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Harnessing of Geothermal Energy in the Öxarfjördur Area, NE Iceland

Axel Björnsson and Hrefna Kristmannsdóttir

Látraströnd 30, 170 Seltjarnarnes, Iceland

axel.bjornsson@orkugardur.is

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ABSTRACT

At the Bay of Öxarfjördur in NE Iceland there is extensive geothermal activity, confined to three fissure swarms transecting the NE volcanic zone. The geothermal systems in the area are low-temperature and boiling low-temperature fields. The area is sparsely populated, but with increasing tourism. A popular National Park with unique geological formations and landscape is located in the district. A municipal district heating system was built about twenty years ago in the eastern part of the area for a fish farming plant as well as the small town Kópasker and nearby rural farm houses. The production water is saline causing much trouble in the operation of the heating system due to corrosion and scaling. Some of the rural farmhouses in the eastern part have not yet been connected to the district heating system. In spite of much effort there has yet to be an established municipal geothermal heating systems in the western part of the area. Buildings in the sparsely populated rural area are mainly heated by electricity and the cost is many fold compared to geothermal heating. There are several options for building a geothermal heating system in the western part of the Öxarfjördur area. A well with a potential for heating most of the area was drilled seven years ago, but severe obstacles, mostly political, have been met in efforts to harness it. Now a site for drilling another well has been decided upon, which will most likely be drilled in the next few months. The plan is to build a municipal central heating system serving all farm houses, a hotel and guest houses in this touristic popular area within the next two years. The utilization of heat pumps for district heating may be rather viable in places as there are excessive resources of lukewarm water in the area. Use of geothermal energy may play a key role in keeping the Öxarfjördur area populated in the future.

1. INTRODUCTION

The bay of Öxarfjördur is located in NE Iceland (Figure 1) where the active zone of rifting and volcanism in Iceland intersects the Tjörnes transverse fracture zone which offsets the plate boundary towards the west (Georgsson et al. 2000, Saemundsson, 1974). The lowland of Öxarfjördur is a 25 km broad N-S trending down faulted sediment filled trough. The area is dominated by the river delta built up by the glacial river Jökulsá á Fjöllum. The river has repeatedly changed its location and flooded the lowland.

The north east volcanic zone is segmented into discrete volcanic systems consisting of a central volcano and a fissure swarm (Figure 2). There are four main fissure swarms within the NE volcanic zone, of which two have been volcanically active in historic time (Saemundsson, 1974). The fissure swarms are the main aquaducts for groundwater flow from the highlands towards the lowland in the north as well as for seawater intruding from the north into the young permeable rock formations.

Extensive geothermal activity is in the Öxarfjördur area, all of which is mostly confined to three fissure swarms transecting the NE volcanic zone (Figure 2). Most of the geothermal manifestations at the surface are within the Krafla fissure swarm, but also in the sandur plain (Georgsson et al., 2000). There have only been detected low-temperature geothermal systems (reservoir temperatures below 150°C) in the Öxarfjördur area so far. Further to the south within the fissure swarms, there are located several powerful high-temperature geothermal systems (Björnsson et al., 2007, Georgsson et al., 1989, 1993, 2000, Kristmannsdóttir et al., 2007). Several geoscientists proposed in the eighties that some of the geothermal fields in Öxarfjördur, located within the northern end of the Krafla fissure swarm (location on Figure 2) might be high-temperature geothermal fields. Later research revealed them to be boiling low-temperature geothermal fields with reservoir temperatures well below 200°C (Karlsdóttir and Flóvenz, 2005). Some of the geothermal systems in Öxarfjördur are probably cooling high-temperature systems.

The groundwater in the area is affected by effluent water from the active high-temperature geothermal systems in the south flowing towards north along the fissure swarms. Volcanic episodes in the fissure swarms also greatly influence the groundwater system in the Öxarfjördur area by increasing amount of geothermal effluent water heating up the water flow in the fissure swarms (Björnsson, 1985, Sigurdsson, 1980). In addition to the high temperature water flowing from south, there is a massive flow of fresh water from the highlands mixing with sea water which has an easy access into the fractured young rock formations, further complicating the groundwater system in the area. The groundwater system in the Öxarfjördur area is thus rather complicated. Fully saline water, brackish and fresh groundwater, occur intermixed and wells located close to each other may yield completely different kind of waters. The groundwater systems as well as the geothermal waters have been studied by several scientists during the last twenty years (Hafstad, 1989, Georgssson et al., 1989, 1993, 2000, Kristmannsdóttir and Klemensson, 2007, Kristmannsdóttir et al., 2007). The geothermal water in the area is brackish, with the salinity partly derived from local sediments building up the Jökulsá river delta and partly by inflow of sea water into the fissure swarms.

One municipal heating system is operated in the area, serving the village of Kópasker and some of the farms along the pipeline. Fish farming has been built up in the area utilizing geothermal water. In the area is a popular National Park with unique geological formations and landscape and tourism is blooming. The sparsely populated rural area is, however, mainly heated by electricity at a very high cost as compared to geothermal heating. The tourist trade is not competitive with other areas in Iceland due to high cost of heating and the lack of geothermal spas. Therefore, the potentials for possible geothermal heating systems are greatly anticipated, but means are limited to explore the area and harness the known geothermal areas.

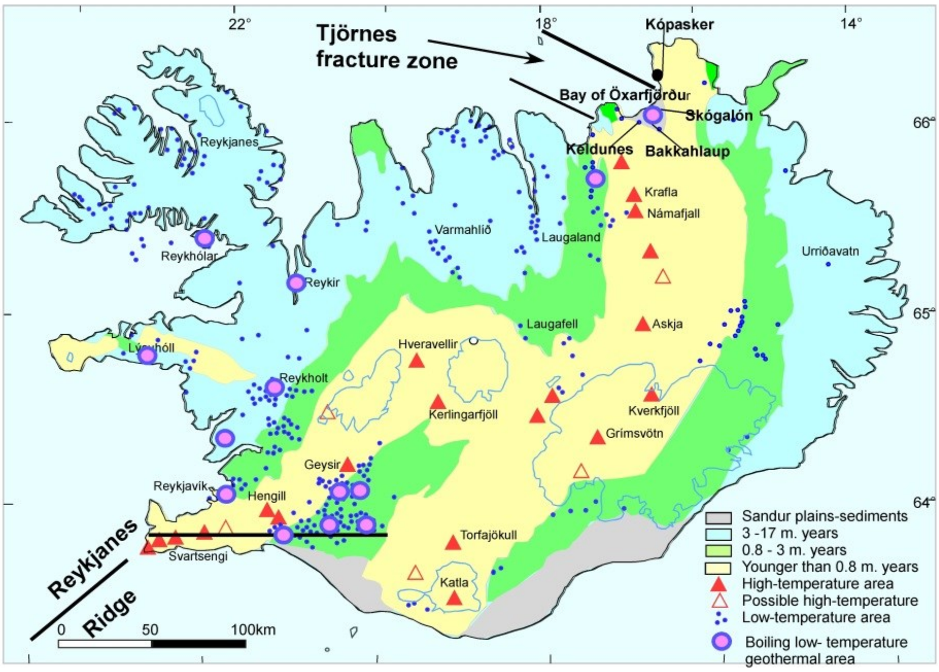

Figure 1. A simplified geological map of Iceland showing the location of high-temperature, low-temperature and boiling low-temperature geothermal fields. The location of the Bay of Öxarfjördur and Skógalón, Bakkahlaup and Keldunes geothermal fields is pointed out. Based on data from Saemundsson, (1979) and Björnsson et al., (1990).

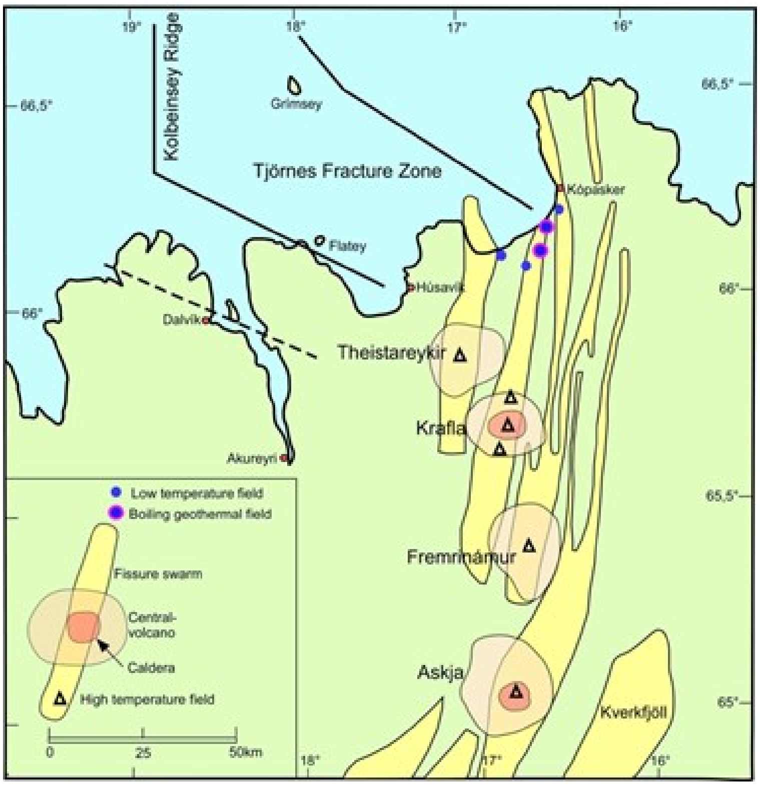

Figure 2 Volcanic systems and fissure swarms in the NE active zone in Iceland (Björnsson et al., 2007). Main geothermal sites in the Öxarfjördur area are also shown.

2. GEOTHERMAL FIELDS IN THE AREA

As pointed out in the introduction there is extensive geothermal activity in the Öxarfjördur area (Figures 1 and 2), but most of the known springs are not hot enough to use them directly for heating. Geothermal prospecting has been on and off during the last forty years, but due to lack of funds in this sparsely populated region it has not yet been very effective and few wells have been drilled. The main two geothermal fields are the Skógalón and Bakkahlaup geothermal fields, but there are also quite a number of other geothermal fields in the Öxarfjördur area and the geothermal potential is assumed to be considerable.

2.1 Skógalón

The Skógalón geothermal system utilized for the Öxarfjörður heating system, is now classified as a boiling low-temperature geothermal field. At shallow levels, very high temperatures, 80-100°C, are found in an area covering several hundred square meters (Georgsson et al., 2000). In several places towards south from the main geothermal field there are geothermal surface manifestations (Georgsson et al., 1993). Four wells have been drilled into the Skógalón field and the heating system for the village of Kópasker utilizes one of them. The one used as production well, AER-3, was drilled down to 322 m in 1988 as an exploration well (Georgsson et al., 2000). It is located a few meters from the ocean shore at a river mouth. During winter a sand reef forms closing the river mouth and thereby creating a lagoon between the reef and the bank. The well is then surrounded by seawater and isolated from the de-aeration tank and booster pump station, some 450 m away. The only way to access the well during winter is by boat, even though that may not always be possible due to ice covering the lagoon. The ice cover is not safe to pass by foot due to numerous hot springs at the bottom of the lagoon. The well head temperature was 96°C at the start of production, but has increased over time by 20°C to 116°C. The salinity of the water is 3‰ (Table 1).

Table 1. Chemical composition of geothermal water in some of the Öxarfjördur geothermal fields. Chemical composition from a well in the Seltjarnarnes geothermal field is shown for comparison.

Location	Öxarfjördur Well AER-03	Bakkahlaup Well BA-03	Bakkahlaup Well BA-04	Keldunes Brunnar spring	Seltjarnarnes Well SN-06
Sample no.	2006-001	2006-02	2008-01	2007-08	HK-11-011
Date	30.01.06	30.01.06	8.02.08	23.5.07	18.10.11
T °C	116	82	76	22	118
pH/°C	6.9/22	7.55/22	8.46/20	8.25/22	8.39/20
SiO_2 mg/L	172	135	158	46.2	147
B µg/L	1260	2370	740	105	251
Na mg/L	949	3410	632	82	577
K mg/L	46	122	28.6	8.0	14.2
Ca mg/L	178	75	57	17.2	486
Mg mg/L	0.311	7.3	0.269	4.85	0.485
Sr mg/L	0.73	1.46	0.103	0.04	2.24
Al µg/L	26	7.2	23	8.9	36
Fe µg/L	45	83.5	4.1	2.0	5.5
Mn µg/L	23	131	1.46	0.04	10.4
CO_2 mg/L	23.2	17.9	37.6	52.8	4.5
Hg µg/L	0.14	0.04	0.02	0.006	0.008
H_2S mg/L	0.24	0.01	0.015	0	0.26
SO_4 mg/L	119	761	145	25.6	321
Cl mg/L	1671	6222	1020	124	1650
F mg/L	0.28	0.15	0.93	0.19	1.1
Cond. µS/cm at. 25°C	5615	18350	3300	536	5210
TDS mg/L	3136	11425	1915	334	3201

2.2 Bakkahlaup

One of the low-temperature geothermal fields is at Bakkahlaup located some 10 km south west of the Skógalón field in the sandur plains of the Öxarfjördur area (Figure 1). The surface manifestations were warm ground spread over a wide area with temperatures as high as 80°C at just 1 m depth after the Krafla fires, but considerably lower before (Georgsson, 2000). The aquifer temperatures are about 80°C, but a temperature as high as 170°C has been measured within one of the wells at relatively shallow depths, but it was much colder deeper down (Karlsdóttir and Flóvez, 2005). Four wells have been drilled into the field mainly with the aim to locate a high-temperature geothermal field indicated by geophysical explorations (Georgsson et al., 2000, Karlsdóttir and Flóvenz, 2005). Three of the wells drilled into the Bakkahlaup field are located east of the river Jökulsá, whereas the last well, BA-04 is located on the western bank of the river north of the farm Keldunes (Figure 3) (Fridleifsson et al., 2007). All the wells yield saline water, but the chemical composition varies (Table 1).

2.3 Other geothermal sites

About 13 geothermal sites are known in the Öxarfjördur area (Georgsson et al., 1993). Of those 7 are located within the Krafla fissure swarm. Most of the sites, except Skógalón and Bakkahlaup have low surface temperatures. Near Skógar just south of Skógalón there is high ground temperature exceeding 90°C, but no flow of water. In the western part of the area surface temperatures of about 50°C have been recorded (Georgsson et al., 2000). A 165 m deep well was drilled there for a fish farming company in 1987 yielding 45°C hot water (Geoorgsson et al. 1993). The water has about 12.3‰ salinity (Kristmannsdóttir and Klemenzson, 2007). All other geothermal manifestations have much lower temperatures. One of the sites with the highest flow rate is in Brunnar near the farm Keldunes (Figure 1). There are several springs yielding tens of liters of lukewarm water, which at present has temperatures up to 22°C (Kristmannsdóttir and Klemensson, 2007). During a major volcano-tectonic rifting event in the Krafla fissure swarm the water temperature in those springs went up to more than 40°C (Björnsson, 1985, Sigurdsson, 1980). Besides the mentioned geothermal sites massive flow of lukewarm water is flowing along the Krafla and Theistareykir fissure swarms (Hafstad, 1989). A big river, Litlaá of about constant temperature of about 12°C is discharged from some of the springs tapping part of the lukewarm flow in the Krafla fissure swarm. The mean annual groundwater temperature in this part of Iceland is about 3°C. Also in the Theistareykir fissure swarm there is a massive flow of about 13°C water towards north.

Figure 3. Well BA-04 being drilled at the western bank of Jökulsá in 2006.

3. KÓPASKER HEATING SYSTEM

The village of Kópasker is located on the east coast of the Bay of Öxarfjördur (Figure 1).The heating system for the village and part of the eastern Öxarfjördur region was built in 1994 using water from well AER-3 in Skógalón (Kristmannsdóttir and Björnsson, 2012).

3.1 Properties of the geothermal water in AER-03

The geothermal water is saline, about 3‰, devoid of oxygen and with low concentration of hydrogen sulfide (Table 1). The chalcedony geothermometer (Fournier, 1977) indicates reservoir temperature about 150°C as well as the relation between calculated activity products in the water and corresponding equilibrium constant for the formation of selected alteration minerals (log Q/K) against temperature in the area (Kristmannsdóttir and Björnsson, 2012). Alkali (Na/K and K/Mg) geothermometers (Arnórsson, 1991, Giggenbach, 1988) indicate somewhat lower reservoir temperatures, but the water is classified as fully equilibrated and mature water according to the plot on the Giggenbach Na-K-Mg and Cl-SO_4-HCO_3 ternary diagrams. As all Icelandic low-temperature geothermal waters, the Skógalón water is in equilibrium with calcite at the reservoir temperatures (Kristmannsdóttir et al., 2010). The gas concentration of the water is rather low, but about 2-6% (vol) of the emanating gas is organic, mostly methane and partly of higher hydrocarbons (C_2H_6, C_3H_8) (Ármannsson et al., 1998). The Öxarfjördur through is filled with sediments and probably thermal formation of biogas has occurred.

3.2 Corrosion in the system

In water of such high salinity as in well AER-03 in Skógalón (Table 1) there is a danger of corrosion by even the slightest uptake of oxygen. As the water is devoid of oxygen at the well head and with a low concentration of hydrogen sulfide one would though not expect too much corrosion problems by utilization of the water. Some uptake of air always happen in the input frames in houses and some corrosion was thus anticipated and installation of heat exchangers in every house was made obligatory from the beginning of operation. Elsewhere in Iceland similar waters have been used in heating systems without any great problems (Kristmannsdóttir, 2004). There substantial corrosion problems have arisen in the system, both from inside the system and also due to corrosion from outside. The design and material choice in the heating system has not been suitable for this kind of water and not adapted to the environmental surroundings or previous constructions. Increase of the water temperature over time also has created more problems and partly changed the original basis for the design of the heating system.

Uptake of air and thus oxygen will eventually happen in hot water flowing through polybutylene pipes, not shielded on the outside by a metal foil or other kinds of preventive measures. When the district heating system in Öxarfjörður was constructed those pipes were used. Later, parts of the distribution net were replaced by steel pipes as the plastic pipes did not last more than a few years at the high temperatures nearest to the tank and pumping station. Corrosion due to oxygen uptake has, therefore, always been a problem in the distribution system of the heating system in Öxarfjördur and will probably be a problem as long as the distribution net is mainly laid in polybutylene pipes unprotected for oxygen uptake. The rate of steel corrosion is higher there than known in any other heating system in the country (Figure 4).

Both input frames and heat exchangers of houses have also quickly corroded and damaged heavily. It is not possible to use steel in the intake frames of houses as the steel construction only holds for a year or two which is a very short time. The intake frames have had to be made from polypropylene pipes and connections. The temperature at the intake is at a maximum about 76°C so polypropylene is a suitable choice for pipes in the distribution net of the village and intake frames of the houses. It is planned to replace the polybutylene pipes with steel pipes in the whole distribution system, except in the first part from the well to the pumping station.

Figure 4. Corroded joints from the distribution system in the eating system in Öxarfjördur.

Figure 5. A View towards north to well AER-03 and steam separator in summer 2006, when the steel pipe was being dug up.

Unfortunately, at one point oxygen uptake took place in the steam separator, causing corrosion within the steel pipes. Fortunately, that mistake was be corrected in time before too much damage was done (Kristmannsdóttir and Björnsson, 2012).

Outside crack corrosion of stainless steel pipes has also occurred in the system. In 2005 the heating system got the advice from an engineer to replace the spoiled plastic pipes distributing the water from the well to the de-aeration tank and booster pump some 450 m away with stainless steel pipes. The plastic pipes had lasted for 12 years, even though they were rather thin walled. The stainless steel pipes, however, only lasted for a year, when they were completely wasted due to corrosion cracking. As the very hot pipes are surrounded by highly saline water saturated by oxygen, such outcome should have been anticipated. Even though the temperature is high for the use of plastic pipes it is still the only viable choice for this first part of the distribution system where the pipes are surrounded by sea water in the lagoon during winter time (Figure 5). So specially made thick walled polybutylene pipes had to be laid the first 450 m from the well head to the de-aeration and pumping station. There may be a small uptake of oxygen in this part of the distribution net, but if the rest of the distribution system is laid in steel pipes or plastic pipes with protection for oxygen uptake the content of hydrogen sulfide will be sufficient to destroy the small amount of oxygen possibly taken up in this first part of the distribution net.

3.3. Scaling

As all Icelandic low-temperature geothermal waters the Skógalón water is in equilibrium with calcite at the reservoir temperatures, but becomes supersaturated by boiling and de-aeration of the water (Kristmannsdóttir and Björnsson, 2012). In the system this has taken place both in the steam separator, by cavitation in the pumps and by de-aeration in the tank. The management of the heating system claims that scaling in the distribution system increased by the increase of well head temperature. There is, however, no written record on this and the scaling has not been monitored by test plates in the distribution system. After complaint from the users it was discovered that the first part of the distribution system from the pumping station was severely clogged and in 2005 it had to be cleaned with acid washing. After that, the steam separator was installed, lowering the production temperature. No scaling was found inside the separator, however, some scaling was found in the pipeline from the separator towards the de-aeration tank and pumping station. The steam separator was in operation in the years 2005-2007 after which it had to be disconnected due to corrosion. After the steam separator was disconnected in 2007 the problems due to cavitation in the pumps became very bad. The temperature of the water was also much too high in first part of the distribution system as well as in the farms nearest to the pumping station. As the super-saturation of calcite in the water has commonly reached values equal to values previously inducing scaling in other Icelandic heating systems it is of no surprise that scaling occurred in the system, especially since the water could boil both at the well head, in the steam separator and by cavitation in the pumps (Kristmannsdóttir et al., 2004). The scaling products are found dispersed around in the system, especially in the intake sieves. This is due to the fact that the scale piles up in the system and are transported through it after break off from original location when the system is shut down and then repressurized. As the water is not supersaturated at the well head there should be a way to avoid any scaling during utilization by a proper design. The solubility of calcite increases by cooling of the water, so cooling of the water under pressure may avoid its supersaturation and subsequent precipitation. This was done in the installation in 2007 by using a cooling device prior to the water entering the de-aeration tank and booster pumping station. This seems to have solved the calcite scaling problem and scaling has not been reported much since then. The calcium concentration of the water was monitored in the years 2007-2010 and did not indicate any scaling in the system as it was constant from the well head through the system to the Kópasker village. At the moment scaling in the system is negligible so it seems like later improvements by installations of cooling device are working. This solution is, however, rather costly as it requires the use of ample electricity for pumping. It also wastes valuable energy by cooling the water without using the energy for either heating or electricity production. The case for scaling in the system seems to be mostly the result of improper handling of the fluid in the system. Scaling could probably have been avoided by proper design of the system in the beginning. A good solution for the heating system would be to install a binary unit at the wellhead and utilize the energy by cooling the water from 116°C to about 80°C. This would both prevent scaling problems and produce electricity instead of using it. At present this solution is not possible due to the high investment cost and poor economic situation in the region.

4. HARNESSING GEOTHERMAL ENERGY IN THE WESTERN PART OF ÖXARFJÖRDUR AREA

The sparsely populated rural area in western part of Öxarfjördur is heated by electricity and a possible geothermal district heating system is greatly anticipated, but means to build it are restricted. Already in the 1970´ties plans were discussed for exploring the area in the aim to build a district heating system. A well was drilled near Keldunes in 1971 to 365 m depth, but was unsuccessful and further exploration was postponed (Saemundsson et al. 1972). The Krafla fires and tectonic rifting event in the Krafla fissure swarm caused many changes in the area increasing water temperature of many springs (Björnsson, 1985, Sigurdsson, 1980). The unrest in the area has probably delayed further plans for geothermal harnessing. As there is excessive flow of lukewarm water along both the Krafla fissure swarm and the Theistareykir fissure swarm the possibility of utilizing heat pumps for district heating seems rather viable in the area. It is rather surprising that no serious study has been made of that solution of part for the district heating problem.

4.1 Drilling of well BA-04

In 2006 well BA-04 was drilled about 3 km north of the farm Keldunes. The well was drilled down to 610 m depth and even though it did not hit aquifers with water of temperatures high enough for electricity generation it yields water of temperatures suitable for district heating. The well yielded almost 20 L/s of 76°C hot water at the end of drilling. The first aquifer of about 64°C and with salinity of 0.9‰ was hit at about 380 m depth (Kristmannsdóttir, 2006, Fridleifson et al., 2007). The main aquifer at about 560 m depth is 78°C (Fridleifson et al., 2007). When the drilling was concluded the temperature of the free flowing water was 76.5°C and salinity of the water after a months flow test was 1.3‰ (Kristmannsdóttir, 2006). The salinity of the water changed from 1.3‰ to about 2‰ during the first production test lasting for 20 months, but has stayed more or less constant since. The yield declined to about 8 L/s in the first two years after drilling, but has been more or less stable since. The bottom temperature of the well is 86°C. After finishing of the well there was performed a long corrosion and scaling test, concluded in January 2008 (Kristmannsdóttir and Björnsson, 2008). Later thorough scaling tests as well as prefeasibility study for the building of a district heating system was made by Tucker (2010) giving promising results. Still another corrosion test was performed in 2010-2011demonstrating almost no corrosion potential of the water (Kristmannsdóttir et al., 2012).

4.2 Chemical properties of well BA-01

The chemical composition of the geothermal water from the BA-04) is shown in Table 1. The geothermal water is classified as sodium chloride waters (Kristmannsdóttir and Björnsson, 2008). Trace concentration of sulphide is in the water. The water is depleted in magnesium as all geothermal waters and the concentration of aluminum is very low as common in saline geothermal waters. The concentration of iron and manganese is low, as well as of zinc and mercury. The concentration of all other analyzed trace elements is very low. Fluoride is found to be rather on the high side. The composition of stable isotopes of $\%^2H$= -80‰ and $\%^{18}O$ = - 11‰ indicates a mixture of three components; groundwater from the southern highlands, seawater and local groundwater (Kristmannsdóttir et al. 2007). Further, very low pMC values (% 14C) for Keldunes indicate that those samples represent a mixture with geothermal effluent water from the Krafla high temperature geothermal field (Kristmannsdóttir et al. 2007). The reservoir temperatures indicated by the calculated chalcedony geothermometer are 140-145°C and according to the sodium-potassium geothermometers they are 125-150°C (Fournier, 1977, Arnórsson et al., 1991). Calculated mineral equilibria for many common alteration minerals in basaltic rocks indicate mixing of waters at reservoir temperatures of 110-140°C.

4.3 Production properties for well BA-04

The chloride concentration of the water, is considered to be too high for direct use in a district heating system. Several saline low-temperature geothermal waters are used for district heating purposes in Iceland, but only by the use of heat exchangers if the salinity exceeds 0.4-0.5‰ (Kristmannsdóttir, 2004). Increased chloride concentration acts as a catalyst for all reactions including corrosion and scaling so one has to be very careful by the utilization of even slightly saline water. The concentration of H_2S in the water is very low so it gives very little corrosion protection by uptake of oxygen. Most Icelandic geothermal waters are nearly in equilibrium with calcite and contain no free CO_2. Calculated saturation with respect to calcite shows the water to be slightly supersaturated and in the beginning extensive downhole scaling of calcite did take place (Kristmannsdóttir and Björnsson, 2008). The scaling in surface pipes and equipment was also considerable in the first flow test. In later tests the scaling turned out to be insignificant. Downhole logging of the well in 2012 showed that there was insignificant scaling inside the production casing and no major narrowing or obstruction was demonstrated deeper down. Possibly, the initial precipitation was due to drilling fluids injected into the well and ceased after normal recharge had been acquired. Prolonged later corrosion and scaling tests have verified that the water is well fit for the use in a heating system, but by the use of heat exchangers in each house (Kristmannsdóttir and Björnsson, 2008, Tucker, 2010, Kristmannsdóttir et al., 2012)

4.3 Future plans

In spite of the thorough testing of well BA-04 and positive results both for production properties and prefeasibility study it has taken a very long time and much effort for the local people to try to convince the municipality of the feasibility of building a district heating system based on well BA-04. A group of locals has even applied for the permission to build it themselves, but the application was declined. At present the status is that the municipality finally requested (spring 2014) a feasibility study to be made by an engineering firm and their results are awaited. The group of locals had in the winter of 2013-2014 asked the authors of this paper to locate a new well near to the farm Keldunes. After a study and evaluation of geological and geothermal data the location has been decided up on (Figure 6) and most likely the well will be drilled in 2014-2015 if the municipality will not in the meantime harness well BA-04 or give the local people permission to do so.

Figure 6. The proposed location of a new well at Keldunes farm (Figure 1), just south of the farmhouses.

5. CONCLUSION

Harnessing of geothermal energy in the Öxarfjördur area for district heating purposes has taken a long time in spite of extensive geothermal activity in the area. The geothermal activity is confined to three fissure swarms transecting the NE volcanic zone. The geothermal systems in the area are low-temperature and boiling low-temperature fields, but so far no high-temperature geothermal fields have been detected in spite of the area being located at the edges of the active zone of rifting and volcanism. The area is sparsely populated, but with increasing tourism. A municipal heating system was built some twenty years ago in the eastern part of the area for a fish farming plant, the small town Kópasker and nearby rural farm houses. In the western part a municipal geothermal heating systems has not yet been established. Buildings there are mainly heated by electricity and the cost is, therefore, many fold the cost of geothermal heating.

Extensive production problems have been faced in the Öxarfjördur heating system, both due to steel corrosion and calcite scaling. Those problems have been various and often induced by the poor design of the system, poor choice of material and changes made without proper consideration. Natural changes in the system also play some role though, as the temperature of the water has increased by 20°C since drilling. The history of the heating system demonstrates a long list of mistakes as improper choice of material and or poor design. The reason is partly limited knowledge and experience at the time of construction, but also the fact that the heating system served few people and had very limited funds to cover high cost of proper consultation. Installation of a binary unit at the wellhead would both prevent scaling problems and produce electricity instead of using it. That would be a very good technical and economical solution in the long run, but probably not possible at present due to high investment cost. The lesson learned from the study of the Öxarfjördur system is that under such difficult conditions much care has to be taken when a system is designed and material choices made.

In the western part of the region are several options for building a geothermal heating system. A well with a potential for heating most of the area was drilled seven years ago, but severe obstacles, mostly political, have been met in efforts to harness it. Now a site for drilling another well has been decided upon, which will most likely be drilled in the next few months if the dispute of the existing well will not be resolved soon. The local people plan to build a central heating system serving all farm houses, a hotel and guest houses in this popular touristic area within the next two years. They realize that the use of geothermal energy may play a key role in keeping the Öxarfjördur area populated in the future.

In some parts of the Öxarfjördur area the installations of heat pumps based on ample resources of lukewarm water may be the best choice for heating alternatives to direct electricity. There are many places in the area with good possibilities for such solutions. There are also possibilities for drilling geothermal wells, but then the financial risk is considerable and for a rural area it may turn out to be safer and cheaper in the end to utilize existing lukewarm water for a heat pump rather than drilling a well.

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