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Integration of Geothermal Energy in the Case of North Eastern Morocco

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Human society is facing various challenges. One of them is growing energy demand as consequence of growing population and fast development of many countries. An important part of a potential solution is sustainable supply of energy. Geothermal energy presents an opportunity for reducing fossil energy consumption and improves the sustainability of processes and the whole society. Geological conditions should be considered when integrating geothermal energy into the energy supply systems. These have significant impact on the temperature and flow-rate of the medium used for energy supply. To achieve an optimal integration of the geothermal energy the generation should be simultaneously analysed – the supply side and the energy consumption - demand side.

The optimal integration of renewable energy needs a trade-off between investment and operating cost. The largest investments for sourcing geothermal energy are usually related to the drilling and the heat exchangers. Pumping the energy transfer fluid also presents a considerable operating cost and a parasitic energy demand. The overall utility supply presents the main operating cost. The aim of this work is to investigate the trade-off between the depth and location of the drilling, and the energy consumption of the demand side.

The trade-off described is evaluated on the case of North Eastern Morocco, where an area with a significant geothermal potential is available. It is not yet exploited as a source of energy. In general the evaluation of the financial aspects for the development of a geothermal system depends strongly on a proper site characterisation. The presented work aims at combining the drilling depth with the temperature, heat flow and the various domains of utilisation. A number of aspects are taken into account, such as the geothermal potential of this province, the legal framework and the identification of markets for geothermal resources – the need requirements for the heat energy at various levels

1. Introduction

The world is facing an era of expensive energy supply, which requires an adaptation of policies and country strategies. It has not only greatly increased the cost but also environmental, social and political impact of all energy using activities. This is a consequence of many factors: enormous increase in global energy demand, driven by continued population growth and economic development, while the rate of discovery of new energy deposits has been dropping.

The capability of the environment to absorb effluents and emissions is close to be saturated. Environmental impacts include those caused by particulate matter, acid rain, and greenhouse effects resulting in climate change. The developing countries are especially vulnerable to those impacts because of lack of infrastructure and facilities to accommodate new circumstances. This results in the increased cost of public health, permanent damage to ecosystems, and risks to the safety of goods and people.

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Geothermal natural resources have the potential for contributing to reduction the mentioned effects. In the work presented here the opportunities for direct geothermal heat utilisation have been analysed. Evaluation of heating requirements of greenhouses and swimming pools are presented in the paper considering the agricultural and tourist sectors of North Eastern Morocco. In this case the evaluation of the energy system requires Process Integration (Klemeš et al., 2010) linking the energy consumption of the demand side to the supply side, where the depth of drilling has significant impact.

2. Geothermal data

Geological and hydrogeological data from boreholes indicates that Liassic carbonates are the main hydrogeothermal reservoir in the region. This reservoir is highly variable in thickness (50-1,140 m) and its top has a maximum depth of 1,370 m. Meteoric waters are driven from high towards lower lands, i.e. from Jbel Hamra to the Angad plain at Oujda and from Beni Snassen to Triffa plain next to Berkane.

According to Zarhloule (1999), the hot temperature and the artesian rise of most of the thermal springs in North Eastern Morocco is due to groundwater circulating at depth within a framework of recent volcanic area and a system of basement faults, individuating horsts and grabens.

Figure 1 shows the distribution of the geothermal gradient (Zarhloule 1999). The largest geothermal gradients are located in the North-Eastern part of Morocco, up to 50 °C km^{-1}. This part of the country is also characterised by high residual magnetic anomalies related to widespread Quaternary volcanism.

Figure 2 presents the heat flow density map obtained from data available for Morocco and the surrounding regions (Rimi, 1999). The regional pattern highlights heat flux increasing north-eastwards, from less than 60 (North Mauritania) to more than 80 - 90 mW m^{-2} in the Eastern Rif, North Eastern Morocco, Alboran Sea and North Western Algeria. The Gibraltar Arc region is characterised by a radial heat flow pattern, with increasing values from the outer ranges towards the central and eastern part of the basin.

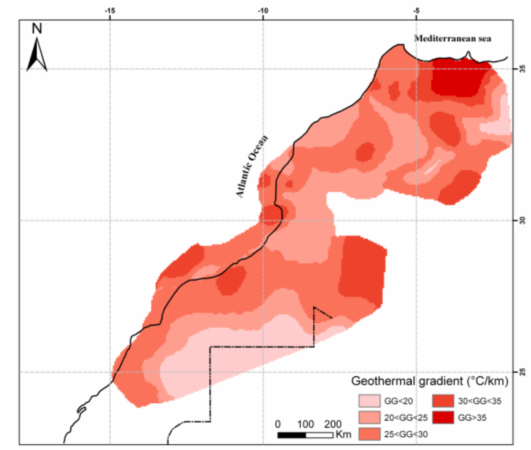

Figure 1: Geothermal gradient map of Morocco (Zarhloule, 1999)

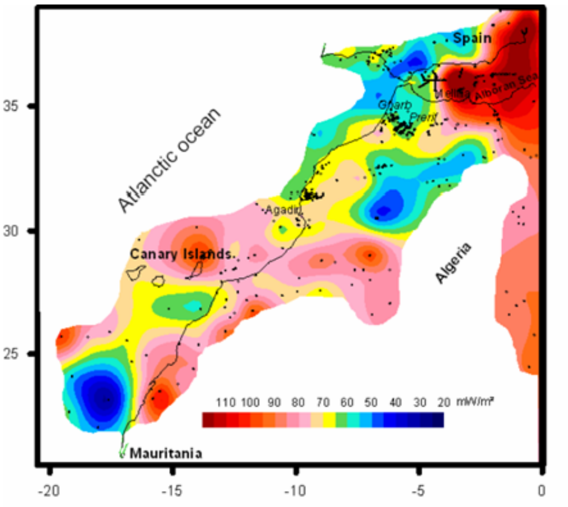

Figure 2: Terrestrial heat flow density in Morocco and neighbouring regions (Rimi, 1999)

Many water boreholes were logged from 2007 to 2009 within the framework of a geothermal survey conducted in North Eastern Morocco to better understanding of the thermal water behaviour inside the Liasic geothermal reservoir. Among the recorded thermal profiles, Figure 3 shows one interesting example for the well 1624/7, located west of Berkane (Rimi et al, 2012).

This hole is characterised by an increase of geothermal gradient at 300 m depth from 29 to 127 °C km^{-1}. It is the depth, where lithology changes from clay to dolomite. At about 470 m depth, the temperature is about 50 ºC. The shape of the thermal profile argues for a conductive thermal regime both in the upper (clay) and in the lower (carbonate) section of the hole. The dolomitic formation continues until the hole bottom (1,042 m depth). By extrapolating the thermal gradient inferred in the lowermost section of the hole, a bottom temperature of about 120 °C is inferred.

The geochemical analysis of thermal waters from six hot springs and boreholes whose discharge temperatures range from 26 to 54 °C has been performed. Discharge rates range from 2.5 to 40 L s^{-1} and TDS varies from about 130 to 30,000 mg L^{-1}. Thermal waters are mainly of Ca-Mg-HCO_3 and Na-Cl type.

Reservoir temperatures were estimated applying several techniques. Average temperatures span from 102 °C, as inferred from quartz, chalcedony and Na-K geothermometers, to 122 °C as obtained from the analysis of mineral equilibria.

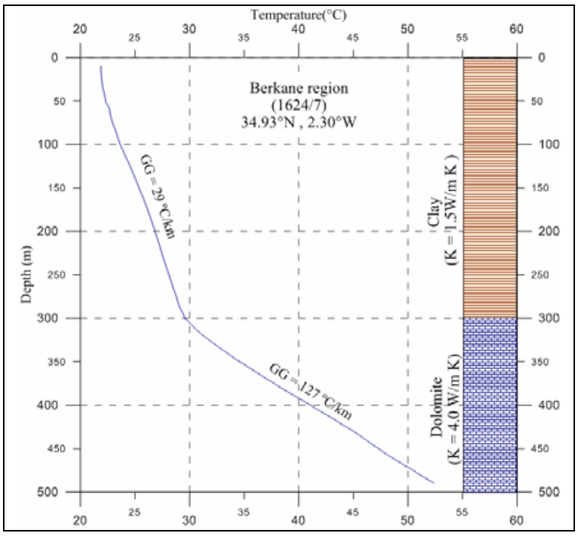

Figure 3: Temperature log of the well 1624-7 in the region of Berkane

The synthetic approach based on the treatment and the compilation of geological, geophysical and hydrogeothermal data, allowed identifying several potential geothermal zones as following (Zarhloule et al, 2010), see (Figure.4:

- Northern Morocco that is characterised by geophysical anomalies (gravity, magnetism and electrical conductivity), high geothermal anomalies, neo-volcanism, neotectonics, important aquifers
- South of Morocco that is characterised by plioquatrenary volcanism, high heat flow, geophysical anomalies,
- Middle part of Morocco that is characterised by three zones, where is a high shallow geothermal gradient, with hot springs that represent discharge from deep reservoir, and upward moving groundwater flow.

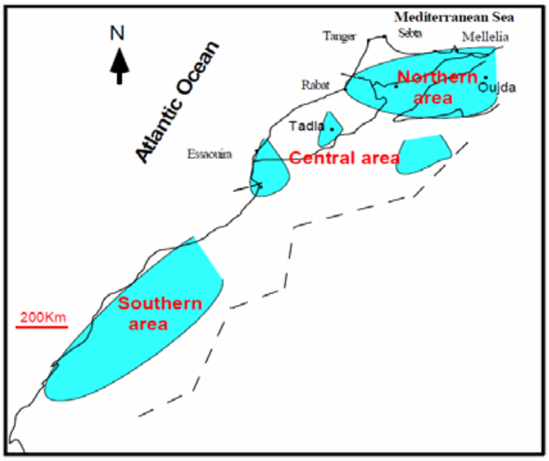

Figure 4: Potential geothermal fields in Morocco (Zarhloule et al, 2010)

3. **Technologies and markets for geothermal energy in North Eastern Morocco**

North Eastern Morocco is one of the most important geothermal fields in the country. No geothermal project was developed until now despite the potential market concerning electricity production and some direct uses such as agriculture, mining, industrial processes and tourism activities (Figure 5). The Estimated Installed Capacity (EIC) in North Eastern Morocco was calculated using the Eq (1). Therefore, the geothermal energy used annually by the natural hot baths in Morocco, remains less than 50 TJ/y, which corresponds to a capacity of 3 MW (Rimi, 2012).

$$\mathrm{EIC} = \text{peak use} \times \Delta T \times 0.004184 \times \text{number of baths} \qquad (1)$$

$$\mathrm{EIC} = 10\ \mathrm{L/s} \times 10\ ^{\circ}\mathrm{C} \times 0.004184 \times 12$$

$$\mathrm{EIC} = 2.51\ \mathrm{MWt}$$

The Annual Energy Use (AEU) $= \text{Average user} \times \Delta T \times 0.1319$

$$\mathrm{AEU} = 3\ \mathrm{L/s} \times 10\ ^{\circ}\mathrm{C} \times 0.1319$$

$$\mathrm{AEU} = 47.48\ \mathrm{TJ/y}$$

One of the major steps that can influence the success of a geothermal project is related to the drilling operation. The challenge of geothermal drillings is to access the reservoir with minimum drilling-induced formation damage at minimum cost. In the low-moderate enthalpy geothermal setting, the risk is higher, when deeper wells are necessary to achieve higher (moderate) temperatures. The drilling cost plays an important economic factor for the site development. According to Sperber et al. (2010), geothermal drillings can be even more expensive (in cost/depth) than onshore oil and gas drilling.

Pinch Analysis application to this case study was performed to improve the economy. This methodology provides a systematic approach for energy saving in processes (Linnhoff and Hindmarsh, 1983) and also in Total Sites introduced by Dhole and Linnhoff (1993) and step by step developed (Klemeš et al, 1977) and recently extended by Varbanov and Klemeš (2012). A very important problem became data reconciliation (Manenti et al., 2011).The heat demands are considered are cold streams and heat supply from geothermal source is considered as hot stream. First the heat demand options are review and after the supply, considering different depth of drilling. The data from the borehole 1624/7 were used.

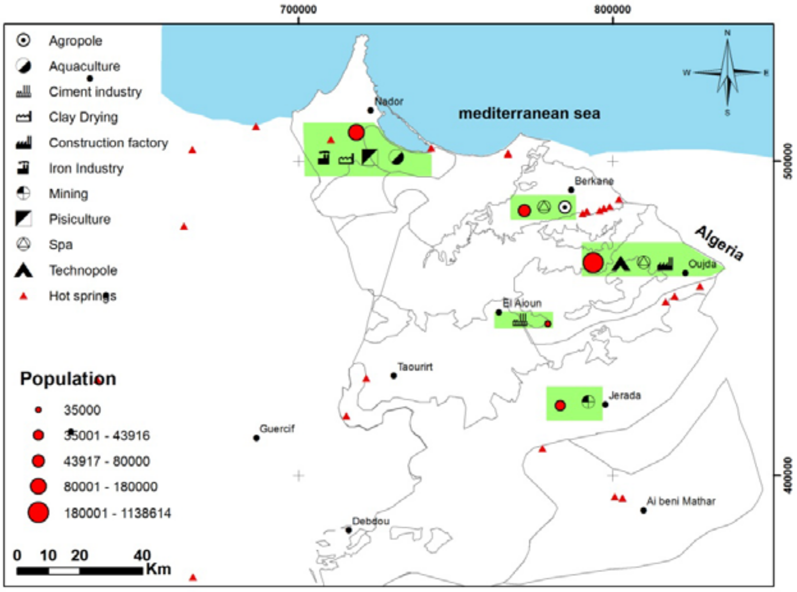

Figure 5: Potential heat-market

3.1 Heat demand

Greenhouses are one of the largest low enthalpy energy consumers in agriculture (Popovski, 1998). As an example, the optimum growth temperature of cucumbers, tomatoes, and lettuce is shown in Figure 6 (Barbier and Fanelli, 1977). The optimal temperature of cultivation with the highest percentage of grown for the lettuce is between 12 - 17 °C, for tomatoes around 17 - 27 °C and for cucumber between 25 and 30 °C. Utilising geothermal energy for heating can reduce operating cost.

Geothermal water is extensively used for hot pools and baths. The desirable temperature for swimming pools is from about 30 °C to 35 °C in spas (Figure 7). In the past, the geothermal water was seldom used for heating or cooling of the spa buildings. Today, indoor adventure pools are often designed instead of pure medical application spas or a combination of both. Pool heating is one of the simplest geothermal applications, as it usually uses the geothermal water directly in the pool to provide the required heat demand especially in low enthalpy environment. In advanced geothermal system, swimming pools are used in the end of other geothermal applications - Cascade use (Lund et al., 2005).

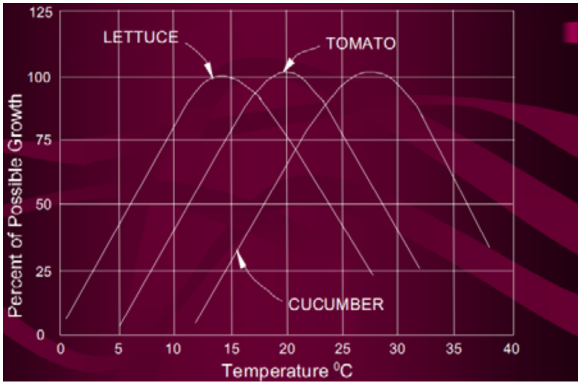

Figure 6: Optimum temperature for growing selected agricultural products. (Barbier and Fanelli, 1977)

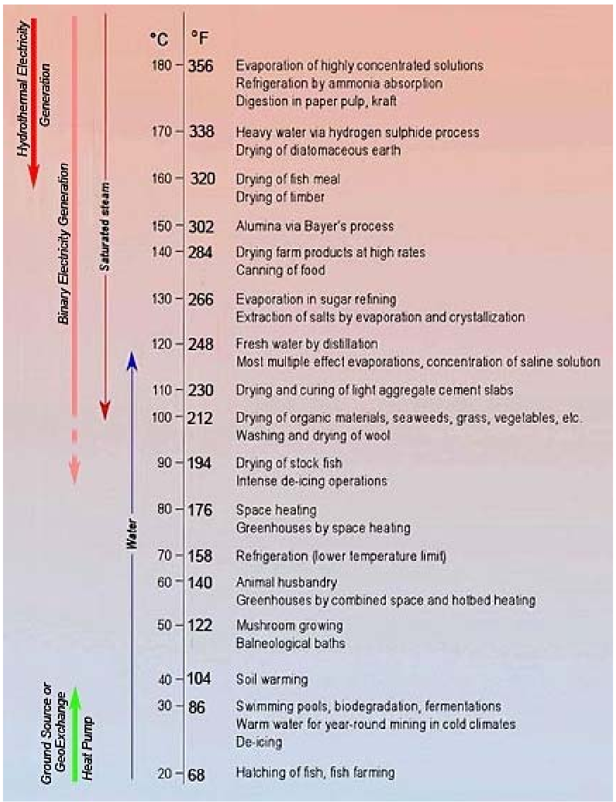

Figure 7: Diagram showing the utilization of geothermal fluids (derived from Lindal, 1973)

3.2 **The Heat supply**

According to the borehole 1624/7, four possible temperatures of supply at certain depth of drilling are evaluated:

- 25 °C, at 100 m depth
- 29 °C, at 300 m depth
- 45 °C, at 450 m depth
- 50 °C, at 470 m depth

Considering different depth of drilling the Heat Integration was performed. The results of each case are presented in Table 1.

From the results obtained it can be concluded, that it is unreasonable to drill deeper than 450 m, with which a 45 °C temperature of supply can be obtained, since there is no demand, which could be covered, if drilling deeper. However, drilling deeper might be reasonable if additional users of hot water are likely to be considered in the future.

Table 1: Results of integration of geothermal energy at different depth of drilling

Temperature of supply	Hot utility requirement [kW]	Cold utility requirement [kW]	Integrated amount of geothermal energy [kW]
25 °C	330	96	30
29 °C	290	224	70
45 °C	0	606	360
50 °C	0	816	360

4. **Conclusion**

North Eastern Morocco is prospective area for geothermal energy; unfortunately, currently the thermal water application is mainly limited to balneology and swimming pools. This paper investigates the relationship between the depth of investigation and the energy consumption of the demand side, with the objective of encouraging investor to promote in other geothermal direct use. The cost of drilling wells is challenging for the geothermal energy industry, especially when deep and complex wells are required for sufficient heat extraction. The potential for major penetration of geothermal energy into the general energy market relies on significant reduction of well construction cost. Data from the borehole 1624/7 were analysed using the Pinch Analysis. The obtained results give a depth of investigation around 450 m, which is enough for greenhouses and swimming pools.

Acknowledgement

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