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Prefeasibility Design of Single Flash in Asal Geothermal Power Plant 2x25 MW, Djibouti

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ABSTRACT

Geologically, the most active structure in Djibouti is Asal area. Six wells have been drilled with various depths ranging from 1137 to 2105m. The first two wells were drilled in 1975 and four others in 1987 to 1988. Well Asal-2 was damaged and the temperature of other wells varies between 260 to 360°C.

In spite of the significant geothermal studies and the deep drilling explorations conducted since 1970 on several geothermal prospect zones, geothermal energy in Djibouti is still to be developed. However, projects to develop a new power plant by using the steam resources from the wells are underway.

The main objectives of this paper are the design of a prefeasibility geothermal power plant with a total net output power that is 2x25 MWe. The modeling and the simulation consist of observing the performance of the system when some input (wet-bulb temperature, cooling water supply system, etc.) conditions change and determining the optimum pressure for technical operation of the system and optimization of the electrical power production process. The simulation and technical analysis using the EES program has proven very useful for calculations, giving the turbine power output of 55.6 MWe and the power plant's electrical consumption as approximately 7.2% of the power from the turbine.

1. INTRODUCTION

Located in East Africa with an area of approximately 23,000 km^2, Djibouti is bordered on the east by the Gulf of Aden, on the southeast by Somalia, on the south and west by Ethiopia and on the north by Eritrea. It is strategically located at the mouth of the Bab el Mandeb strait, which links the Red Sea with the Gulf of Aden.

Geologically, Djibouti lies at the junction of three active, major coastal spreading centres: the Eastern Africa Rift zone, the Red Sea Rift and the Gulf of Aden. The rift zone is still expanding by about one millimetre per year. This unique geographical area is characterized by the presence of geothermal resources revealed by numerous hot springs and fumaroles found in different parts of the country (Figure I). The total geothermal potential is believed to reach about 1000 MWe from approximately 13 locations. The most important geothermal prospect in Djibouti, the Asal prospect (also spelled Assal), is on an active rift zone that extends from the Ghoubbet al Kharab through Lake Asal. The combined electricity generation potential of the three Asal geothermal systems (Gale le Goma, Fiale and South of Asal Lake) is estimated to be between 115 and 329 MWe (Elmi and Axelsson, 2010). Electricity in Djibouti has one of the more expensive prices per kWh in Africa because all electricity is generated by fossil fuel (and the fuel's price fluctuates with the price of the market). The government's priority is to support the development of an alternative energy. Contribution of renewable energy, especially geothermal energy, will gradually be increased to replace oil. In response to this preoccupation, a new power plant using the steam resources from wells is underway. Today we are on the eve of an important drilling program (four deviated production wells) led by the ministry of energy in charge of natural resources. This program is financed by a public banking consortium led by the World Bank (with the OPEP fund, ADB, GEF and AFD) in order to build a producing unit of 50 MWe in the first step. In this report, the main purpose is the prefeasibility design of a single flash geothermal power plant of 2x25 MWe in Asal (Gale le Goma) in Djibouti.

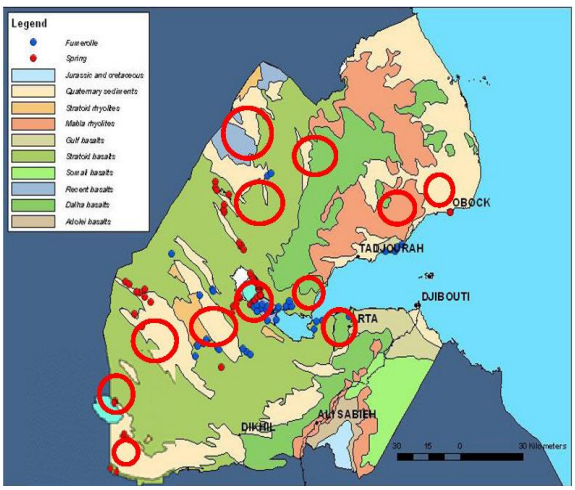


Figure 1: Simplified geological map of the Republic of Djibouti, indicating hydrothermal events: Potential sites (red circles), hot springs (red dots) and fumaroles (blue points)

2. WELL PRODUCTIVITY DATA

A total six wells have been drilled in this area from 1975 to 1988. The three boreholes Asal 1, 3 and 6 (A-1, A-3 and A-6) are located in the southern zone of the Asal rift, inside the half circle of hyaloclastite known as Gale le Goma (Elmi, 2005). 40 m separate wells A-1 and A-3. The distance between A-3 and A-6 is approximately 300m along a line striking NW-SE. Asal 4 (A-4) and Asal 5 (A-5) are located toward the central part of the rift (Figure 2). A-5 was drilled in the Inner Rift, about 1 km west of Lava Lake. A-4 is located about 2 km north-northeast of the site of A-3 and A-6, close to a NW-SE fracture. Asal 2 (A-2) is located 800 m southeast of the A-3 site (Aquater, 1989).

Wells A-3 and A-6 encountered the same reservoir as A-1 with temperatures of 260-280°C. Well A-4 showed temperatures close to the boiling point curve below 200 mbsl, with temperature close to 350°C at the bottom. Well A-5 showed sharply increasing temperature below 200 mbsl, with a maximum of about 180°C at 500 m depth (Figure 3). Below that the rocks are drastically cooled down, as compared to alteration mineralogy, with temperatures as low as 60-70°C at 900-1000 m depth. After that the temperature rises steeply with depth and reaches about 360°C at the bottom. Wells A-4 and A-5 showed very little permeability and could not be flow-tested (Aquater, 1989).

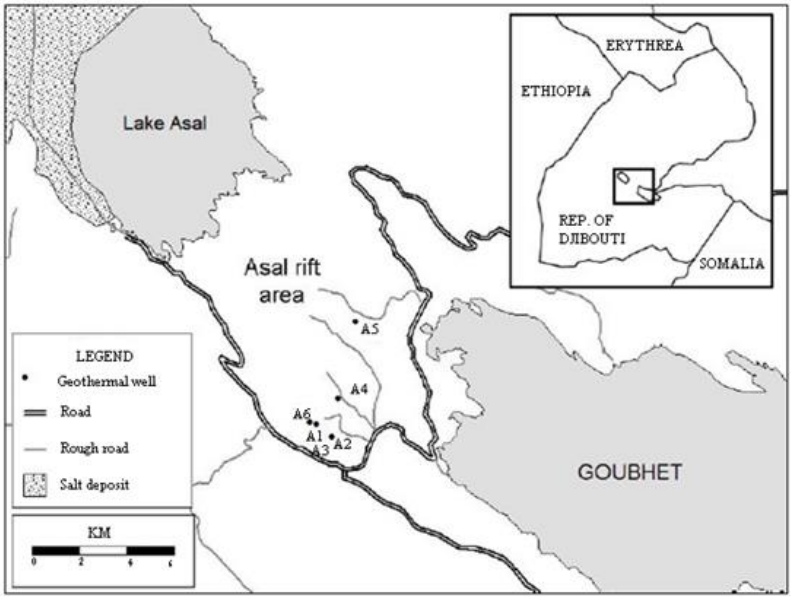


FIGURE 2: Wells locations in the Asal geothermal field (Elmi and Axelsson, 2010)

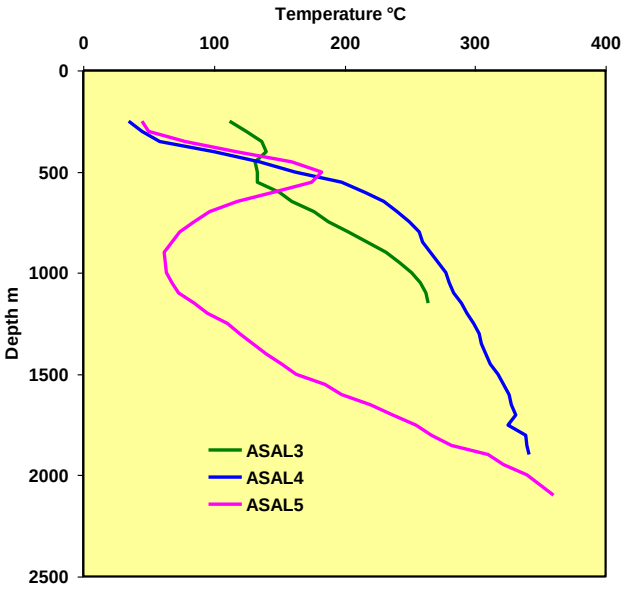


FIGURE 3: Temperatures profiles of wells A3, A4 and A5 (Jalludin, 2009)

Three wells have been discharge tested A-1, A-3 and A-6 (Aquater, 1989, Virkir-Orkint, 1990) and measurements have shown total well flow in the range 20-60 kg/s. The best producer is A-3, which under stabilized conditions has produced about 40 kg/s of fluid,

4-5 kg/s of which is steam. A three month test of the well showed a significant decline in production that was interpreted as due to formation of deposits in the pipelines hampering the flow (Figure 6). The enthalpy of the fluid was in the range 1069 – 1090 kJ/kg. A pressure connection has been found between well A-3 and A-2 and A-6, but wells A-4 and A-5 did not respond to flow testing of A-3. The reservoir permeability thickness product (kh) was found to be in the range of 7-11 Dm and an average porosity of 5% or less was indicated. The size of the drainage area for well A-3 was observed to be in the range 7-9 km2 (Virkir-Orkint, 1990).

2.1 Scale deposition

From October 1989 to April 1990 Virkir-Orkint, carried out a comprehensive scaling/corrosion study in Asal, Djibouti (Virkir-Orkint 1990). Certain patterns can be discerned vs. distance from the wellhead, with deposition at different pressures and possibly different environments of deposition. In Table 4 the analysis of seven samples from different sampling locations from A-3 is reported. The analytical results are normalised to a sum of 100%.

Thus it can be seen that the composition differs greatly according to the distance from the wellhead; sulphides, mostly galena being more prominent close to the wellhead but silicates and finally silica further away from the wellhead. In A-3 scales, significant concentrations of carbonate (0.5-2.2% as CO2), characterized as siderite, were also found. The distance from the wellhead does not tell the whole story. A sample from an orifice at the opening of the separator line in A3 contained nearly exclusively galena. The thickness of the scale is also pressure dependent and an experiment on the separator line in A3 shows a significant increase in scaling rate between 17.7 bar and 16.2 bar (Figure 4), the increase being concomitant with a large increase in iron silicate deposition. Iron silicates start precipitating at temperatures below about 200°C (15.5 bara), but at lower temperatures (<150°C) amorphous silica precipitation becomes prominent (Ármannsson and Hardardóttir, 2010).

Scaling and reservoir pressure drop explain the decrease in flowrate (Figure 6). At the flash zone between 650 and 750 m, the diameter of the wellbore was reduced by about 20 mm. Between 600 m and the wellhead, the diameter reduction was around 15 mm. At low pressure in the surface equipment, the main deposition was FeSiO3 and at high pressure (i.e. down in the well) it was galena PbS.

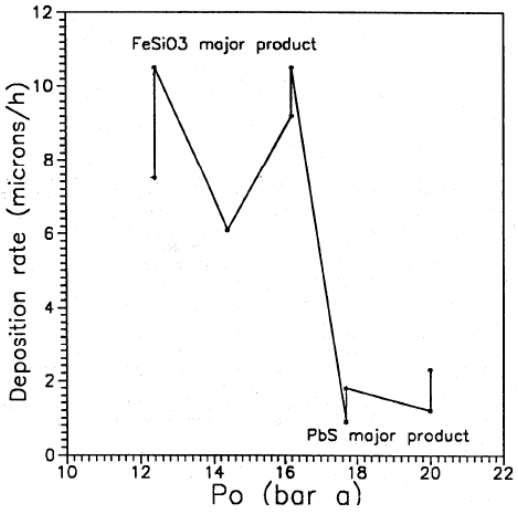


FIGURE 4 : Thickness of scales on coupons at different pressures (Ármannsson and Hardardóttir, 2010)

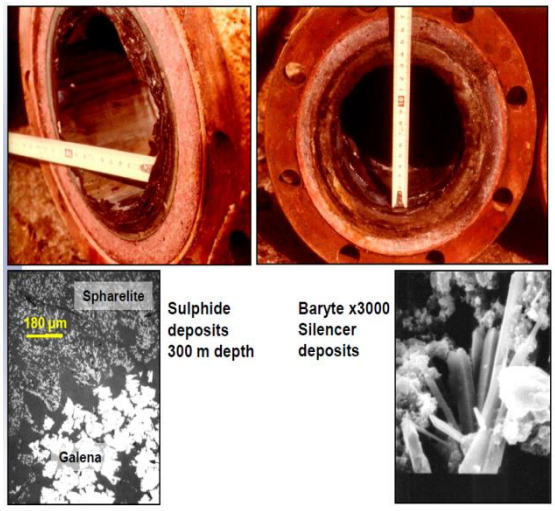


FIGURE 5: Scale deposits in 6 inch production Liner Asal 1 geothermal well

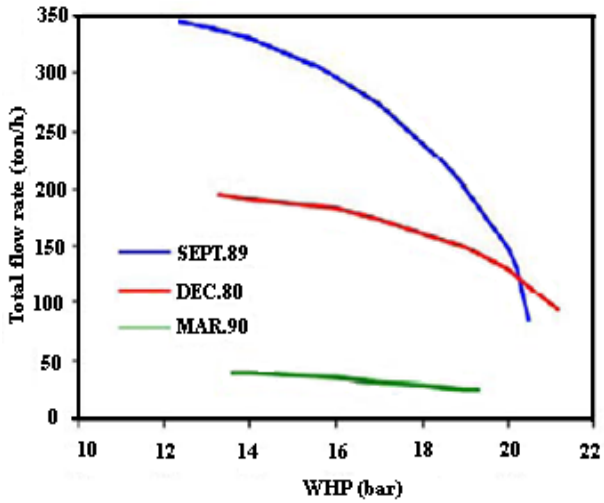


FIGURE 6: Output characteristic curves for different test well Asal 3 (Jalludin, 2009)

2.2 Scale prevention and recommendation

As has been observed the extent of iron silicate scaling in Asal is small above 16 barg and the recommendation is to keep the wellhead pressure well above that. Amorphous silica scales similarly are best avoided by keeping the separator pressure of the power plant above that of amorphous silica saturation. The sulphide and iron silicate scales may be dealt with by inhibition, but the amorphous silica deposits by pressure (temperature) control (Ármannsson and Hardardóttir, 2010).

3. Calculations and results

In order to extract from the geothermal fluid as much energy as possible, a single-flash cycle has been proposed for this study.

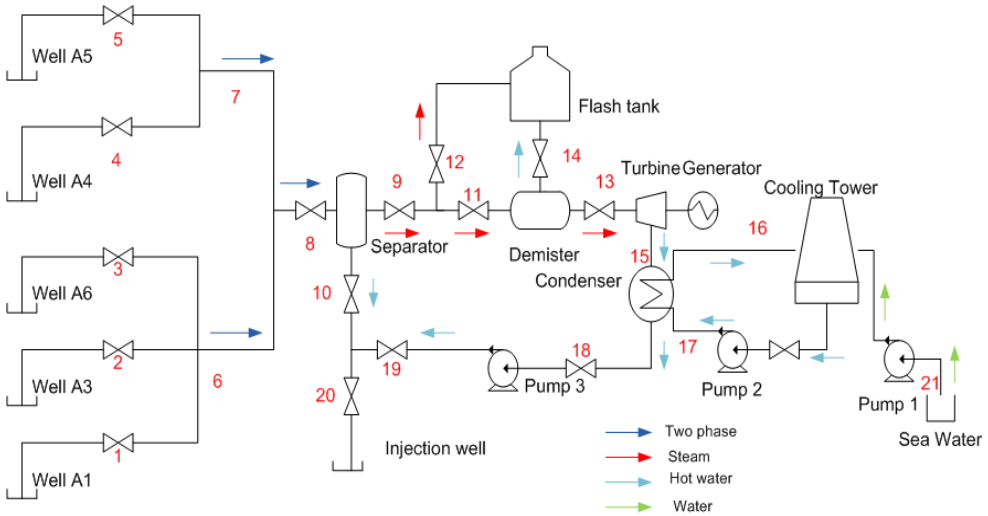


FIGURE 7: Flow diagram of Asal geothermal power plant

3.1 Optimum separator pressure

The optimum separator pressure is defined as the pressure at which the power plant's output is maximized. To find the optimum pressure of the separator, the wet-bulb temperature is kept constant and the power plant output is calculated for different separator pressures. The separator pressures were varied between 4 and 17.7 bar for different wet-bulb temperatures of the surrounding.

The results of the calculations with the plant output power versus the separator pressures for different wet-bulb temperatures are shown in Figure 8. The uppermost curve gives the highest power output. It is the curve calculated by a condenser pressure of 0.06 bars or by a wet-bulb temperature of 16°C. The highest power output in this curve is 54583 kWe and given by separator pressure of 9 bar. The 9 bar separator pressure is then calculated to be the optimum separator pressure, giving the maximum output power. However it cannot be used in the case of the Asal geothermal power plant because of the problem of deposition explained above (see § 2). In this case the separator pressure selected is 17.7 bars. With this pressure, the scaling is minimized to eliminate the decrease of 30-40% in flowrate three months (Figure 6). The power output (51643 kWe) generated with 17.7 bars is lower than that calculated with 9 bar in the same condition. The calculations of turbine power, output power and auxiliary power (kWe) for different condenser pressures at the 17.7 bars separator pressure are summarized in Table 1 (Hamoud, 2010).

The condenser pressure has an interrelationship with the wet-bulb temperature (Table 1). According to the table, the turbine and output power decreases as the wet-bulb temperature decreases. But the gap between turbine power and output power reduces when the pressure of the condenser decreases, due to auxiliary power as seen in Figure 8 and Table 1.

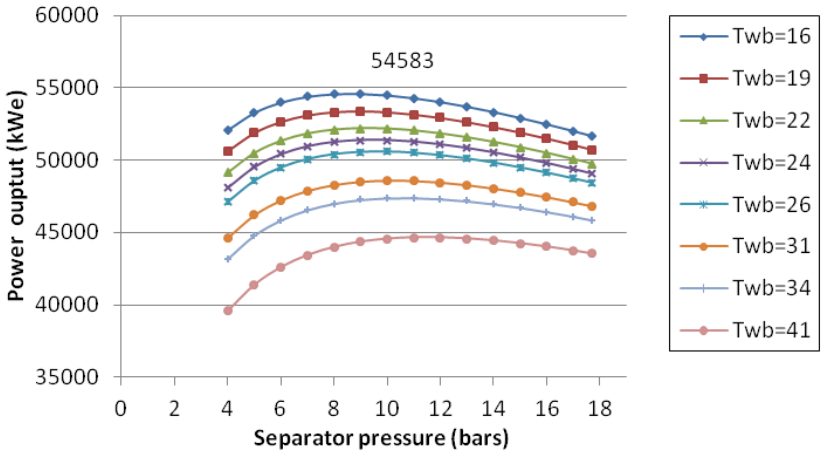


FIGURE 8: Separator pressure vs. Power output

Table 1: Output and auxiliary powers for 17.7 bars separator pressure

Wet-bulb Temperature (°C)	Condenser pressure	Turbine power	Output power	Auxiliary power
16	0,06	55603	51643	3959
19	0,07	54430	50694	3736
22	0,08	53277	49747	3529
24	0,09	52505	49104	3401
26	0,10	51736	48457	3279
34	0,15	48697	45843	2855
41	0,21	46083	43532	2551

After deducting the separator pressure by 0.01 bars due to lost pressure in the demister, the optimum inlet pressure of the turbine is obtained. Hence, the optimum inlet pressure of the turbine is 17.69 bars.

3.2 Wet-bulb temperature's influence

The wet-bulb temperature is varied between 16 and 42°C with the separator pressure kept constant at 17.7 bars. The output power increases when the wet-bulb temperature decreases. The power is a function of the auxiliary power and the auxiliary power is a function of fan, vacuum pump and water pump power requirements. The fan and vacuum pump power decrease when the wet-bulb temperature increases.

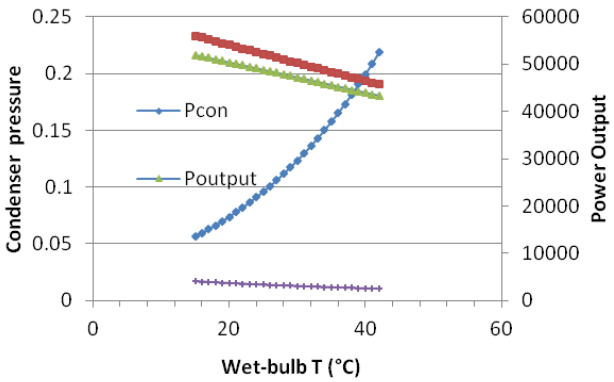


FIGURE 9: Wet-bulb temperature versus power output and condenser pressure

4. CONCLUSION

The government of Djibouti is committed to development of environmentally sound geothermal energy to overcome the growing energy demands of the country and to support economic development. The energy strategy of the government is to offset the dependency on imported petroleum products and the related high cost energy. Therefore the concretization of this actual geothermal development program will contribute to electricity generation and energy self-dependency.

The work presented in this report contributes to the modeling of a geothermal power plant in order to see the effect of outside temperature (wet-bulb temperature) on the system. When the wet-bulb temperature increases, the condenser pressure increases and an increase of pressure in the condenser means a reduction of the net power output. The net output power decreases linearly. The thermodynamic analysis of the power plant design, calculations and recommendation gave a maximum power output of the plant by operating the condenser at 0.06 bars and the separator pressure at 17.7 bars. At this design pressure, the turbine power would be 55.6 MW with net power output of 51.6 MW, given the auxiliary power for pumping, cooling tower fan and others is 4 MW.

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