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Geothermal Drilling Fluid Meets Performance, Environmental, and Regulatory Challenges in the Alps

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Abstract

Over the last few years, the process of moving to green energy along with the need for increased gas production in Europe has driven increased geothermal drilling in the Alps. This has led to adjusting all drilling-related technologies to satisfy geothermal requirements, including drilling fluids. The Alps are characterized by reservoir composed of hard rock drilling through granite and Gneiss, low ROPs, fractures with fluid losses, and fluid degradation from high bottom hole temperatures. All of these challenges must be addressed while meeting stringent local environmental regulations.

It is of extreme importance to get the fluid components approved by local authorities so that the fluid can be disposed in an easy and economical way. After verifying that the fluid components and disposal water qualified in the environmental WGK class 1, a polymeric water-based drilling fluid (WBDF), formulated with a proprietary polysaccharide-based biopolymer, was selected that would provide viscosity, reduce fluid loss, and encapsulate the marl to be faced during the intermediate section. The WBDF formulation was enhanced with an appropriate bridging package to avoid seepage losses, strengthen the wellbore, and minimize risk of stuck pipe.

The 1.42 sg WBDF showed rheological and temperature stability, excellent resistance to chemical contamination, tolerance to high salinity, and low torque and trouble-free drilling through limestone and marl – all with the lowest risk in terms of environmental impact. Furthermore, running the fluid through a dewatering process to reduce the disposal volume performed well and minimized waste haul off.

Introduction

The green energy transition is pushing the most developed countries in the world, in particular all European countries, to increase the production of energy from renewable sources. The main focus, between the non-hydrocarbon resources, has stayed on solar and wind, but also geothermal power is seen as an alternative thanks to the fact that it is considered the only stable resource over the whole year and it is independent of any weather condition.

Figure 1 shows the consumption of geothermal energy measured in installed generation capacity, and it is easy to recognize that most of the countries are located along the border of the Pacific plate, also called the Ring of Fire.

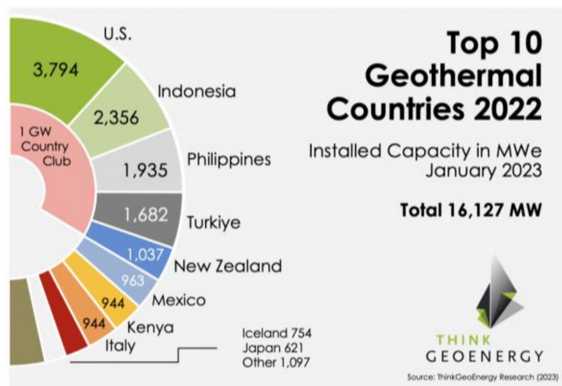

Figure 1 – Top Geothermal Countries in 2022 based on installed generation capacity (Mwe) (Think Geoenergy, 2023b)

The energy demand is growing and will continue to growth in the upcoming decades as shown in Figure 2, and Geothermal needs to be more economic in order to accelerate development.

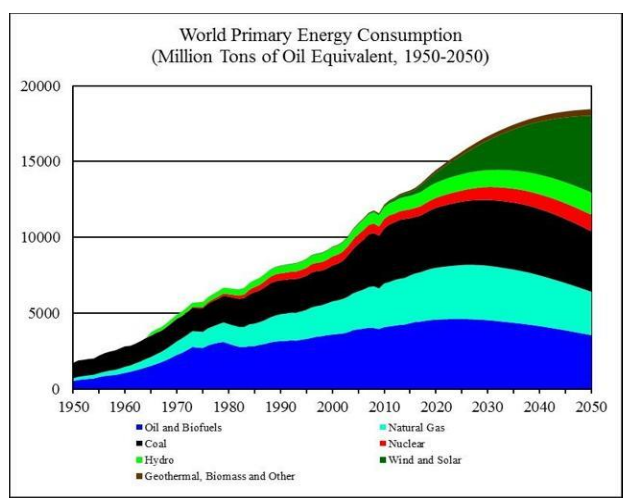

Figure 2 – World energy consumption by source shown historically from 1950 and predicted to 2050 (Li, 2017)

Development in Geothermal drilling has been seen globally, in countries along the ring of fire, but also in Europe, thanks to the large investment seen after the pandemic and during the green energy transition. Looking more in detail at the energy demand, focusing on European countries, we will see an increase in installed capacity for geothermal heating projects in most of the European countries, with an investment of $7.4 billion between 2022 and 2030, with the countries in central-north Europe leading the growth as reported below in Figure 3.

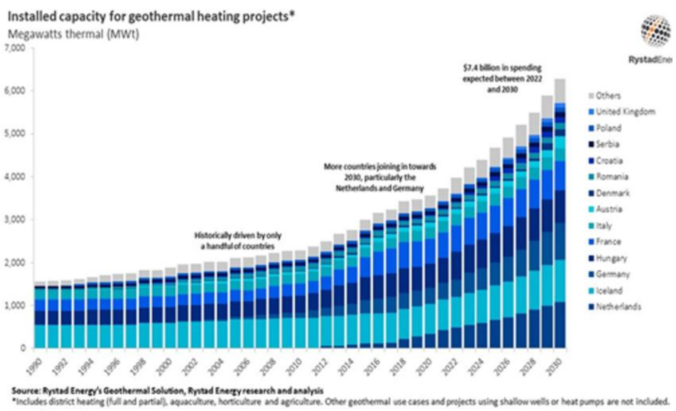

Figure 3 – Installed capacity for Geothermal heating project in Europe till 2030 (Rystad Energy's Geothermal Solution, 2022)

These facilities will be designed mostly to use Geothermal sources of medium enthalpy. This means that the produced water temperature will range from 100 to 200°C as reported in Figure 4:

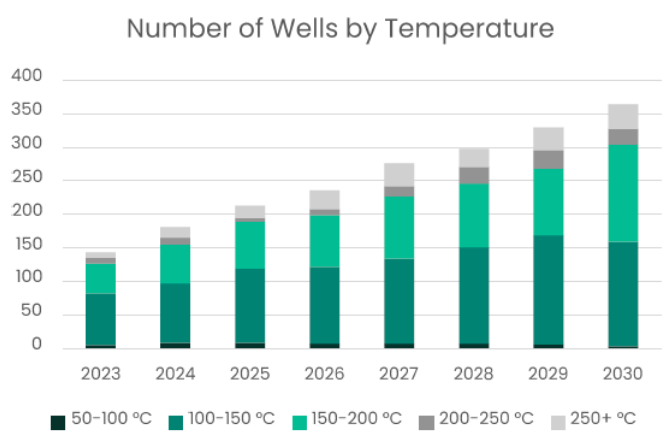

Figure 4 –Number of wells by Temperature to be drilled in Europe till 2030 (Rystad Energy's Geothermal Solution, 2022)

Figure 5 shows the area of major interest from a geological standpoint to develop geothermal energy production.

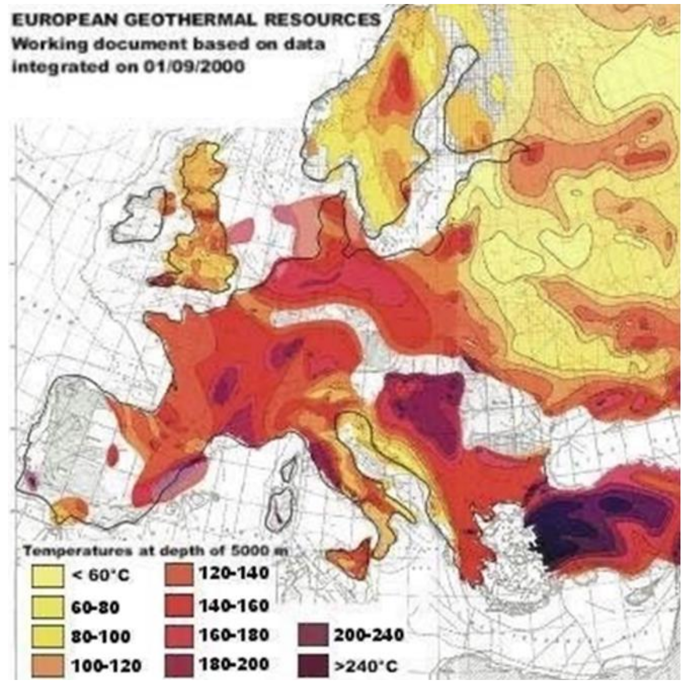

Figure 5 – Temperature at depth of 5,000 m in Europe onshore

More than the geothermal, well-known fields like the oldest one in the world, located in Tuscany (Italy) (Pallotta et al., 2020) (Manzella et al., 2019) (Bargiacchi et al, 2020) or Iceland, both characterized by high enthalpy areas, produce steam at high temperature (Santilano et al., 2015). There are many fields, in central Europe, characterized as medium enthalpy, capable of providing water from a medium to high temperature that can be used for heating systems of small communities or sometimes to feed the needs of large facilities, like hospitals (Williams et al., 2011).

Challenges related to the drilling fluids in geothermal applications are mainly related to the high temperatures encountered while drilling in such environments, the presence of acid gasses in the reservoir, hard rock formations, and finally, formation losses (Cole et al., 2017). While drilling in the European continent, all of the above challenges must be treated using chemicals with a low environmental impact due to the stringent environmental regulations in place.

Geothermal Drilling Fluids Design

A geothermal drilling fluid designed to be used in Europe must meet not only the fluid's specifications dictated by downhole challenges such as mud weight, rheological and fluid loss properties, high temperature stability, inhibition, etc., but also be formulated with chemicals that will fit with local environmental regulations while minimizing disposal costs that are strictly affected by the fluid's chemical composition.

Drilling Fluids Performances (pre-spud design)

Challenges related to the drilling fluids performance in geothermal applications are mainly related to the high temperatures encountered while drilling in such environments, the presence of acid gasses in the reservoir, commonly hard rock which results in low penetration rates, and finally, formation losses. Many of the fields in Europe have different lithological profiles, and the aim of this project in the Alps was to develop a hydro-geothermal reservoir within the Middle Jurassic Dogger to produce geothermal water naturally contained in the aquifer for district heating. It was assumed that the reservoir properties of the target interval were largely controlled by the nearby fault zone that provided permeability through a fractured zone around the fault.

The starting point for a fluid formulation is usually the lithology, but in geothermal applications, this must be interpolated with the geothermal gradient to validate that fluid specifications meet drilling requirements like thermal stabilization when the fluid is exposed at high bottom hole temperatures. This specific project in the Alps is based on a low-medium enthalpy resource. In fact, the anticipated reservoir temperature is approximately 85°C at the top of the reservoir (2133 m TVD) and 92°C at the base of the reservoir (2333 m TVD). The average geothermal gradient in this field is expected to be 3.52 °C/100 m ± 0.25°C/100 m. This geothermal gradient is also responsible for the different kind of formations to be drilled.

While the surface formations are mainly composed of silts and clay marls, the intermediate formations are characterized by mainly limestone, fine grained to brecciated and dolomitized, interbedded with marls. As expected, reservoir is mainly characterized by limestone and calcareous marls. In this scenario, considering the not prohibitive temperature environment and different level of marls, with variable reactivity, a variety of fluids were evaluated and proposed to drill different intervals.

Initially the operator required the use of a potassium chloride-based drilling fluid system to inhibit the clay and marl formations with addition of polymers to ensure the required viscosity and fluid loss control targets.

During the planning phase, to avoid the use of any chlorides, the fluid team suggested an alternative fluid formulation comprising of specialized proprietary polysaccharide-based biopolymers designed to ensure viscosity and fluid loss needs as well as providing further encapsulation of drill cuttings. The next generation water-based fluid is formulated with two key engineered polysaccharide-based biopolymers. One provides viscosity and encapsulation and the other acts as a fluid loss control reducer. This chloride free system has been largely used onshore in most of the European Union in substitution of common potassium chloride-based fluids which results in a lower environmental impact and lower disposal cost. Moreover, this system is easy to manage, ensuring optimal fluid properties.

As is a common approach while designing a geothermal water-based drilling fluid, rheological properties are checked and validated before and after hot rolling which is carried out at the expected downhole temperature. To address this first requirement, a base formulation was mixed with 2.5 kg/m^3 of magnesium oxide for alkalinity control and 7.0 kg/m^3 of proprietary polysaccharide viscosifier with a secondary function as an encapsulating agent. Rheology results can be seen on Table 1.

Tabel 1 – Rheology of base fluid before and after hot rolling for 16 hrs @ 90°C as per expected BHST

Rheology	Unit	BHR	AHR
600 rpm	lb/100ft²	48	39
300 rpm	lb/100ft²	36	30
200 rpm	lb/100ft²	31	26
100 rpm	lb/100ft²	25	21
60 rpm	lb/100ft²	21	19
30 rpm	lb/100ft²	17	15
6 rpm	lb/100ft²	10	10
3 rpm	lb/100ft²	8	8
Plastic Viscosity (PV)	cP	12	9
Yield Point (YP)	lb/100ft²	24	21

After hot rolling, the base fluid was then treated with a different and environmentally friendly fluid loss reducers at a concentration of 12 Kg/m^3 in order to meet the required API fluid loss targets <4.5 ml while minimizing the impact of fluid rheology. The following filtration control polymers were tested:

- Proprietary starch-based polysaccharide/Fluid Loss
- Proprietary starch-based polysaccharide/Ultra Low Vis
- Pure Extra Low Vis Polyanionic Cellulose
- Modified Starch

A bridging package composed by sized calcium carbonate materials were also selected for bridging, to control potential losses and improve the quality of the filter cake. The bridging blend was selected and optimized using proprietary software to confirm the suitable bridging properties. Figure 6 shows the curve from bridging software used to optimize the blend of marble materials. The Blue line is the calculated target for ideal bridging while the red one is the optimized blend of bridging agents utilized in the final fluid.

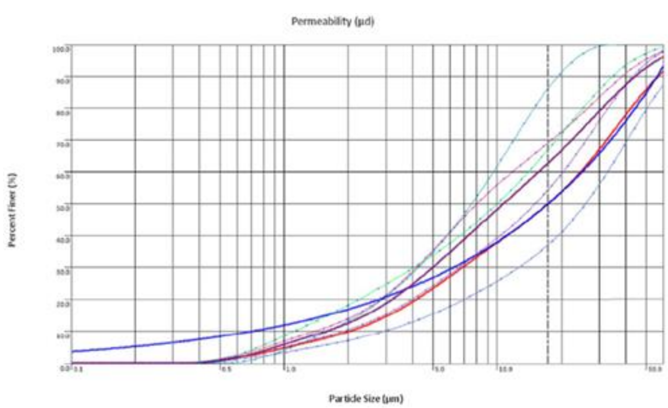

Figure 6: Outcome from bridging package design-Blue Line Target, Red Line Optimal blend

Rheology and filtration properties of the final fluid formulations are shown on Table 2.

Table 2 – Results of Base Fluid after treatment with differ fluid loss reducers and carbonatic bridging material

Products	F1 (Kg/m3)		F2 (Kg/m3)		F3 (Kg/m3)		F4 (Kg/m3)	
Magnesium Oxide	2.5		2.5		2.5		2.5	
Proprietary starch based polysaccharide/Viscosifier	7		7		7		7	
Proprietary starch based polysaccharide/Fluid Loss	12		-		-		-	
Proprietary starch based polysaccharide/UltraLow Vis	-		12		-		-	
Pure Extra Low Vis PAC	-		-		12		-	
Modified Starch	-		-				12	
Size CaCO3	120		120		120		120	
API FL / Spurt Loss [ml]	6,6 / 2,0		6,5 / 2,1		5,6 / 1,2		4,4 / 0,5	
Rheology T	**20 °C**	**50 °C**	**20 °C**	**50 °C**	**20 °C**	**50 °C**	**20 °C**	**50 °C**
600 (lb/100ft²)	159	110	140	103	88	61	69	62
300 (lb/100ft²)	115	80	115	75	57	41	51	45
200 (lb/100ft²)	98	66	88	63	43	32	43	37
100 (lb/100ft²)	72	48	64	46	31	23	32	28
6 (lb/100ft²)	22	14	20	14	9	7	12	10
3 (lb/100ft²)	18	10	16	11	7	5	10	8
PV (cP)	44	30	25	28	31	20	18	17
YP (lb/100ft²)	71	50	90	47	26	21	33	28
Gel strenght 10 sec (lb/100ft²)		15		13		6		9
After additional 20 hrs static ageing at room T								
Rheology T	**20 °C**	**50 °C**	**20 °C**	**50 °C**	**20 °C**	**50 °C**	**20 °C**	**50 °C**
600 rpm (lb/100ft²)	156	112	138	97	85	58	72	54
300 rpm (lb/100ft²)	113	82	106	70	56	39	52	40
200 rpm (lb/100ft²)	98	67	93	58	45	31	43	32
100 rpm (lb/100ft²)	72	48	68	42	31	22	31	24
6 rpm (lb/100ft²)	21	14	20	13	10	7	11	8
3 rpm (lb/100ft²)	17	11	16	10	8	5	9	6
Plastic Visosity (cP)	43	30	32	27	29	19	20	14
Yield Point (lb/100ft²)	70	52	74	43	27	20	32	26
Gel strenght 10 sec (lb/100ft²)		12		10		6		6

Formulation 4, containing a proprietary polysaccharide based viscosifier and a modified starch fluid loss reducer, fully in compliance with environmental regulations dictated by European legislation including North Sea, showed the lowest impact on the fluid's rheology and ensured optimized fluid loss as requested by the operator. This formulation was technically approved to be used in the field.

As the second step of this study, this formulation was evaluated from an environmental perspective to assess if its components would have fit with the environmental regulations imposed by the European Union, in particular the Alps legislation.

Drilling Fluids Environmental properties (pre-spud tests)

The main challenges for drilling wells in the European Union and in particular in the Alps are to design a suitable drilling fluid capable of dealing with the typical drilling problems related to the geothermal environment, be in compliance with stringent environmental regulations and minimize the exhausted fluid's disposal costs.

A deep analysis of the environmental regulations and chemical classification was conducted to assess the type of waste that would be derived from the use of the selected drilling fluid to evaluate the final disposal cost of the waste fluid. Furthermore, to reduce waste costs, a solids control system comprising of a centrifuge and dewatering unit was design to minimize the fluid's volume associated to solid waste to be disposed of at a dedicated landfill.

Dewatering is the process of removing colloidal size solids by the addition of chemicals to coagulate and flocculate the solids in the drilling fluid; then this blended chemically enhanced fluid is pumped to a decanting centrifuge that mechanically separates the solids from the water (Figure 7).

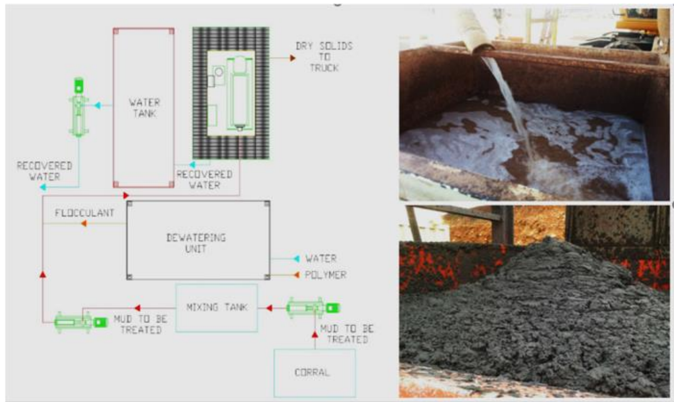

Figure 7: Dewatering Process

The proposed WBDF (Formulation 4) that successfully passed the performances lab testing, was already categorized in Germany for its final disposal. Environmental tests performed on this fluid in the past by certificated third party laboratories, showed that the exhausted drilling fluid made with a concentration up to 3% w/v polysaccharide-based biopolymers, is categorized as WGK 1 (light water hazardous) e.g. for German regulation.

The testing protocol previews an examination of the criteria for substances and mixtures not hazardous to water. Here below the extract of the German environmental law AwSV (Annex 1, 2):

- (Section 2.1 for Substances) - Substances are not hazardous to water if they fulfil all of the following requirements: a) The sum according to number 4.4 is zero. b) A liquid substance has a water solubility of less than 10 mg/l. (c) A solid substance has a solubility in water of less than 100 mg/l. (d) No test is known to show acute toxicity to a fish species (96 h LC50) or a water flea species (48 h EC50) or inhibition of algal growth (72 h IC50) below the solubility limit. Valid tests must have been carried out on two of the above-mentioned organisms. e) A liquid organic substance is readily biodegradable. f) A solid organic substance is either readily biodegradable or has no increased bioaccumulation potential. g) No substance hazardous to water is produced by ready biodegradability or abiotic degradability. h) The substance is not a floating liquid substance according to number 1.3.
- (Section 2.2 for Mixture) - Mixtures are not hazardous to water if they fulfil all of the following requirements: a) The

content of substances of WGK 1 is less than 3 percent by mass. b) The content of substances of WGK 2 is less than 0.2 percent by mass. c) The content of substances of WGK 3 is less than 0.2 per cent by mass. d) The content of unidentified substances is less than 0.2 per cent by mass. E) No carcinogenic substances according to number 1.2 have been intentionally added to the mixture. f) No substances of WGK 3 have been intentionally added to the mixture. g) No substances whose water-polluting properties are not known have been intentionally added to the mixture. h) No dispersants or emulsifiers have been intentionally added to the mixture. i) The mixture does not float in surface waters.

Based on their chemical composition both biopolymers were classified as WGK 1 (slightly hazardous to water) based on the analogue WGK entries of the components in the database and the results of the chemical analysis according to AwSV.

The mixture (proposed WBDF formulated using those polysaccharide-based biopolymers) was evaluated by the local German authorities and this is the response: "For the application mixture, based on a product WGK 1 according to section 2.2, the NWG (not hazardous to water) criteria would be fulfilled at a product content of less than 3% w/v. As the typical application concentration of biopolymers in the drilling fluid is a maximum of 1% w/v according to the manufacturer's specifications, this range is safely adhered to".

This legislation scenario and regulations vary in others European countries. In fact, in the Alps (Schweizersche Eidgenossenschaft Swiss Confederation), the landfills are divided in 5 categories which are identified by letters from A to E, representing an ascending scale of increased potential risk of the waste to be deposed of. Crucial for the authorization of a landfill deposit are:

- Total pollutants content (mg/kg of dry matter)
- Eluate levels (mg/L) of the waste
- and regarding the drilling fluids, the main limiting factor is the Dissolved Organic Carbon (DOC).

It is easy to imagine that waste classified as Type A is cheaper to dispose of than Type B. Just as a reference, the difference in cost from waste classified as Type E compared with Type C is up to 6 times higher, and this can be more expensive than the whole drilling fluid cost needed to drill a well. As reference, below are summarized the kind of waste expected to be included in each type:

- Type A landfills are meant for waste such as, for example, excavation and quarrying material where the presence of pollution can be excluded, as listed (cf. Appendix 5 Paragraph 1 VVEA) in the appendix to the Ordinance on Waste (VVEA, SR 814.600).
- In Type B landfills, individually identified waste and other mineral wastes are permitted, as long as the requirements for threshold values and eluate levels can be shown to be fulfilled (cf. Appendix 5 Paragraph 2 VVEA).
- Type C landfills are designated for the deposit of inorganic and difficult to dissolve waste and waste containing metals. That is mainly dependent on their previous treatment, for example, heat treatment, and the aim is to largely eliminate organic pollution (cf. Appendix 5 Paragraph 3 VVEA).
- Incineration residues such as waste incineration slag are typical of the types of waste permitted in Type D landfills (cf. Appendix 5 Paragraph 4 VVEA).
- In Type E landfills, finally, the range of waste is larger, although there is a strict maximum total content for organic material that must be adhered to. The individually listed types of waste may be deposited. Other types of waste are also permitted as long as they adhere to the fixed threshold values (cf. Appendix 5 Paragraph 5 VVEA).

In addition, typical Type C or E type disposals are only possible up to 0.5% w/v soluble salt content in the untreated waste. As reference, we report, in Table 3, the main parameters to meet to get the "benefit" to dispose in Type C landfill:

Table 3 – main parameters to meet to get the "benefit" to dispose in Type C landfill

Stoff	Grenzwert
Aluminium	10,0 mg/L
Arsen	0,1 mg/L
Barium	5,0 mg/L
Blei	1,0 mg/L
Cadmium	0,1 mg/L
Chrom-(III)	2,0 mg/L
Cobalt	0,5 mg/L
Kupfer	0,5 mg/L
Nickel	2,0 mg/L
Quecksilber	0,01 mg/L
Zink	10,0 mg/L
Zinn	2,0 mg/L

Stoff	Grenzwert
Ammoniak/Ammonium	5,0 mg N/L
Cyanid (frei)	0,1 mg CN-/L
Chrom (VI)	0,1 mg/L
Fluoride	10,0 mg/L
Nitrite	1,0 mg/L
Sulfite	1,0 mg/L
Sulfide	0,1 mg/L
Phosphat	10,0 mg P/L
Gelöster organischer Kohlenstoff (DOC)	20,0 mg C/L
pH-Wert	6 bis 12

Stoff	Grenzwert in mg/kg Trockensubstanz
Leichtflüchtige Chlorkohlenwasserstoffe (LCKW)*	1
Polychlorierte Biphenyle (PCB)**	1
Aliphatische Kohlenwasserstoffe C_5–C_{10}***	10
Aliphatische Kohlenwasserstoffe C_{10}–C_{40}	500
Monocyclische aromatische Kohlenwasserstoffe (BTEX)****	10
Benzol	1
Polycyclische aromatische Kohlenwasserstoffe (PAK)*****	25
Benzo(*a*)pyren	3
Gesamter organischer Kohlenstoff, der bis 400 °C freigesetzt wird (TOC400)	20 000
*, **, ***, ****, ***** gemäss Erläuterungen zu Ziffer 2.3 Buchstabe b	

During the planning phase while designing the drilling fluid, together with the target to achieve the required performance and properties, the aim was to minimize its environmental impact and consequently costs related to the final disposal at selected landfill.

The primary weighting material commonly utilized onshore in Central Europe, is sodium chloride to saturation at 1.19 sg and then use barite and/or calcium carbonate to achieve the desired final mud weight.

The worst-case scenario, in terms of waste classification and cost would be the landfill Type E that however accepts a maximum of 0.5% w/v salt concentration. To reduce the salt concentration in a salt saturated drilling fluid to such a low level would require a massive dilution resulting in a large volume to be disposed of with excessive costs.

Initially the operator required a polymeric fluid with potassium carbonate to inhibit potential marl formation present in the surface and intermediate intervals. This fluid was tested with and without barite in a certificated laboratory to determine its disposal type category (A, B, C, D, E). The purpose of this test was to determine whether the addition of calcium carbonate as weighting agent (Rezeptur 1, Table 4) in substitution of barite (Rezeptur 2, Table 4), would have impacted the final chemical result.

Table 4 – Results of Polymeric fluid with Barite and Calcium Carbonat (ANALYTIKUM Lab – Merseburg, Germany)

Bohrspülproben nach Eluatparametern LAGA und DepV; Bestell-Nr.: 71738

GBA-Nummer		21M05133	21M05133
Probe-Nummer		001	002
Material		Wasser	Wasser
Probenbezeichnung		**WBM Rezeptur 1**	**Rezeptur 2**
Probemenge		1 l	1 l
Probeneingang		05.10.2021	05.10.2021
Analysenergebnisse	***Einheit***		
pH-Wert von Wasser (Labor 20°C)		9,7	9,7
Leitfähigkeit	µS/cm	9900	12000
Ges.-Gehalt an gel. Feststoffen	mg/L	8500	12000
Cyanid ges.	mg/L	<0,0050	<0,0050
Cyanid, leicht freisetzbar	mg/L	<0,0050	<0,0050
Phenolindex	mg/L	<0,010	<0,010
DOC	mg/L	2300	870
Fluorid	mg/L	<0,50	1,3
Chlorid	mg/L	2000	2600
Sulfat	mg/L	550	790
Quecksilber	mg/L	0,00012	0,00032
Chrom ges.	mg/L	0,0078	0,0056
Nickel	mg/L	<0,010	0,020
Kupfer	mg/L	0,027	0,74
Zink	mg/L	0,012	0,082
Arsen	mg/L	0,0020	0,065
Selen	mg/L	<0,0010	0,0015
Molybdän	mg/L	<0,010	0,021
Cadmium	mg/L	<0,0010	<0,0010
Antimon	mg/L	<0,0010	0,023
Barium	mg/L	0,014	1,1
Blei	mg/L	<0,0050	<0,0050
Zentrifugieren			
Filtrieren			

BG = Bestimmungsgrenze MU = Messunsicherheit n.a. = nicht auswertbar n.b. = nicht bestimmbar n.n. = nicht nachweisbar

To minimize potential risks of waste thus reducing disposal costs, the target was to classify the drilling fluid within category Type C and the main parameter to monitor was the DOC which, to meet the requirement of Type C disposal must be below 20 mg/L. In accordance with Table 4, both fluids, with calcium carbonate and barite, presented a very high DOC values (2300 and 870 mg/L) far above the required specification.

The fluid team suggested an environmentally friendly alternative drilling fluid (WBDF, F4) largely used in onshore offset wells in Central-North Europe formulated with an engineered polysaccharide-based biopolymer acting as viscosifier and shale encapsulator, a modified starch fluid loss reducer able to meet the fluid loss specification with low impact on fluid's rheology and sized calcium carbonate material. Table 5 presents results of proposed WBDF issued by the selected environmental laboratory.

Table 5 – Analysis of a Biopolymer based drilling fluid (ANALYTIKUM Lab – Merseburg, Germany).

GBA-Nummer		21M06545
Probe-Nummer		001
Material		Kreidespülung
Probenbezeichnung		**Kreidespülung vom 01.12.2021**
Probemenge		1 l
Probeneingang		06.12.2021
Analysenergebnisse	***Einheit***	
pH-Wert von Wasser (Labor 20°C)		10,4
Leitfähigkeit	µS/cm	2800
Ges.-Gehalt an gel. Feststoffen	mg/L	2100
Cyanid ges.	mg/L	<0,0050
Cyanid, leicht freisetzbar	mg/L	<0,0050
Phenolindex	mg/L	<0,010
DOC	mg/L	200
Fluorid	mg/L	<0,50
Chlorid	mg/L	270
Sulfat	mg/L	57
Quecksilber	mg/L	0,00096
Chrom ges.	mg/L	<0,0050
Nickel	mg/L	0,046
Kupfer	mg/L	0,0079
Zink	mg/L	<0,010
Arsen	mg/L	<0,0010
Selen	mg/L	<0,0010
Molybdän	mg/L	<0,010
Cadmium	mg/L	<0,0010
Antimon	mg/L	<0,0010
Barium	mg/L	<0,010
Blei	mg/L	<0,0050
Abwasseraufschluss		

BG = Bestimmungsgrenze MU = Messunsicherheit n.a. = nicht auswertbar n.b. = nicht bestimmbar n.n. = nicht nachweisbar

The use of this formulation ensured a reduced DOC value to below 200 mg/L, within the limit dictated by local authorities.

Further tests were performed onsite during drilling activity, (degradation test). At the beginning of operations, the DOC of exhausted drilling fluid was evaluated and found to be 80 mg/L.

Since the drilling operations proceeded very fast, it was not possible to perform additional environmental lab testing to monitor the DOC of exhausted drilling fluid generated throughout the entire project.

Due to the uncertainties on real DOC values, operator decided to dispose all waste coming from the drilling fluid directly in Type E (most hazardous waste material classification) landfill at higher disposal cost. The fluid team suggested at the end of the project to evaluate other options to further reduce the DOC in the exhausted drilling fluid and in fluid remaining on cuttings. A Hi-G Dryer designed to dry cuttings, additional shale shakers or offsite treatment systems should be also considered.

Drilling performance of the Geothermal Fluid

Tanks to the excellent performance of an engineered environmentally friendly WBDF, a geothermal well in the Alps with medium enthalpy, was successfully drilled without any significant operational issues addressing all environmental requirements imposed by local lows. The drilling team achieved all operational objectives in a safe and faster manner.

The WBDF was formulated with a proprietary polysaccharide-based biopolymer with multiple functions of viscosifier, shale encapsulator as well as fluid loss reducer.

Utilization of a modified starch contributed to maintain API filtrates in the target with minimum impact of fluid's rheology.

Potassium carbonate was selected as chloride free shale inhibitor in substitution of polyamine to provide adequate inhibition of the marl present in the surface section as well as intermediate sections.

A dedicated bridging package was selected to minimize seepage losses, strength the wellbore and ensure improved filter cake quality.

The fluid was validated for the use by local environmental authorities following the results of the environmental tests performed during the pre-spud and the results of other environmental regulations in other countries of the European Union.

Brief description of operations of each hole section is outlined below.

23" surface hole to 450 m MD

Surface section in 23" was drilled without any operational issues with the use of unweighted WBDF to section TD at 450 m MD. Casing was safely run and cemented in according to the drilling program.

17 ½" first intermediate hole to 1228 m MD

This section was drilled using same WBDF as per previous interval. While drilling, at the depth of 590 m, mud weight was promptly weighted up to 1.42 sg to control a gas kick.

Pilot tests performed on rig site proved that this kind of drilling fluid was able to be weighted up with calcium carbonate to a density of 1.42 sg without affecting negatively its rheological profile by maintaining the rest of fluid's properties within the planned ranges. However, due to downhole tools limitations in using only calcium carbonate as weighting agent, the project engineers decided to increase the density to 1.36 sg with calcium carbonate and then up to 1.42 sg with addition of barite. The WBDF was able to keep the borehole stable for more than 48 hours, the time needed to pull the bit out of hole and perform the casing run. The 13 3/8" casing was then cemented.

12 ¼" second intermediate hole to 1950 m MD

Before spud the section, mud was centrifuged to 1.20 sg. Deviation angle was built with a max inclination of 33°. Prior to drilling into the "Membres d´Effingen" formation found at the depth of 1523 m MD, potassium concentration in the drilling fluid's water phase was raised from 28.0 to 45.5 g/L with addition of potassium carbonate and kept until section TD to provide extra inhibition to the marls. The low MBT values confirmed the good inhibition of the fluid. Cuttings on shakers resulted well separated and inhibited (Figure 8). 9 5/8" casing was run and safely cemented.

Figure 8: Cuttings on shakers-from section 12 ¼"

8 ½" reservoir hole to 2418 m MD

Prior to commencing drilling the reservoir section, the 1.20 sg WBDF was displaced out of the cased hole with new WBDF at 1.10 sg with same chemicals package as per previous sections without potassium carbonate. This section was successfully drilled to well TD at 2418 m MD with final deviation of 50° with steady ROPs and with low torque readings throughout drilling operations without recording formation losses.

Conclusions

- The green energy transition is an ongoing process in all European countries, and is growing year by year. Geothermal energy, which is considered a green energy resource, is continuing to grow.
- Rock type and its reactivity is depending on enthalpy, consequently Geothermal Drilling Fluids are formulated and tested.
- Central European countries have extensive hydrothermal geothermal activity, and their experiences can provide valuable insights for geothermal projects in other regions.
- Currently geothermal drilling relies on practices and procedures from the Oil & Gas industry, but these are not always fit for purpose on geothermal projects.
- Geothermal fluid design needs to be standardized. Firstly, the rheological profile of a fluid must be checked before and after hot rolling at the anticipated BHST to verify the fluid is compliant with the drilling requirements, then, a proper analysis on the fluid loss agents and their performance must be verified.
- The bridging package design in a geothermal fluid is mandatory because it helps in reducing fluid loss, strengthening the filter cake, and it has to cure microfractures responsible for seepage loss.
- Once the chemicals related to the rheology and the fluid loss control have been chosen, the studies should continue including all chemicals needed to solve other drilling requirements, like shale inhibition, lubricity, etc.

- As geothermal energy production is considered a green energy source, also the technique utilized to drill geothermal wells must meet more stringent environmental standards, potentially more than local regulations.
- Geothermal drilling has economics which are typically quite a bit lower than hydrocarbon projects, and disposal costs associated with the drilling fluid may be equal, if not higher than the cost of the fluid. A carefully evaluation of the environmental impact and disposal costs of fluids should be always included in the mud design process.
- Each country in Europe has its own fluid disposal regulations. This limits the sharing of different experiences and best practices from an environmental standpoint.

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Nomenclature

% w/v	*Weight/volume percentage*
AHR	*After hot rolling*
API	*American Petroleum Institute*
API FL	*API Fluid Loss test*
AwSV	*German Regulation to treat hazardous materials*
BHR	*Before hot rolling*
BHST	*Bottom Hole Static Temperature*
C	*Temperature, Celsius*
C/100 m	*Temperature gradient, Celsius every 100 meters*
cP	*Viscosity, Centipoise*
DepV	*Deponieverordnung, German Landfill regulation*
DOC	*Dissolved Organic Carbon*
EC50	*Concentration of drug that produce 50% of the maximum effect*
IC50	*Concentration of an enzyme inhibitor needed to inhibit 50% of the target*
kg/m3	*Concentration, kilogram per cubic meter*
LAGA	*Bund/Länder-Arbeitsgemeinschaft Abfall, German Federal/States Working Group on Waste*
lb/100ft2	*Pound per hundred square feet*
LC50	*Concentration of active principle in air or water able to kill 50% of animals that get it*
MBT	*Methylene blue test*
mg/kg	*Concentration, milligram per kilogram*
mg/L-g/L	*Concentration, milligram per liter-grams per liter*
ml	*Volume, milliliter*
NWG	*Nicht wassergefährdend, water not hazardous*
ROP	*Rate of Penetration*
rpm	*Revolutions per minute*
sg	*Density, Specific Gravity*
TD	*Total depth*
TVD	*Total vertical depth*
VVEA	*Verordnung über die Vermeidung und die Entsorgung von Abfällen, Swiss ordinance on the prevention and disposal of waste*
WBDF	*Water-based Drilling Fluids*
WGK	*Wassergefahrdungsklasse, environmental classification of water in Germany*

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