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Tracer Tests at Reykjanes Geothermal Field, Iceland

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ABSTRACT

HS Orka owns and operates 100 MW geothermal power plant at Reykjanes, Iceland. In August 2013 a two phase tracer test, one for the liquid phase and one for the steam phase, was carried out in Reykjanes geothermal field. The objective was to explore hydrological properties and pathways in the geothermal system at Reykjanes. The chemical tracers chosen for this test were 2.7 naphtalene disulfonic acid (2.7 NDS) for the liquid phase and methanol for the steam phase. The two phase tracer was injected into an injection well located to the east of the main production field, directionally drilled and cased down to 719 m. Samples of both brine and condensate have been collected from the beginning from each of the production wells, frequently for the first month, then twice a week for one month and weekly after that.

Achieved experience from the two phase tracer test, encourage a tracer test on a newly drilled well located on a proposed injection area, more than 1 km north east to the production area. The objective was to explore the connection between the proposed injection site and the production part of the area. In January 2014 the liquid tracer 2-naphtalene sulfonate (2-NS) was injected into the proposed injection well. Sampling will coincide with the two phase tracer test.

1. INTRODUCTION

HS Orka hf., located at the Reykjanes peninsula, is the largest privately owned energy company in Iceland producing approximately 9% of the country's power need. Installed power capacity is 175 MW_e from the company's two geothermal power plants at Svartsengi, 75 MW, and Reykjaens, 100 MW. In addition, HS Orka generates 150 MW thermal energy for district heating and supplies fresh water to the municipalities at the Reykjanes peninsula. Both power plants are connected to the Icelandic transmission grid.

1.1 Reykjanes geothermal field

The Reykjanes field is a hot, two-phase geothermal reservoir, with measured temperature exceeding 300°C in the reservoir and fluid salinity of seawater. The Reykjanes geothermal area is located at the SW tip of the Reykjanes peninsula (Figure 1), where the Mid-Atlantic Ridge rises above sea level. The geothermal systems is a sub-aerial continuation of the Reykjanes ridge.

Exploration and development of the Reykjanes geothermal field dates back to about 1956 when the first well was drilled, more exploration drilling followed in 1968 and 1969. The first proper production well, RN-8, was drilled in 1969 and started production in 1970. In the years 1970-2006 the average production rate in the field was 40-80 kg/s, first only from one well, RN-8, but in 1983 well RN-9 was added. (Óskarsson et al., 2013) The reservoir has been in operation for power production since May 2006, when Reykjanes power plant started generation of 100 MW_e with two 50 MW_e steam turbines.

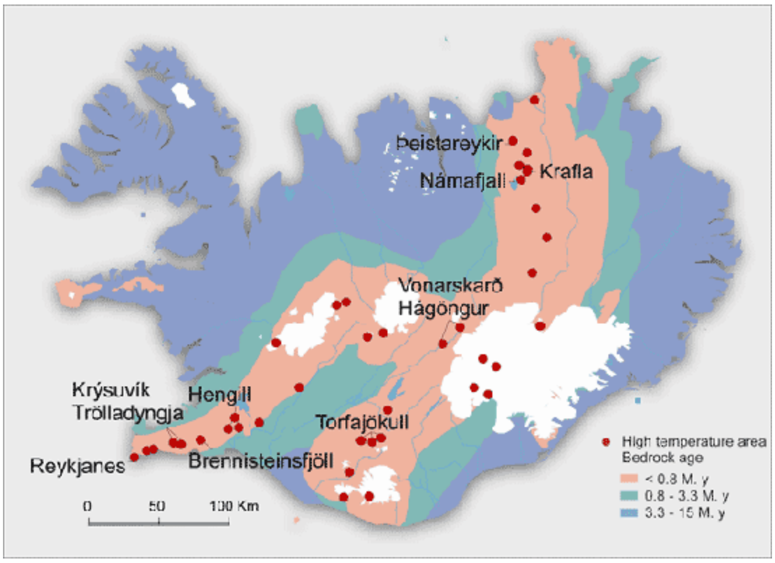

Figure 1: Map showing the Mid-Atlantic Ridge splitting Iceland and separating the North American and Eurasian Plates. The high temperature areas are located on the Ridge.

Average production from the reservoir is 520 kg/s of 220°C, 22 bar WHP, geothermal fluid. Approximately 140 kg/s of the waste fluid, a mixture of brine and condensate, is injected into one well RN-20 at 800 m distance from the production zone. A proposed injection site is located NE of the production area. One injection well, RN-33, was drilled there in late 2013 (Figure 2), further drilling is considered.

In this paper, a two sequential tracer tests conducted at the Reykjeanes field in 2013 and 2014, will be discussed. Tracer test is a powerful method for characterizing the subsurface flow rates. The tests were carried out to explore hydrological properties and pathways in the geothermal system at Reykjanes as well as connectivity between the injection and production parts of the field.

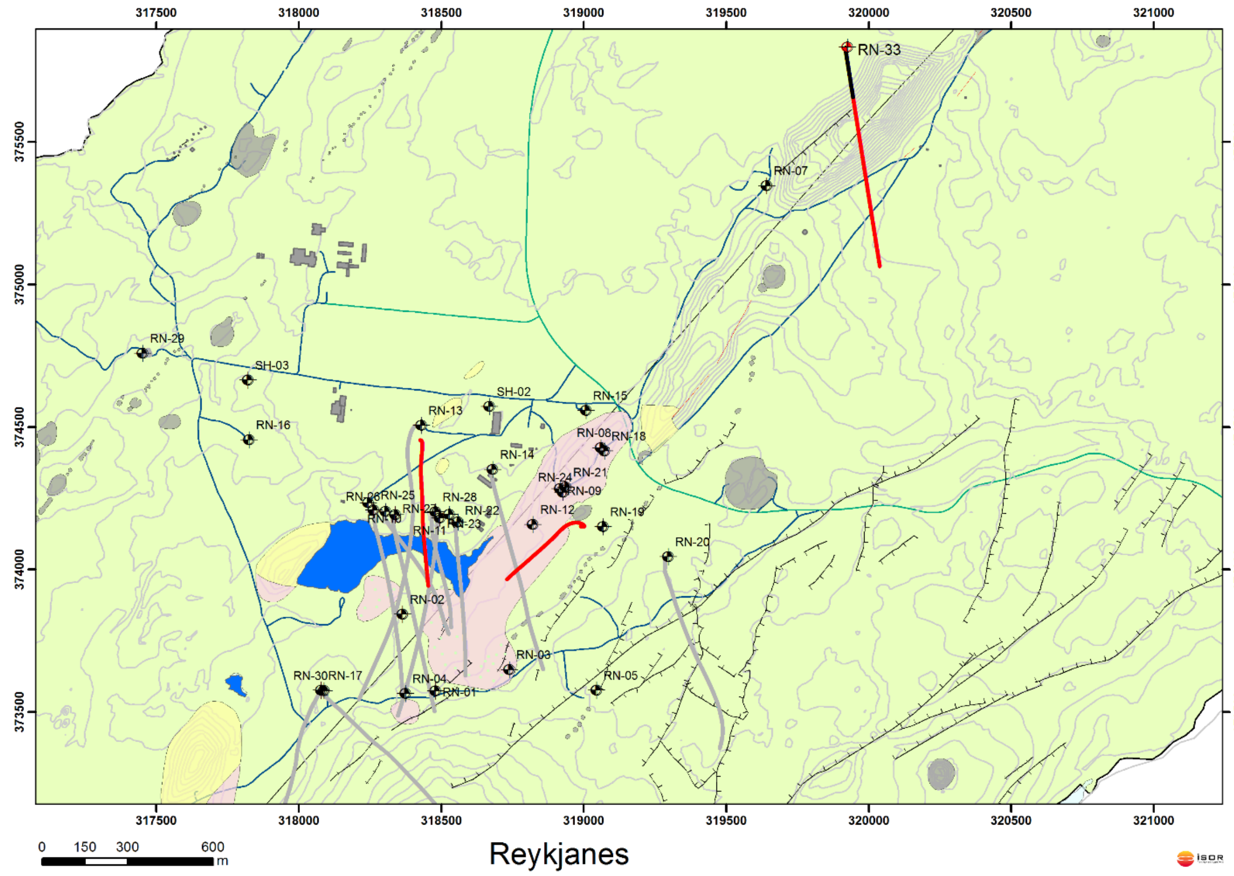

Figure 2: Reykjanes production field, RN-20 TT#1 injection o

2 TRACER TESTS

In August 2013 and January 2014, two separated but sequential tracer tests were conducted in the geothermal system at Reykjanes. The objective was to explore hydrological properties and pathways in the geothermal system at Reykajnes. Early attempts to quantify injection returns from injection well RN-20 using iodide tracer was unsuccessful, most likely because the high reservoir temperature caused breakdown of the chemical tracer.

More thermally stable chemicals were chosen for the current tests, naphthalene sulfonates for the liquid phase and methanol for the steam phase. These tracer have proven to be excellent tracers in high temperature geothermal reservoirs, they are environmentally benign and detectable at very low concentration. (Rose et al., 2002, Adams et al., 2004).

2.1 Tracer injection

The first test (TT#1) started August 12th 2013 by injection of two tracers into well RN-20; 75 kg of 2.7 naphthalene disulfonate (2.7 NDS) and 2.000 l of methanol (MeOH). The 2.7 NDS is a liquid phase tracer expected to travel with the liquid phase through the reservoir, and the MeOH was expected to travel with the steam phase. Injection into well RN-20 during the test was approx. 140 kg/s (75% brine, 25% condensate).

The second test (TT#2) started on January 10th 2014 by injection of 150 kg of 2-naphtalene sulfonate (2- NS) into a newly drilled well RN-33, located on a proposed injection area more than 1 km north east to the production area (Figure 2). Injection into the well was approx. 55 kg/s fresh water for about 6 months.

2.2 Sampling and analyzes.

Brine and condensate samples have been collected from all production wells in the field. Sampling was frequent the first 48 hours of TT#1, in order to capture potential rapid breakthrough of the steam phase tracer, then twice a week for one month and weekly after that. Samples are collected into a 60 ml glass bottles, condensate samples with Webre separator but brine samples with a simple T-shape separator (Figure 3).

The naphthalene sulfonates were analyzed by Iceland Geosurvay (ISOR) using High Performance Liquid Chromatography (HPLC) with fluorescence detection. Detection limits for the naphthalene sulfonates in the salty fluid of Reykjanes is 0.2 ppb. The methanol samples were analyzed by Peter Rose and his team at the Energy & Geoscience Institute of University of Utah. The samples were analyzed using Solid Phase Microextraction (SPME) followed by GC/MS. The method provides a detection limits of 25 ppb. Selected samples were analyzed for methanol, in total 190 samples were analyzed

Figure 3: Simple T-shape separator to collect brine samples. The bucket collects excess liquid during washout prior sampling.

3 TRACER RETURNS

The tracer recovery curves are shown in Figures 4-8. As of the end of July 2014 only small amounts of tracers have been recovered. About 11 kg of 2.7 NDS, or about 15% of the 75 kg injected in TT#1, and about 2 kg of 2-NS (TT#2), corresponding to 1.3% of the 150 kg injected, has been recovered. Only an insignificant amount of the MeOH, steam-phase tracer, was recovered (Axelsson, 2014).

The return curve on Figure 4 shows a rapid return of MeOH at a low concentration (just above detection limits) in most of the wells, with 4 peak values. The return is not quite as expected considering the existence of a steam cap in the reservoir, a disintegration of the MeOH injected due to the high reservoir temperature must be considered, however a decent explanation for this behavior hasn’t been found. The rapid return of a low concentration MeOH might imply a connection between the injection into RN-20 to the shallow feed zones, where MeOH quickly travels through the steam cap and enters shallow feed zones of the production wells.

The 2.7 NDS has penetrated through most of the field, detected in 10 out of 16 wells sampled, and is by the end of July 2104 declining in all wells detected. The most significant recovery has been through well RN-19, with both the shortest arrival time and the largest peak (Figure 5), indicating strong connection with the injection well. Other wells show moderate to low recovery. The 6 production wells that have not seen the 2.7-NDS tracer share deep feed zones, which might indicate that injection into well RN-20 is not supporting the deep roots of the reservoir. An interesting behavior is seen in both of wells RN-19 and RN-21 (Figure 6 and Figure 7), where a very brief peak with relatively high MeOH concentration is seen approximately at the time of the 2.7 NDS breakthrough. In both cases the peak only involves one sample. The reason for this is not understood, but it appears that a small amount of MeOH travelled with the part of the injected water that had the highest velocity while travelling between wells (Axelsson, 2014).

By the end of July 2014, 2-NS (TT#2) concentration continues to climb and has so far penetrated only the northern part of the field. Calculated recovery of the 2-NS (TT#2) is mainly from one well, RN-18, which shows the most directly connections to the injection well RN-33. Recovery through other wells has both been less and considerably slower. Recovery curve for return of TT#2, 2-NS, is shown on (Figure 8) (Axelsson, 2014).

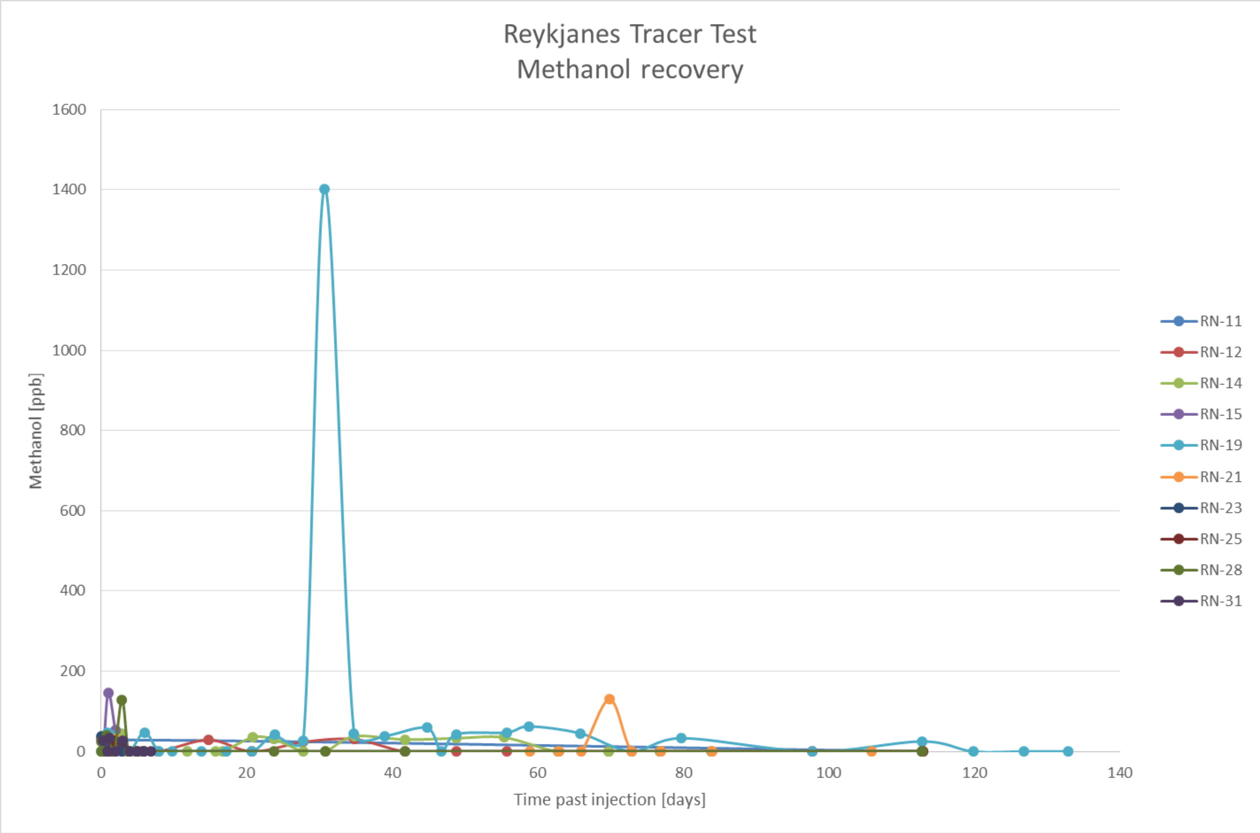

Figure 4: Methanol recovery from TT#1, injection of two phase tracer, MeOH and 2.7 NDS, into well RN-20.

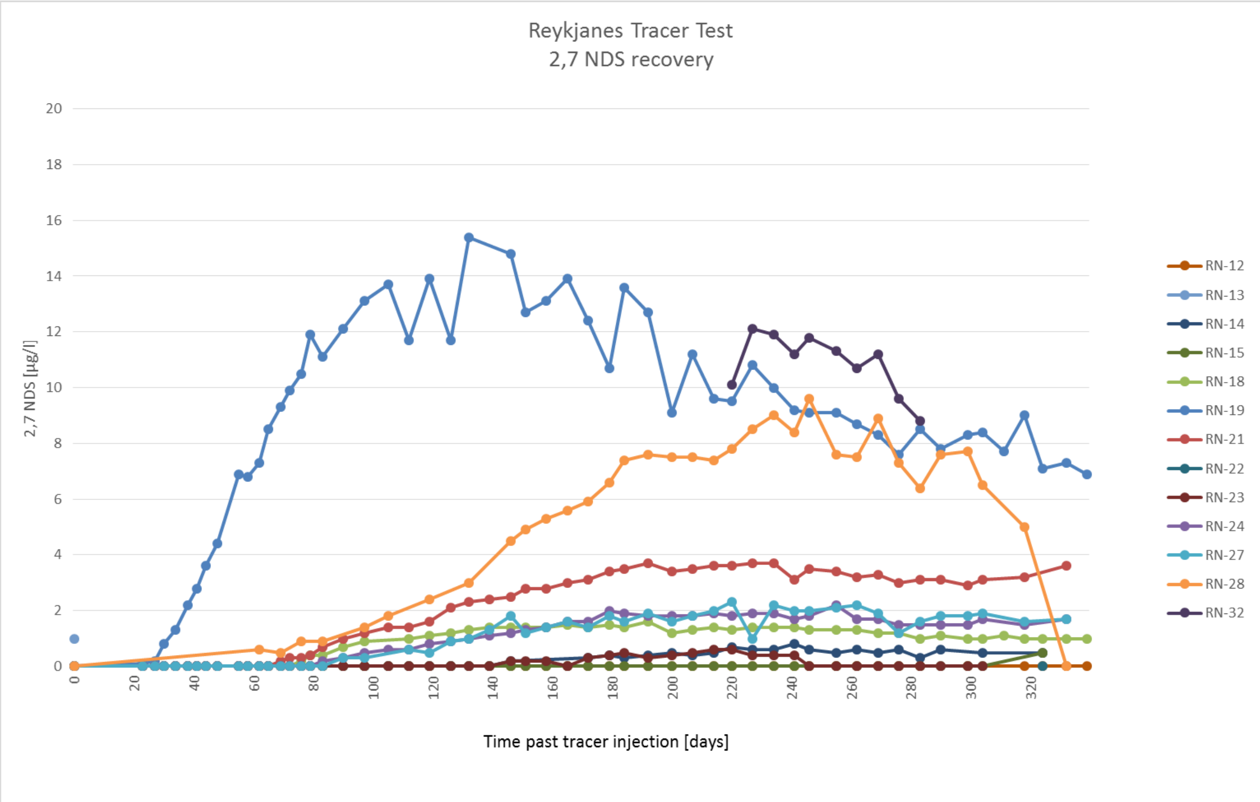

Figure 5: 2.7-NDS recovery from TT#1, injection of two phase tracer, MeOH and 2.7 NDS, into well RN-20.

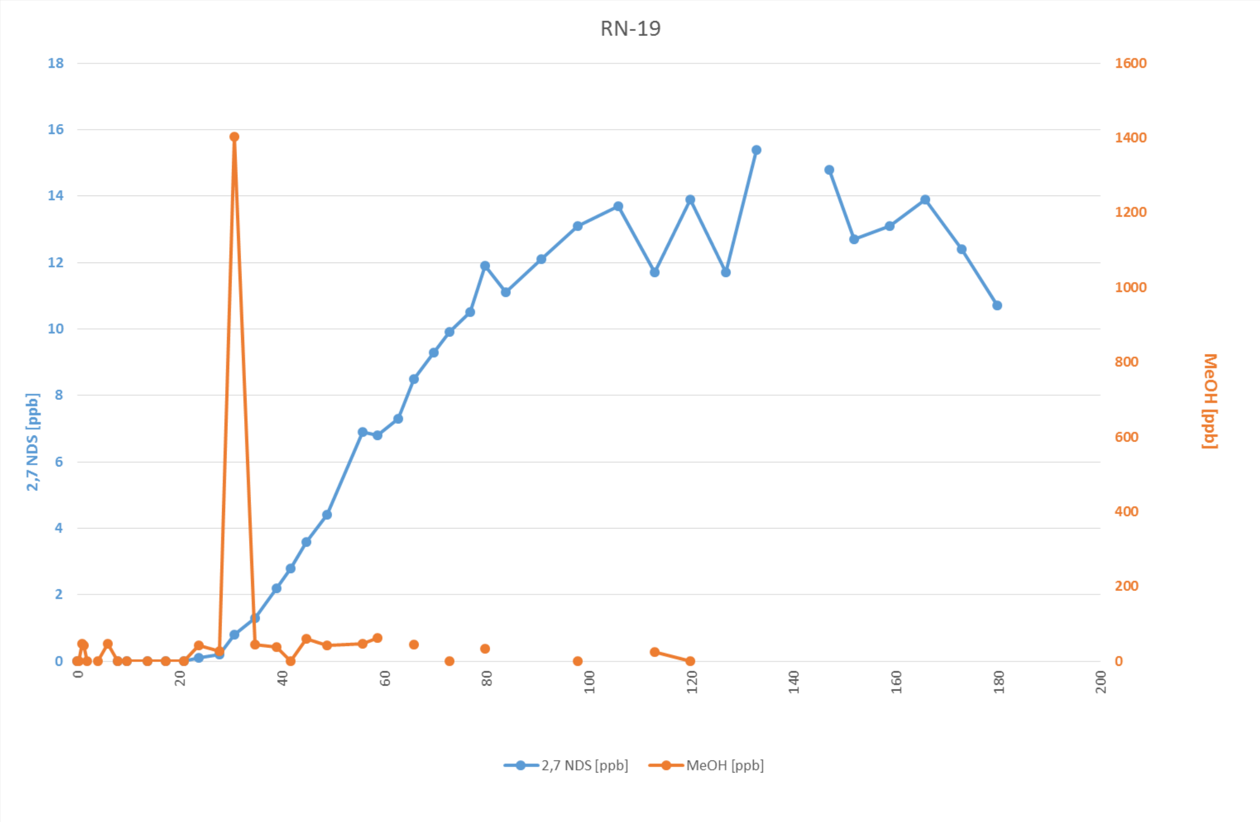

Figure 6: Simultaneous appearance of methanol and the 2.7 NDS tracers for well RN-19 on day 30 past injection.

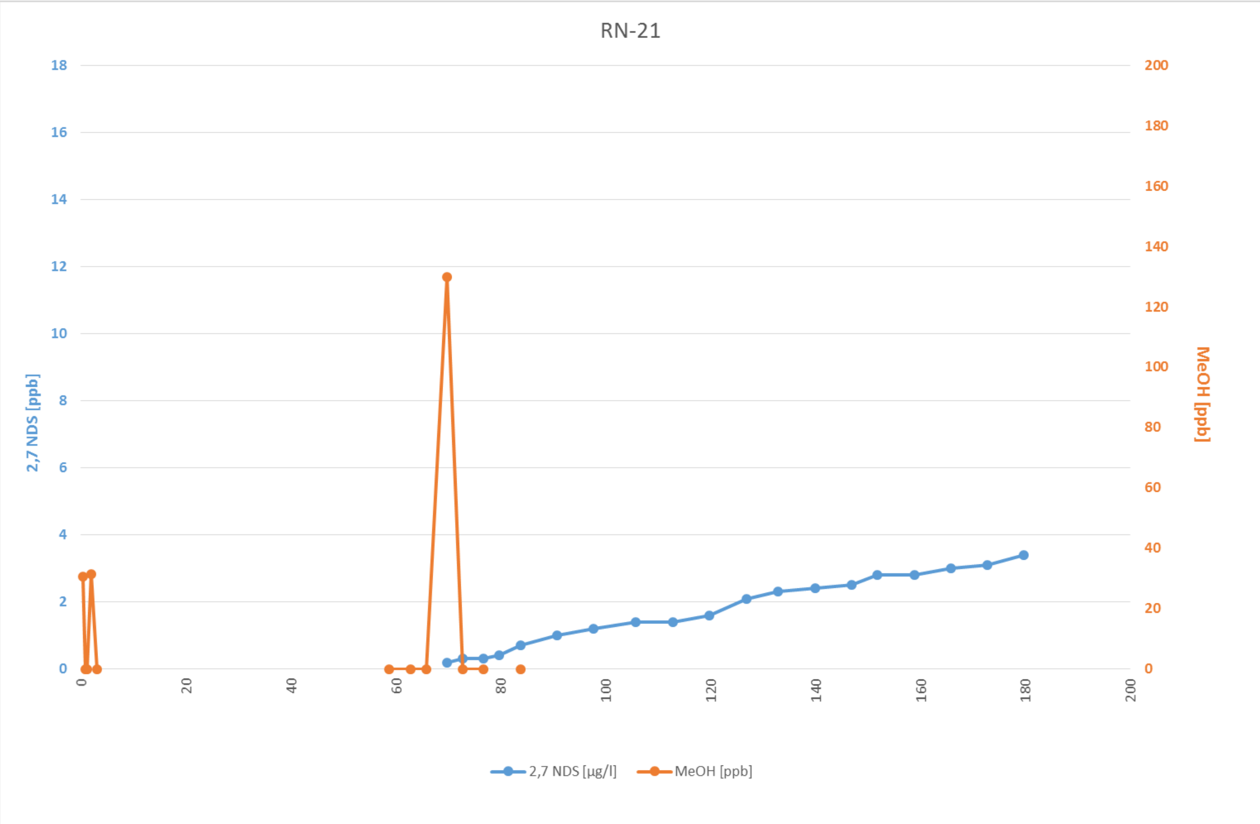

Figure 7: Simultaneous appearance of methanol and the 2.7 NDS tracers for well RN-21 on day 70 past injection.

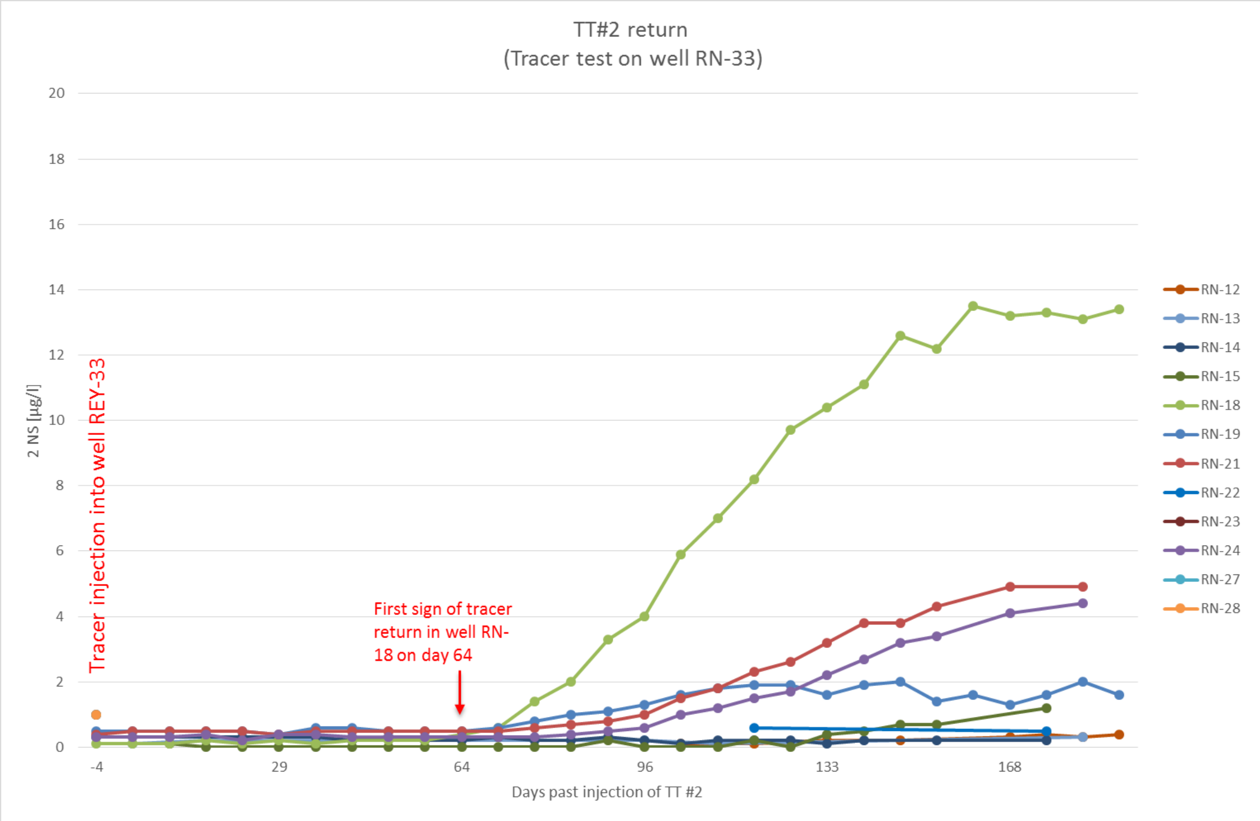

Figure 8: 2-NS recovery from TT#2, tracer returned in well RN-18 day 64 past injection and is still rising in July 2014.

4 CONCLUSION

Two separated but sequential tracer tests have recently been conducted at Reykjanes geothermal field to explore the hydrological properties and pathways in the geothermal system. As of the end of July 2014 only small amounts of tracers have been recovered. About 11 kg of 2.7 NDS, or about 15% of the 75 kg injected in TT#1, and about 2 kg of 2-NS (TT#2), corresponding to 1.3% of the 150 kg injected, has been recovered. Only an insignificant amount of the MeOH, steam-phase tracer, was recovered (Axelsson, 2014). The 2.7 NDS has been detected in 10 out of 16 production wells and is decreasing in the field while the 2-NS continues to climb and has so far penetrated only the northern part of the field.

Tracer return interpretation as of the end of July 2014:

- Injection into well RN-20 could have limited support to the deeper reservoir in the western part of the well field as tracer has not showed up in well there with dominant deep feed zones.
- The water injected into RN-20 most likely leaves at moderate depth, below 1.000 m or below the steam cap. A moderate support to the shallower feed zones of the well field could be achieved.
- The rapid return of a low concentration MeOH might imply a connection between RN-20 and the shallow feed zones of the well field. The tracer test imply that a minority of MeOH quickly travels through the steam cap to shallow feed zones of the well field.
- 2-NS is still rising and has not penetrated through the field yet, however, the test imply strong connection between the proposed injection site and the production site is an actuality.

The two tracer teste discussed above are bringing invaluable information on the hydrological properties and pathways in the north east and east part of the reservoir. Achieved experience has encourages HS Orka to explore the subsurface pathways and flow rates to the south and west as well. Two liquid tracer tests are scheduled in the Reykjanes geothermal field in the next few months. The forthcoming tests will certainly bring additional invaluable information to our current knowledge of the Reykjanes system.

5 REFERENCES

Axelsson, G., (2014): Analysis of tracer tests conducted in the Reykjanes geothermal system 2013-2014, draft, Iceland GeoSurvey, ISOR-14037

Óskarsson, F. and Friðriksson, Þ, (2013): Geochemical Monitoring in 2012 Reykjanes – Production Field, Iceland GeoSurvey, ISOR-2013/015

Adams, M., Yamada, Y., Yagi, M., Kasteler, C., Kilbourn, P., Dahdah, N., (2004): Alcohols as two phase tracers. Proceedings, Twenty-Ninth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, 2004.

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Rose, P., Capuno, V., Peh, A., Kilbourn, P. and Kasteler, C., (2002): The use of the naphthalene sulfonates as tracers in high temperature geothermal systems. Proceedings, 23rd PNOC Geothermal Conference.