.5^A	0.3	0.2^D	20.0	10	35	60	–	100
No. 7		0.34	0.5	0.4^A	0.1	0.4^D	25.0	10	10	70	–	100
No. 8		0.38	0.5	0.4^A	0.1	0.4^D	25.0	10	10	100	–	100
No. 9	**120°C 70 MPa**	0.34	0.5	0.4^A	0.1	0.4^D	20.0	10	10	50	–	100
No. 10		0.34	0.5	0.4^A	0.1	0.4^D	25.0	10	10	70	–	100
No. 11		0.38	0.5	0.4^A	0.1	0.4^D	25.0	10	10	100	–	100
No. 12		0.38	0.5	0.4^A	0.1	0.45^D	25.0	10	10	110	–	100

Quantity of additives are given in percent of dry cement mass

* two types of liquefiers were used, i.e. A and B,

** two types of retarders were used, i.e. C and D,

*** bwow – in relation to the mass of working water (NaCl)

Table 5

Results of analyses of cement slurries for temperatures 90 to 120°C and pressures 60 to 70 MPa after PN-EN ISO 10426

Composition of slurry	Temperature Pressure	Density [kg/m^3]	Water settlement at 90° [%]	Plastic viscosity [mPa·s]	Yield point [Pa]	Filtration [cm^3/30 min]	Thickening time [h-min] 30 Bc and 100 Bc
No. 1	**90°C 60 MPa**	2050	0.0	118.5	9.8	42	30 Bc: 3-41 100 Bc: 3-52
No. 2		2100	0.0	179.5	20.4	32	30 Bc: 3-44 100 Bc: 4-02
No. 3		2140	0.0	121.5	8.4	40	30 Bc: 3-43 100 Bc: 3-56
No. 4	**95°C 60 MPa**	2030	0.0	125.5	5.7	46	30 Bc: 3-54 100 Bc: 4-37
No. 5		2060	0.0	223.5	23.7	28	30 Bc: 3-44 100 Bc: 4-59
No. 6	**110°C 70 MPa**	2180	0.0	152.0	21.6	20	30 Bc: 3-52 100 Bc: 4-31
No. 7		2200	0.0	124.5	11.8	40	30 Bc: 5-35 100 Bc: 6-05
No. 8		2290	0.0	136.5	11.8	38	30 Bc: 4-40 100 Bc: 4-48
No. 9	**120°C 70 MPa**	2150	0.0	112.5	9.8	46	30 Bc: 4-00 100 Bc: 4-08
No. 10		2200	0.0	124.5	11.8	44	30 Bc: 3-22 100 Bc: 3-30
No. 11		2290	0.0	136.5	11.8	44	30 Bc: 3-18 100 Bc: 3-24
No. 12		2350	0.0	165.0	13.4	40	30 Bc: 3-25 100 Bc: 4-13

The density of cement slurries analyzed at temperature of 90°C and pressure of 60 MPa (compositions No. 1, 2 and 3) ranged between 2050 and 2140 kg/m^3. Their thickening times were about 3 h 40 min to 4 hours. For slurry No. 2 (density 2100 kg/m^3) with 10% microcement early compressive stress tests were performed (Fig. 3), mechanical compressive stress with two standard cuboids (Figs 2 and 10, Tab. 6) and also porosity measurements (Tab. 7, Fig. 11). Slurry No. 2 started to bind before 5 hours. The resistance determined on ultrasonic cement analyzer (UCA) increased to 22 MPa after a period up to 72 h (3 days); this value informs us about the good condition of the slurry bonding in the wellbore-like conditions. After 28 days the strength of sample No. 2 was about 30 MPa (Fig. 10, Tab. 6). The general porosity of sample No. 2 equaled to 30.4%. The largest pores (over 10,000 nm) constituted only about 1.8% of the whole, whereas smaller pores (under 100 nm) as much as 95% of total pores.

a) b)

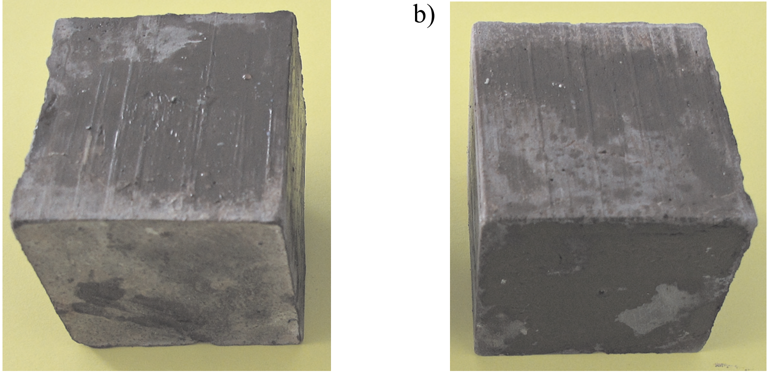

Fig. 2. Cubes 2 × 2 × 2 inch (a, b) made of cement slurry No. 2 for mechanical compressive tests (hydration time 7 days)

The analyses of slurries Nos 4 and 5 were performed at a temperature of 95°C and pressure 60 MPa. The density of these slurries equaled to 2030 and 2060 kg/m^3, respectively. Their thickening times were 4–5 hours. The microstructure and SEM elemental analysis of particular sample areas for hardened cement slurry No. 4 were presented in Figures 4–9. The compressive strength of hardened slurry No. 4 after 28 days of hydration equaled to 33 MPa (Fig. 10, Tab. 6).

Cement slurries analyzed in temperature 110°C and pressure 70 MPa were denoted as 6 to 8. Their density ranged between 2180 and 2290 kg/m^3, and thickening times were 4 to 6 hours. Porosity tests were made for slurry No. 6 (with 60% hematite and 35% silica powder). General porosity of sample No. 6 was 28.1%. The largest pores (over 10,000 nm in diameter) constituted only 1.3% of total pores whereas pores of 10,000 to 100 nm about 1%. The smallest pores below 100 nm in diameter constituted about 97.7% of pores (Tab. 7, Fig. 12). The compressive strength of sample No. 6 was about 35 MPa after 28 days of hardening (Fig. 10, Tab. 6).

Another series of tests were performed for cement slurries Nos 9, 10, 11 and 12 at temperature of 120°C and pressure 70 MPa. The density of these slurries oscillated between 2150 and 2350 kg/m^3. The thickening times were 3 h 30 min to 4 hours. Slurry No. 9, containing 50% of hematite, had very high compressive strength after 28 days of hydration, i.e. over 35 MPa (Fig. 10, Tab. 6).

Filtrations of all analyzed slurries in temperature 90 to 120°C were lower than 50 cm^3/30 min (most frequently 30–40 cm^3/30 min, depending on the amount of added antifiltration agent and latex). The slurries had zero water settlement and plastic viscosity mostly equaled to a hundred or so mPa.s (which allows for injecting the slurry into the annular space).

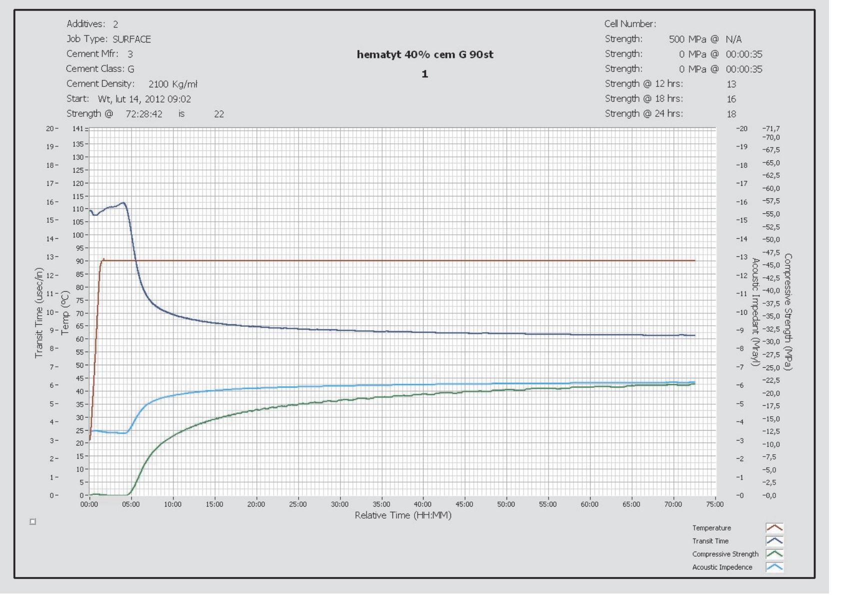

Fig. 3. Increasing initial compressive strength for cement slurry No. 2 in 72 h (3 days) of hydration in wellbore-simulation conditions (based on a test performed with apparatus UCA)

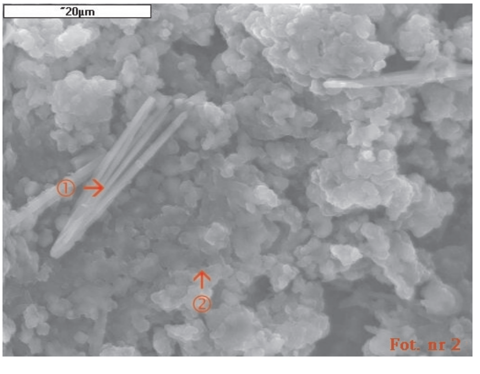

Fig. 4. Microstructure of hardened slurry No. 4. Visible CSH phase modified with Cl^- ions. Magnif. 2000× [7]

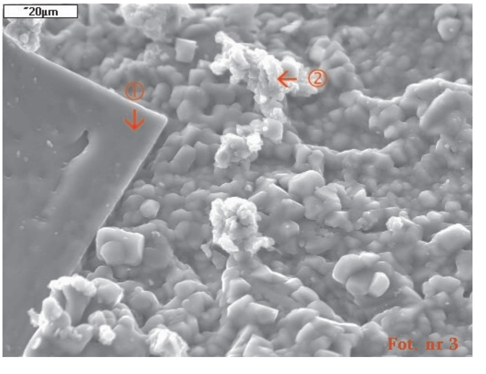

Fig. 5. Microstructure of hardened slurry No. 4. Visible clustered gel of CSH phase modified with Cl^- ions forming intergrowths with regular halite (NaCl) crystals. Magnif. 2000× [7]

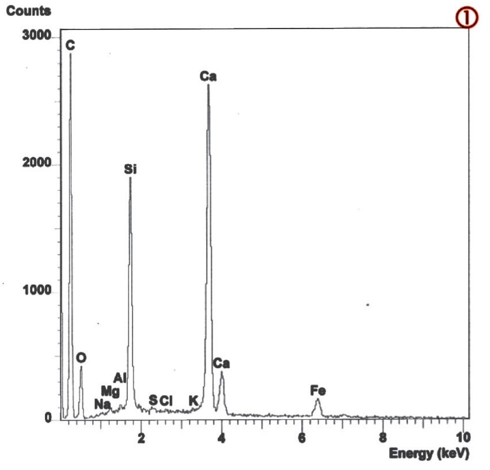

Fig. 6. Elemental analysis of sample visible in Figure 4 p. 1, proving the presence of CSH phase, which forms intergrowths with monosulphate and calcite

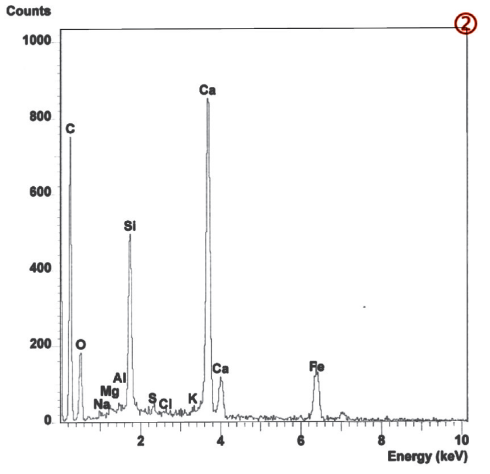

Fig. 7. Elemental analysis of sample visible in Figure 4 p. 2, proving the presence of CSH phase, which forms intergrowths with hematite (Fe_2O_3) and calcite

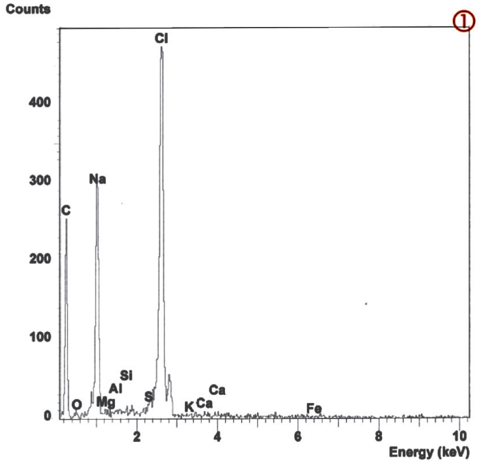

Fig. 8. Elemental analysis of sample visible in Figure 5 p. 1, proving the presence of halite (NaCl) monocrystals

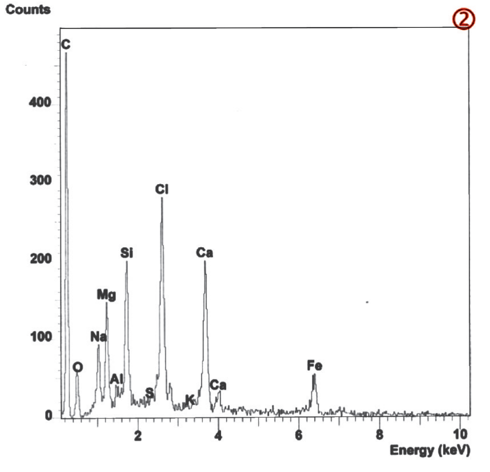

Fig. 9. Elemental analysis of sample visible in Figure 5 p. 2, proving the presence of CSH phase modified with Cl^- ions, which forms intergrowths with hematite (Fe_2O_3), halite crystals and basic magnesium chloride

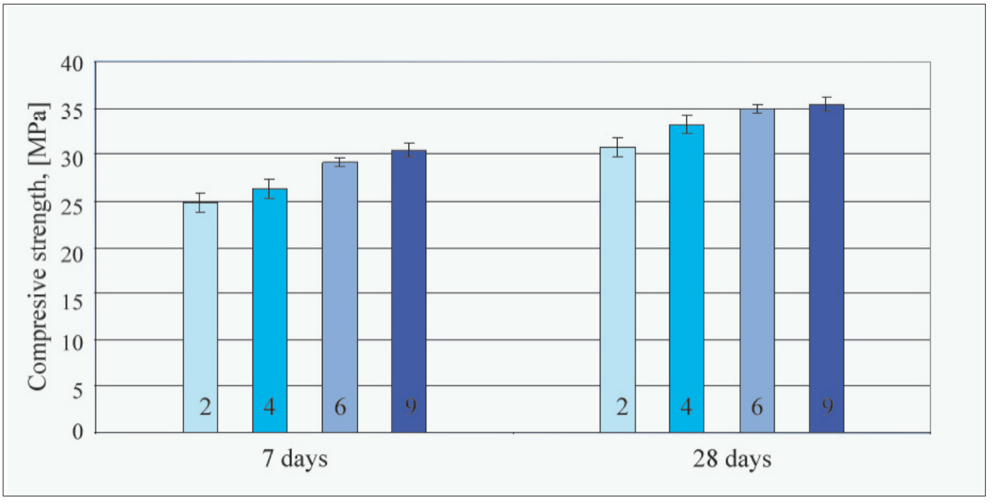

Fig. 10. Compressive strength for cement samples tested at temperature 90–120°C
Composition No. 2, temp. 90°C (density: 2.10 g/cm^3),
Composition No. 4, temp. 95°C (density: 2.03 g/cm^3),
Composition No. 6, temp. 110°C (density: 2.18 g/cm^3),
Composition No. 9, temp. 120°C (density: 2.15 g/cm^3)

Statistical calculations (Tab. 6) were based on the obtained measurement results and aimed at determining average values of compressive strength of particular samples and confidence interval (for assumed confidence coefficient: $1 - \alpha = 0.95$). The compressive strength values obtained for three samples (in line with standard PN-EN ISO 10426) were presented and on this basis arithmetic average in MPa was calculated. In the successive parts of table 6 the following calculations have been presented:

– standard deviation of samples:

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

– confidence level $^{(*)}$:

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

– confidence interval $^{(*)}$:

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

$^{*)}$ confidence coefficient assumed in the calculations equaled to $1 - \alpha = 0.95$, where:

n – population of samples,

x_i – results of samples,

x – arithmetic average of samples,

t_α – t Student variable from the table for the distribution for $n - 1$ degrees of freedom,

ρ – probability that compressive strength of hardened cement slurry equals to $1 - \alpha$ in an interval described with equation [3].

Table 6

Statistical calculations for the obtained compressive strength test results of hardened cement samples deposited at temperature 90 to 120°C

Sample of hardened cement slurry	Results of compressive stress tests (Ws) for three samples of hardened cement slurry [MPa]			Arithmetic mean Ws [MPa]	Standard deviation of samples	Confidence level (for $1 - \alpha = 0.95$)	Confidence interval (for $1 - \alpha = 0.95$)
	Sample						
	1	2	3				
Composition No. 2 (7 days)	24.9	24.4	25.2	24.8333	0.3300	1.0040	23.8293 – 25.8373
Composition No. 4 (7 days)	26.3	26.0	26.7	26.3333	0.2867	0.8724	25.4609 – 27.2057
Composition No. 6 (7 days)	29.1	29.4	29.0	29.1667	0.1700	0.5171	28.6496 – 29.6838
Composition No. 9 (7 days)	30.3	30.3	30.9	30.5000	0.2828	0.8605	29.6395 – 31.3605
Composition No. 2 (28 days)	30.7	30.4	31.2	30.7667	0.3300	1.0040	29.7627 – 31.7707
Composition No. 4 (28 days)	33.3	32.7	33.6	33.2000	0.3742	1.1384	32.0616 – 34.3384
Composition No. 6 (28 days)	35.0	35.1	34.8	34.9667	0.1247	0.3795	34.5872 – 35.3462
Composition No. 9 (28 days)	35.4	35.1	35.7	35.4000	0.2449	0.7452	34.6548 – 36.1452

Table 7

General porosity and distribution of pore diameter in hardened cement slurries No. 2 and No. 6

Sample	General porosity [%]	Participation of pores of a give diameter [%]		
		>10.000 nm	10.000–100 nm	<100 nm
No. 2	30.4	1.8	3.2	95.0
No. 6	28.1	1.3	1.0	97.7

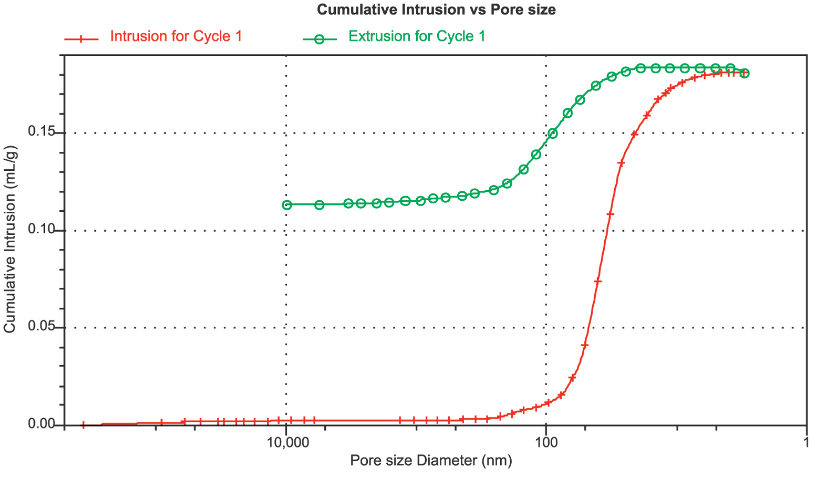

Fig. 11. Distribution of pores in a sample of hardened cement slurry No. 2

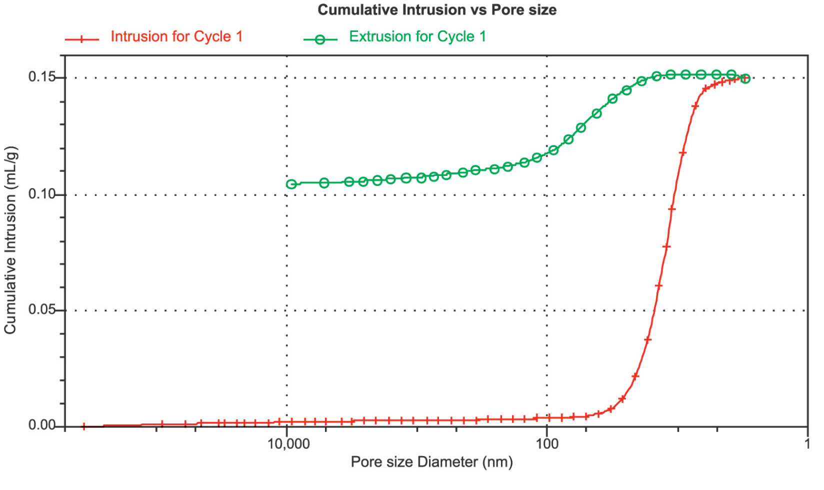

Fig. 12. Distribution of pores in a sample of hardened cement slurry No. 6

4. CONCLUSIONS

The Oil and Gas Institute in cooperation with Cement Services in Wołomin (now EXALO) worked out many recipes of heavy cement slurries 2050 to 2350 kg/m^3 of density, which were successfully used for sealing production casing in deep wellbores. These recipes have been used while sealing wellbores of dynamic temperature of ca. 90°C to ca. 120°C. The gathered experience and the experimental results proved that G type HRS drilling cement (meeting the standard PN-EN ISO 10426-1) should be used in such conditions. The additives and admixtures applied in the slurries are attested and allowed to use in high pressure and high temperature conditions. Among substances added to the slurry are, e.g. latex (prevents gas migration and lowers filtration), hematite (increases density of slurry) or silica powder (increases thermal resistance at high temperature). The matrix of hardened cement slurry can be sealed up with microcement so that the obtained microsurface is more compact.

Prior to cementing, sealing slurries are thoroughly analyzed with specialist equipment at the OGI laboratory. The analyses focus on the most technological parameters affecting the course and efficiency of the cementing job. The density of the slurry is adjusted to the gradient of reservoir pressure and fracturing pressure, filtration is lowered below 50 cm^3/30 min whereas water settlement is reduced to zero. Rheological parameters are also regulated. The slurry thickening time (time after which the consistency of the slurry was 30 Bc) is so selected as to exceed the planned time of sealing pipes by a safety margin. Besides the increasing mechanical resistance is also characterized with a noninvasive ultrasonic cement analysis method at the OGI laboratory. These analyses are used for determining the time after which cement slurry is transformed from liquid form into solid form. The compressive strength, porosity and microstructure of hardened cement slurries are also analyzed after fresh cement slurry has been hardened in special pressure autoclaves. The components of the recipes are so selected as to obtain the highest possible strength of the hardened cement slurry and minimum porosity (with smallest possible participation of capillary pores). The compressive strength of the samples is very high: after 28 days it exceeds 30 MPa. Low porosity values were obtained for the analyzed cement slurries; the large-diameter pores constitute only about 1–2% of total pore.

The detailed analyses of slurries and hardened cement slurries as well as works on the improvement of recipes, resulted in the systematic improvement of the quality of cementing jobs on production casing in deep wellbores on hydrocarbon deposits.

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