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ANALYSIS OF WASTE MUD STABILITY****

1. INTRODUCTION

Drilling for oil or gas is facilitated by the drilling fluid which is designed to perform a number of functions during the drilling operation. It removal cuttings to the surface, lubricating the drill bits, maintaining the stability of the hole and preventing the inflow-outflow of fluids between the borehole and the shale. Owing to their multiple functions, muds are complex polymeric-mineral microcomposites of differentiated chemical and mineralogical-phase composition with varying share of colloidal phase in dispersed solid phase in an aqueous (water based mud - WBM) or non-aqueous (oil based mud – OMB) suspending medium [1,9]. In the course of drilling operations fluids are contaminated and after being used they become waste mud. The analyzed waste mud have a colloidal-suspension form [5]. The stability of presented waste mud systems mainly results from the high participation of clayey minerals, mainly of smectite group, long-chain polymers and chemicals [4,8]. Waste mud also contain amorphous admixtures. These admixtures are attributed to the presence of clayey minerals, which were mechanically degraded in the process of drilling and also participation of polymeric organic substances or polymeric-clayey complexes. These admixtures may directly affect the stability of concentrated dispersions, and so create problems with their environmental management.

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The paper is aimed at determining selected physicochemical properties of mud in view of their management and environmental protection. The stability of these dispersions was analyzed by measuring the intensity of light which was transmitted and scattered several times. This method allows for a quick identification of stability of the analyzed dispersion systems by the characteristic phenomena taking place at the interface of phases in the structure of the analyzed systems without disturbing their structure over the measurement time.

2. MATERIALS USED AND TESTING METHOD

The following used drilling mud were analyzed:

- bentonite drilling fluid (taken from borehole after drilling down to 200 m),
- KCl/polymer drilling fluid (1200 m),
- polymeric drilling fluid – for drilling-up operations (3030 m),
- saline-barite drilling fluid (3411 m),
- chloride-polymeric inhibited drilling fluid (4040 m).

These mud were taken from wells drilled between May 2013 to December 2013. Fluid samples were taken after finishing drilling operation in a given section of well.

The stability of muds was determined with the use of an optic analyzer Turbiscan Lab., Formulaction, equipped with a source of infrared light of wavelength $\lambda = 880$ nm and two synchronized detectors. The transmission detector (disposed at an angle of 180^{o}) receives light which passed through the sample, whereas the backscatter detector (disposed at an angle of 45^{o}) receives the light backscattered from the sample. The high resolution of measurement allows for making measurements every 40 μm. Thanks to the regulation of the scanning frequency, we can have destabilization profiles in a function of time. The duration time of one scan is 20 s. Turbiscan makes use of the multiple light scattering technique [2,6,7].

The turbiscan stability index (TSI) was worked out for evaluating the stability of analyzed systems. The following assumption was made: the lower is the TSI value, the more stable is the system.

The rheological properties of waste mud give an idea of the stability of these systems. The obtained results were correlated with the results obtained with Turbiscan. The rheological parameters of waste mud were analyzed in line with the standard EN-ISO 10416:2008 „*Petroleum and natural gas industries – Drilling fluids - Laboratory testing”.*

3. RESULTS OF MEASUREMENTS AND THEIR INTERPRETATION

Physical properties of the analyzed waste muds are listed in tables 1 and 2.

The stability analyses with light backscattering were performed at temperatures: 20^{o}C, 40^{o}C and 60^{o}C for 24 hrs. The backscattering changes during analysis of waste bentonite mud at temperatures 20^{o}C, 40^{o}C and 60^{o}C are presented in figs. 1 to 3, and the destabilization plot of waste bentonite mud as a change of TSI value during the analysis, is given in fig. 4.

Table 1

Physical properties of waste muds

Type of mud	Density [g/cm^3]	Solids content [wt%]	C_{org} content [wt%]	pH		Filtracja [ml]		Filtrate mineralization [mg/dm^3]
				20^{o}C	60^{O}C	20^{O}C	w60^{O}C	
Bentonite	1,17	22,50	1,64	7,5	7,5	17,5	20,5	701,5
Potassium – polymer	1,14	22,90	8,30	9,5	9,0	6,0	6,5	6120,1
Polymeric for drilling up operations	1,10	19,50	11,56	9,5	9,5	2,9	3,5	6337,9
Saline-barite	2,26	-	-	8	10	2,5	13,5	5149,0
Inhibited chloride-polymeric	1,27	39,00	6,01	9,5	10	4,5	5	5417,4

Table 2

Rheological parameters of analyzed mud

Type of mud	Rheological parameters		Temperature		
			20 [^{o}C]	40 [^{o}C]	60 [^{o}C]
Bentonite	**Herschel-Bulkley model**	Yield point [Pa]	22,041	29, 957	30,730
		Consistency coefficient k_{HB} [Pa*s^n]	0,146	0,2423	-
		Exponential n_{HB} [-]	0,708	0,6235	-
	Apparent viscosity for 1022.040[s^{-1}] [Pa*s]		0,041	0,048	0,040
Potassium – polymer	**Herschel-Bulkley model**	Yield point [Pa]	0,047	0,712	0,744
		Consistency coefficient k_{HB} [Pa*s^n]	0,055	0,037	0,017
		Exponential n_{HB} [-]	0,816	0,830	0,893
	Apparent viscosity for 1022.040[s^{-1}] [Pa*s]		0,015	0,012	0,009
Polymeric for drilling up operations	**Herschel-Bulkley model**	Yield point [Pa]	1,119	2,472	1,400
		Consistency coefficient k_{HB} [Pa*s^n]	0,896	0,626	0,489
		Exponential n_{HB} [-]	0,531	0,539	0,567
	Apparent viscosity for 1022.040[s^{-1}] [Pa*s]		0,036	0,028	0,026
Saline-barite	**Herschel-Bulkley**	Yield point [Pa]	2,506	0,958	0,427
		Współczynnik konsystencji k_{HB} [Pa*s^n]	0,411	0,066	0,040
		Exponential n_{HB} [-]	0,290	0,923	0,967
	Apparent viscosity for 1022.040[s^{-1}] [Pa*s]		0,072	0,039	0,033
Inhibited chloride-polymeric	**Herschel-Bulkley model**	Yield point [Pa]	0,465	1,401	2,453
		Consistency coefficient k_{HB} [Pa*s^n]	0,330	0,164	0,115
		Exponential n_{HB} [-]	0,726	0,730	0,740
	Apparent viscosity for 1022.040[s^{-1}] [Pa*s]		0,049	0,026	0,021

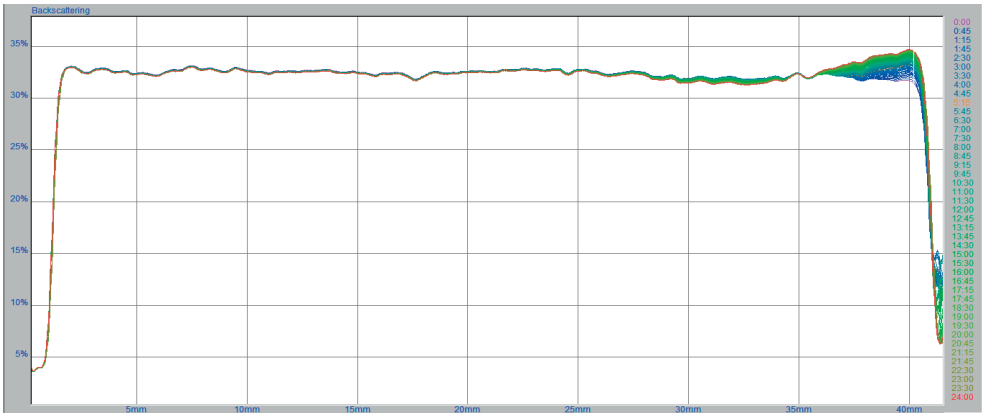

Fig. 1. Profile of backscattering changes during analysis of a bentonite mud scanned at 20°C

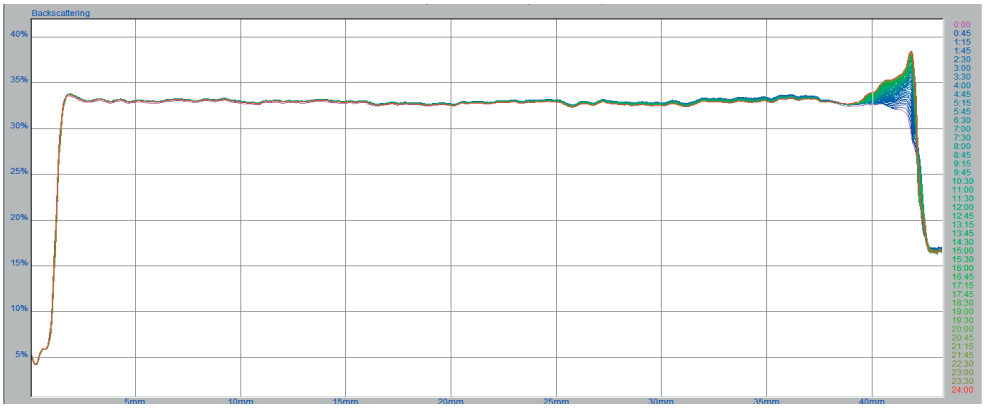

Fig. 2. Profile of backscattering changes during analysis of a bentonite mud scanned at 40°C

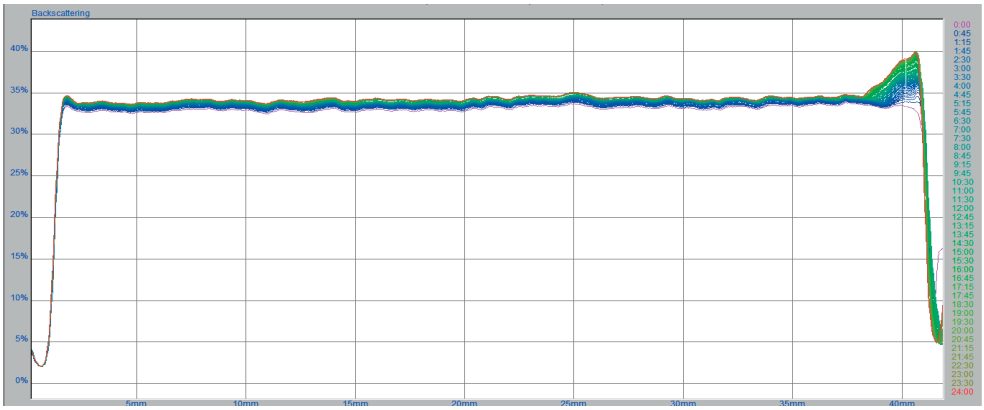

Fig. 3. Profile of backscattering changes during analysis of a bentonite mud scanned at 60°C

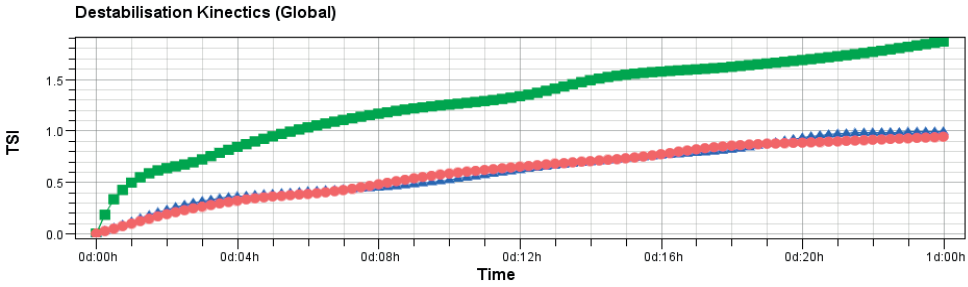

Fig. 4. Change of TSI coefficient during analysis of a bentonite mud (red line for 20°C, blue line for 40 °C and green line for 60 °C)

The analysis of plots presented in figures 1 to 3 reveals that the dispersion in the upper part of the measuring cup is slightly denser. This effect becomes more distinct with the growing scanning temperature (60°C). Considering the TSI value, the dispersion may be classified as stable at temperatures 20 °C and 40 °C (fig. 4, table 3).

Table 3

Change of TSI value for three temperatures of bentonite mud

Waste bentonite mud		
20°C	40°C	60°C
0.9	**1.0**	**1.9**

The analysis of physical properties of bentonite muds listed in tables 1 and 2 reveals that with the increasing temperature mud slightly changes its properties. The observed changes are congruent with the scans, especially as far as dispersion densification at temperature 60°C is concerned.

The backscatter profiles during the analysis of potassium-polymeric mud is presented in figs. 5 to 7, whereas the change of TSI value during the analysis of potassium-polymeric mud is given in fig. 8 and table 4.

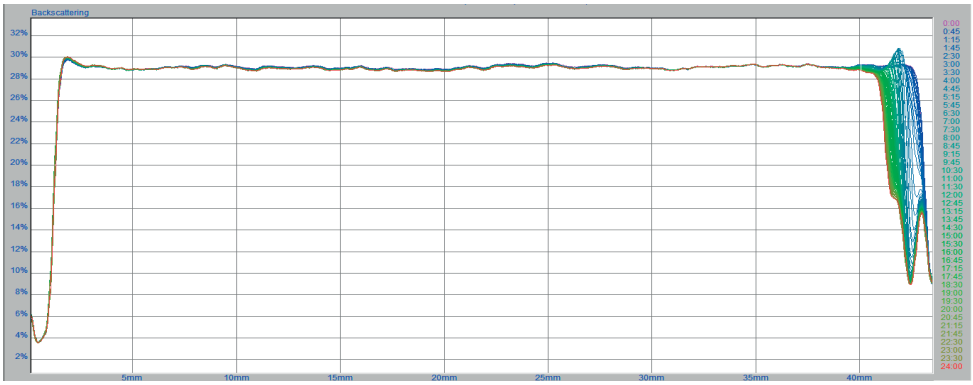

Fig. 5. Profile of backscattering changes during the analysis of a potassium-polymeric mud scanned at 20°C

Fig. 6. Profile of backscattering changes during the analysis of a potassium-polymeric mud scanned at 40°C

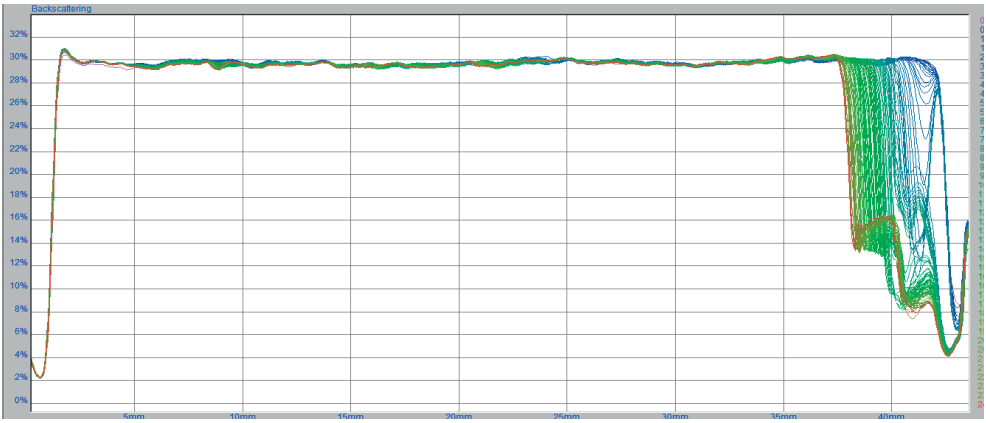

Fig. 7. Profile of backscattering changes during the analysis of a potassium-polymeric mud scanned at 60°C

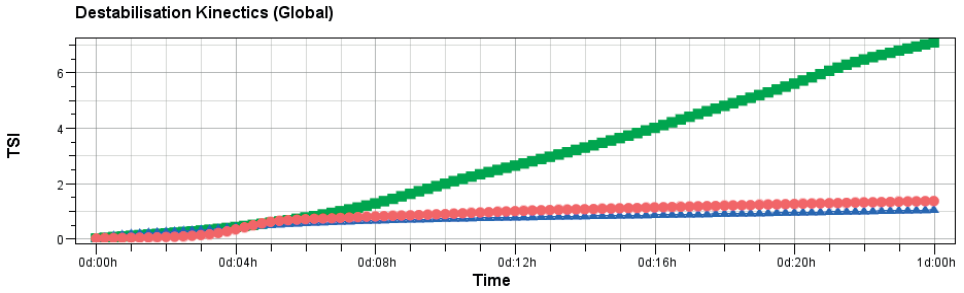

Fig. 8. Change of TSI coefficient during analysis of a potassium-polymeric mud (red line for 20°C, blue line for 40 °C and green line for 60 °C)

Table 4

Change of TSI values for three temperatures of potassium-polymeric mud

Waste potassium-polymeric mud		
20°C	40°C	60°C
1.4	**1**	**7.1**

The data presented in figs. 5 to 7 show to a considerable drop of backscattering at temperature 40°C. The main instability effect for the analysed mud is its clearing in the upper part of the measuring cup (lower TSI content). The TSI content (fig. 8, table 4) reveals the instability of samples (especially at 60°C), which also finds its expression in the measured rheological parameters – lowering of apparent viscosity and consistency coefficient. Slight increase of the yield point may be attributed to the densification of the dispersion in a layer under the clearing stratum (table 2).

The backscattering changes during analysis of drilling-up waste polymeric mud at temperatures 20°C, 40°C and 60°C are presented in figs. 9 to 11, and the kinetics of destabilization of drilling-up waste polymeric mud as a change of TSI value during the analysis, is given in fig. 12 and table 5.

Table 5

Change of TSI values for three temperatures of drilling-up polymeric mud

Drilling-up waste polymeric mud		
20°C	40°C	60°C
1	**3.4**	**5.4**

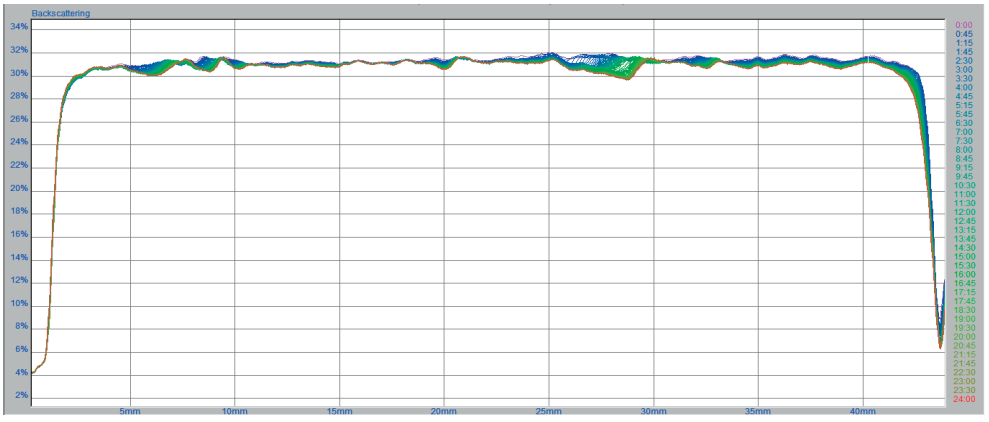

Fig. 9. Profile of backscattering changes during the analysis of a drilling-up polymeric mud scanned at 20°C

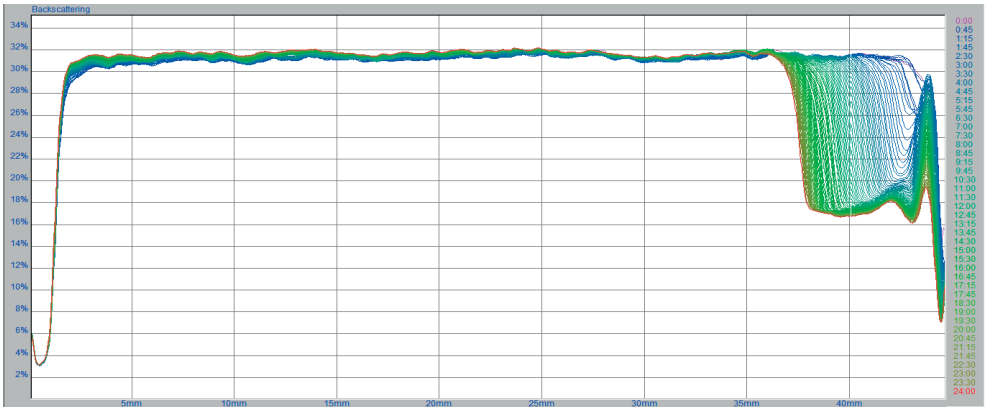

Fig. 10. Profile of backscattering changes during the analysis of a drilling-up polymeric mud scanned at 40°C

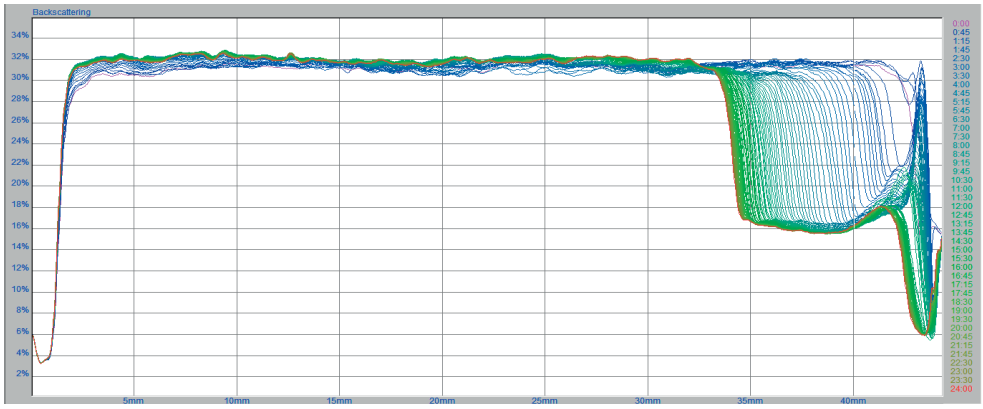

Fig. 11. Profile of backscattering changes during the analysis of a drilling-up polymeric mud scanned at 60°C

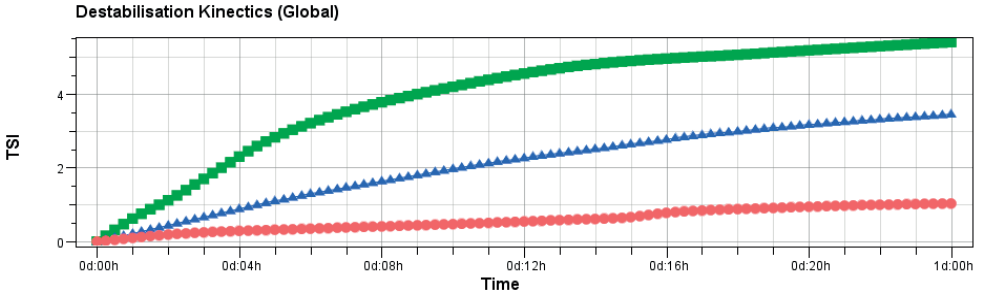

Fig. 12. Change of TSI coefficient during analysis of a drilling-up polymeric mud (red line for 20°C, blue line for 40 °C and green line for 60 °C)

The sample scanned at a temperature of 20°C (fig. 9) shows to small clearing of the sample in the upper part of the measuring cup, evidenced by a little drop of the backscatter in the delamination of scans. In the remaining part of the samples flocculation is registered.

The backscatter changes during the analysis of a drilling-up polymeric mud at 40°C and 60°C is presented in figs. 10 and 11. Clearing of samples in the upper part of the measuring cup has been observed. The increase of backscatter caused by sample densification with the growing temperature is visualized in the below scans. These phenomena develop more dynamically with the increasing temperature. The changes of the TSI values (table 5 and fig. 12) are indicative of higher instability of samples with the increasing temperature. The scanned sample at a temperature 60°C is over five times less stable than the sample scanned at 20°C.

The data presented in tables 1 and 2 show that viscosity and yield point values change to a small degree. These changes may be explained with the increase of fine dispersive molecules, change of conformation of polymeric chains, especially at temperature 60°C.

The changes of backscatter during the analysis of saline-barite mud samples are presented in figs. 13 to 15, whereas the TSI changes during the analysis of saline-barite mud are given in fig. 16 and table 6.

Table 6

Change of TSI values for three temperatures of saline-barite mud

Waste saline-barite mud		
20°C	40°C	60°C
0.8	**10**	**15.7**

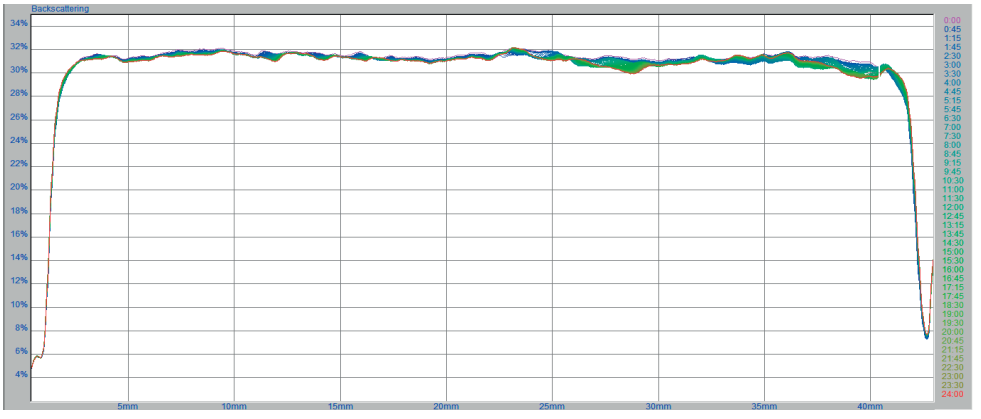

Fig. 13. Profile of backscattering changes during the analysis of a saline-barite mud scanned at 20°C

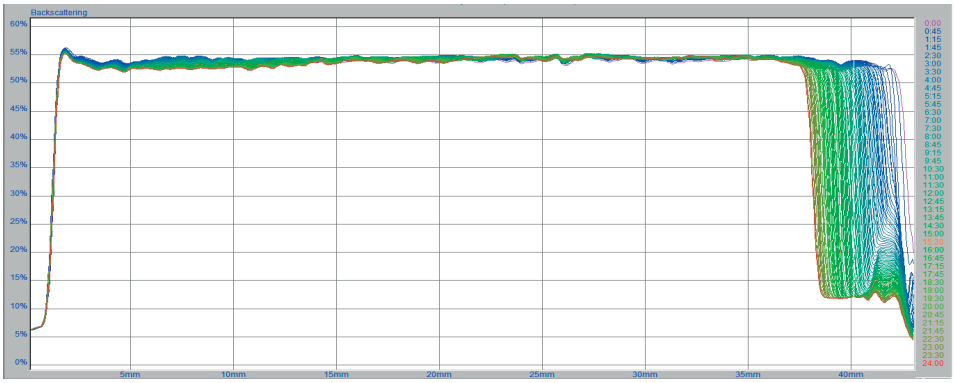

Fig. 14. Profile of backscattering changes during the analysis of a saline-barite mud scanned at 40°C

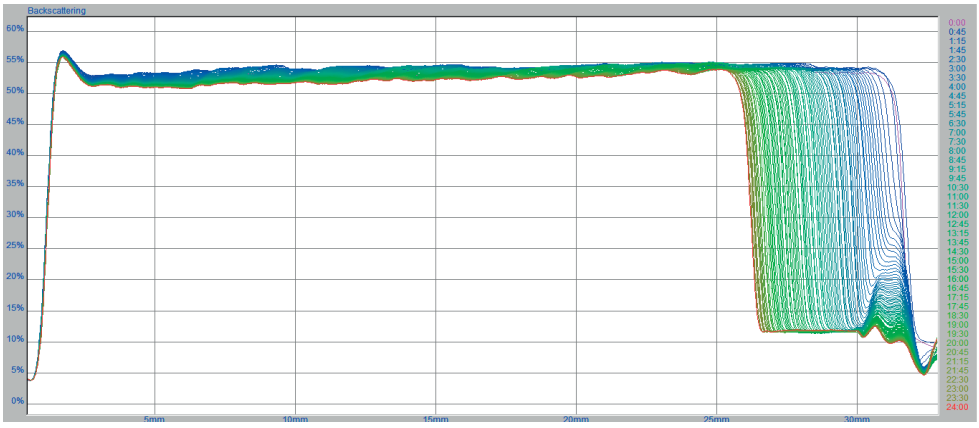

Fig. 15. Profile of backscattering changes during the analysis of a saline-barite mud scanned at 60°C

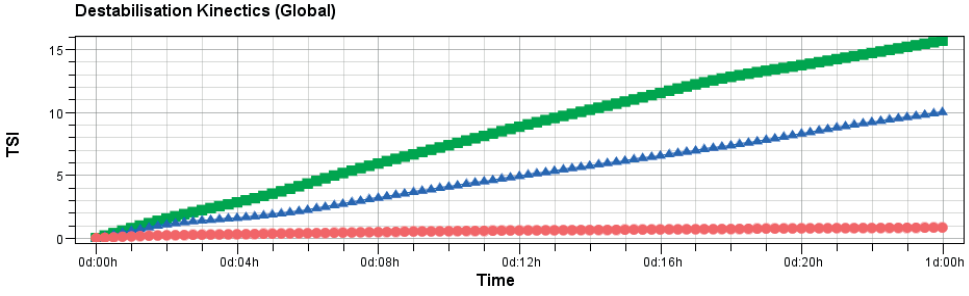

Fig. 16. Change of TSI coefficient during analysis of a saline-barite mud (red line for 20^{O}C, blue line for 40 ^{O}C and green line for 60 ^{O}C)

The analysis of profiles of saline-barite mud backscattering profiles in figs. 13 to 15 shows that the main phenomenon is flocculation taking place at 20°C. The clearing of the sample in the upper part of the measuring cup at a temperature of 40°C and 60°C is the major instability phenomenon. It gains in dynamics at higher temperatures (60°C) as visualized in fig. 16 and table 6.

Changes of saline-barite mud properties (considerable rheological and filtration changes of mud - tables 1 and 2) were recorded. Apparent viscosity, consistency coefficient and yield point were definitely lowered, resembling the character of Newtonian fluids. The liquid phase of the analyzed mud received through filtration at temperature 60°C increased its volume over 5 times as compared to the volume of filtrate at temperature 20 °C.

The profiles of backscattering of inhibited chloride-polymeric waste mud are presented in figs. 17 to 19.

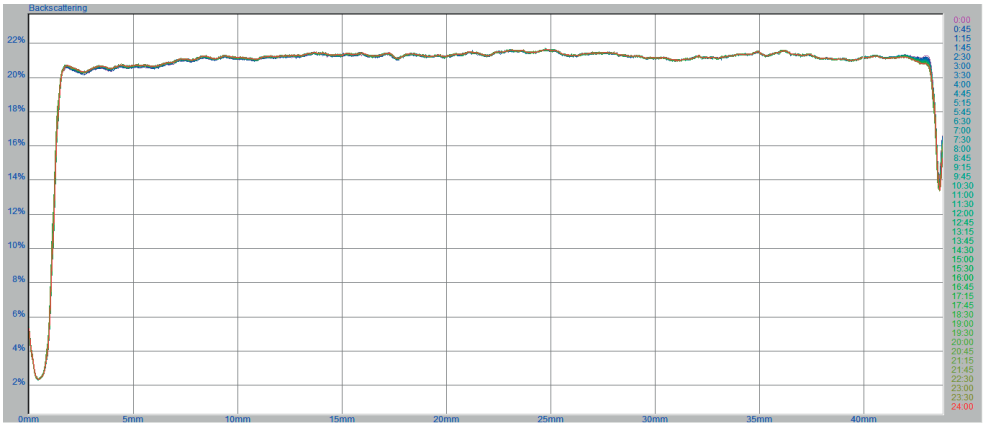

Fig. 17. Profile of backscattering changes during the analysis of an inhibited chloride-polymeric mud scanned at 20°C

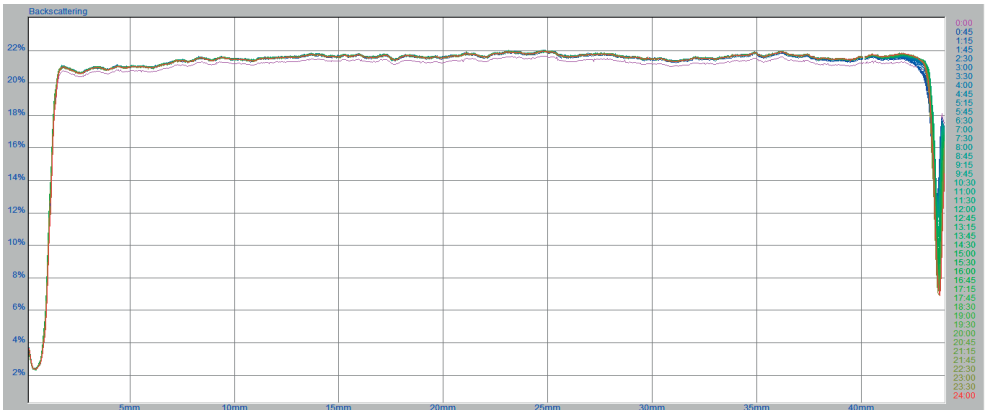

Fig. 18. Profile of backscattering changes during the analysis of an inhibited chloride-polymeric mud scanned at 40°C

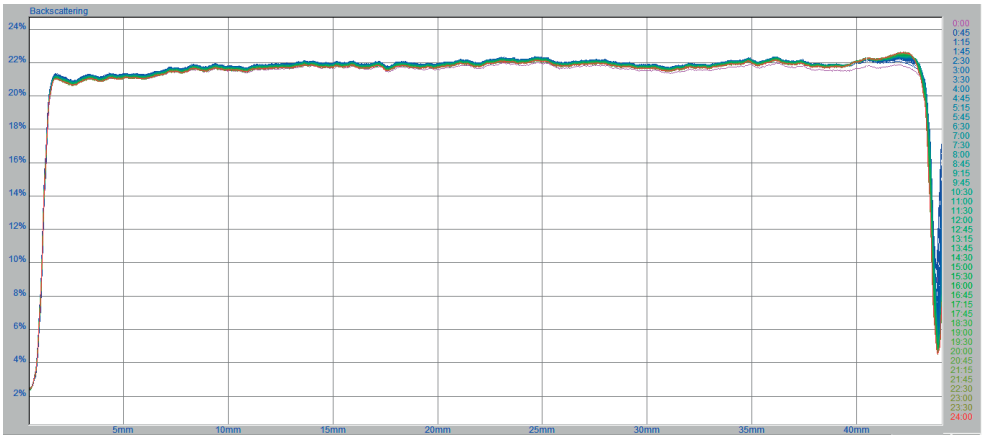

Fig. 19. Profile of backscattering changes during the analysis of an inhibited chloride-polymeric mud scanned at 60°C

The variability of TSI factor in a function of temperature for an inhibited chloride-polymeric mud sample is presented in fig. 20 and table 7.

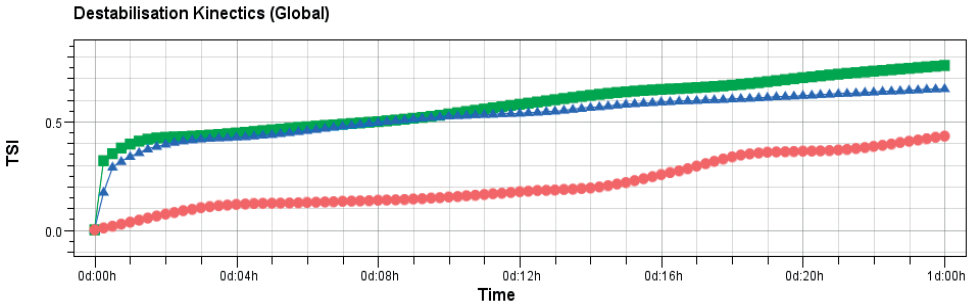

Fig. 20. Change of TSI coefficient during analysis of an inhibited chloride-polymeric mud (red line for 20^{O}C, blue line for 40 ^{O}C and green line for 60 ^{O}C)

Table 7

Change of TSI values for inhibited chloride-polymeric mud

Waste inhibited chloride-polymeric mud		
20°C	40°C	60°C
0.4	0.7	0.8

The changes of backscattering during the analysis of inhibited chloride-polymeric mud are presented in figs. 17 to 19. The analysis of the plots reveals that mud is stable regardless

the sxcanning temperature. This was proved by theTSI values, i.e. TSI <1 (fig. 18 and table 7). The changes of rheological parameters (especially the yield point) of the analyzed waste mud listed in table 2, may be influenced by the polymeric and fine dispersion phase content.

4. CONCLUSIONS

- The analyses performed on selected waste muds with the use of multiple light scattering and optical analyzer Turbiscan Lab., Formulaction prove the usablity of this method in works on waste destabilzation.
- This method can be used for illustrating waste muds stability and determining directions of works on destabilization of such systems in view of liquid and solid phases separation.
- It should be stresses that the clearing effect is a precursor, which evidences the sedimentological possibilities of the analyzed dispersions.
- Chemical destabilization of waste inhibited chloride-polymeric mud, which was recorded as stable, will require deeper and more complex ingerention .
- Specific forces acting between organic polymers and mineral phase of waste (especially clayey phase) are physical forces, just like Van der Waals forces, electrical forces and hydration forces. The stabilization of inner dispersion structures enriched by polymers and electrical charges from functional groups leads to the electrospatial stabilization of dispersions.
- During stabilization of the discussed dispersions, especially at high temperatures, their viscosity and yield point change. These changes may be caused by:
  - decomposition of aggregates into smaller parts, which manifests itself with higher viscosity and reinforced coagulation/flocculation;
  - sedimentation of particles of bigger diameters;
  - change of diffusion layer resulting from the presence of liquefying diffusion in muds, presence of organic compounds (decomposition, linking or change of chains conformation), which usually manifests itself in higher viscosity of the dispersion;
  - high salt content in dispersion.

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