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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 1137 to 2105m. The first two wells have been drilled in 1975 and the 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, the geothermal energy in Djibouti is still to be developed. But actually, the priority is to develop a new power plant by using the steam resources from the wells are underway.

The main objectives of this paper are to design a prefeasibility geothermal power plant with a total net output power that is 2x25 MWe. The modelling and the simulation of the model consist to observe the performance of the system when some inputs (Wet-bulb temperature, cooling water supply system, etc…) conditions change. And to determine also the optimum and adequate pressure for the technical operation of the system and optimize the electrical power production process. The simulation and technical analysis using EES program has proven very useful for calculations giving the turbine power output 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 potentials are believed to reach the amount of about 1000 MWe from approximately of 13 locations. The most important geothermal prospect in Djibouti, the Asal prospect (other spelling 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 329MWe (Elmi and Axelsson, 2010). The electricity in Djibouti is one of the more expensive prices per kWh in Africa. Because all electricity is generated by 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 by using the steam resources from the wells are underway. Today we are on the eve of an important drilling program (drilling of 4 deviated production wells) leading 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 up a production unit of 50 MWe in the first step. In this report, the main purpose shall be the prefeasibility design of single flash in Asal (Gale le Goma) geothermal power plant 2x25 MWe in Djibouti.

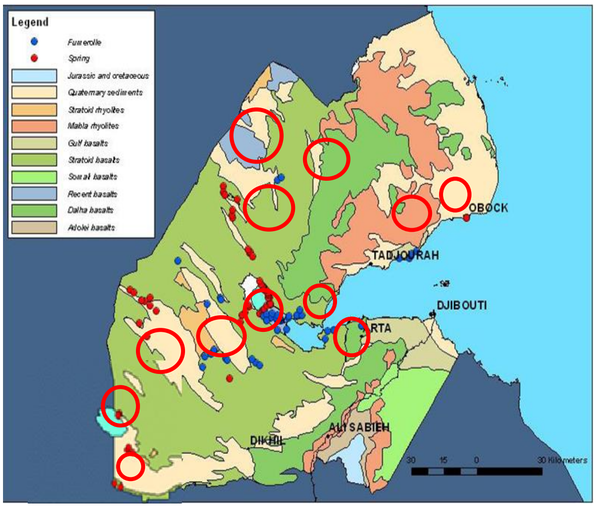


**Figure 1: Simplified geological map of the Republic of Djibouti, indicating hydrothermal events: Potential sites (red circles), hot springs (red dots) and fumaroles (blue points).**

## 2. WELLS PRODUCTIVITY DATA

A total six wells have been drilled in this area at 1975 to 1988. The three boreholes Asal 1, 3 and 6 are located in the southern zone of the Asal rift, inside the half circle of hyaloclastite known as Gale le Koma (Elmi, 2005). 40 m are separated well Asal 1 and Asal 3. The distance between Asal 3 and 6 is approximately 300m; along a line striking NW-SE. Asal 4 and Asal 5 are located toward the central part of the rift (Figure 2). A5 was drilled in the Inner Rift, about 1 km west of Lava Lake. Asal 4 is located about 2 km north-northeast of the site of Asal 3 and 6, close to a NW-SE fracture. Well Asal 2 is located 800 m southeast of the Asal 3 site (Aquater, 1989).

Wells A3 and A6 encountered the same reservoir as A1 with temperature of 260-280°C. Well A4 showed temperatures close to the boiling curve below 200 mbsl, with temperature close to 350°C at the bottom. Well A5 showed sharply increasing temperature below 200 mbsl, with 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 temperature 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).

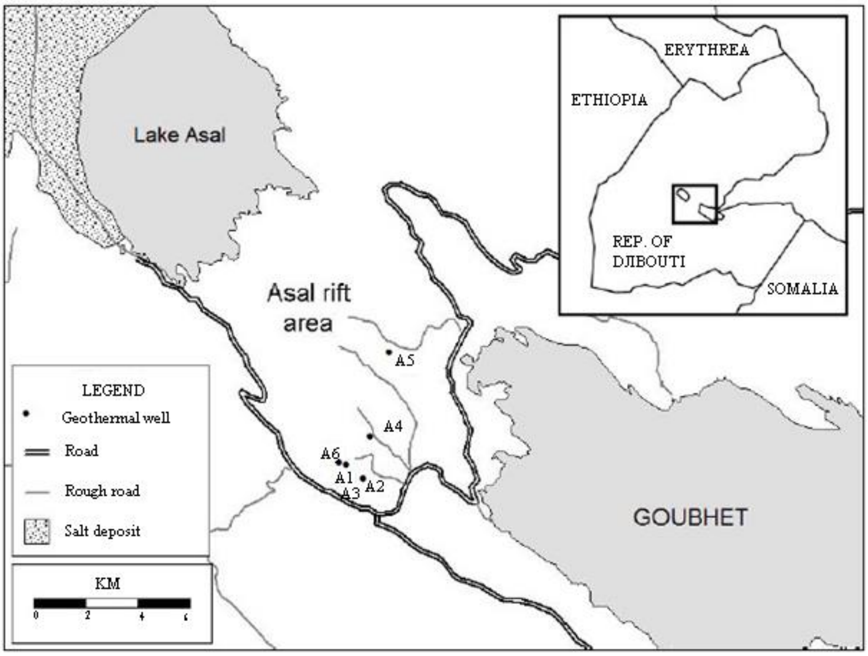


FIGURE 2: Wells locations in the Asal geothermal field (Elmi and Axelsson, 2010).

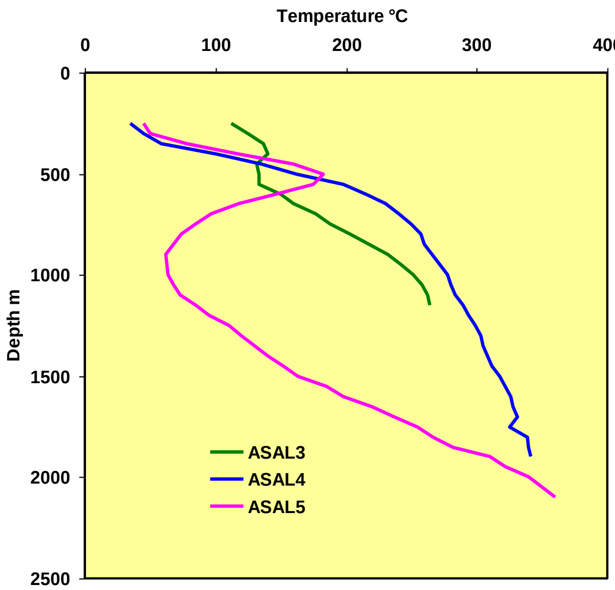


FIGURE 3: Temperatures profiles of wells A3, A4 and A5 (Jalludin, 2009).

Three wells have been discharge tested A1, A3 and A6 (Aquater, 1989, Virkir-Orkint, 1990), and measurements have shown total well flow in the range 20-60 kg/s. The best producer is A3 which under stabilized conditions has produced about 40 kg/s of fluid, 4-5 kg/s of which are steams. A three month test of the well showed a significant decline in production that was interpreted as due to formation of deposits in the pipes 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 A3, and A2 and A6 but wells A4 and A5 did not respond to flow testing of A3. 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 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 in distance from wellhead, deposition at different pressures and possibly the environment of deposition. In Table 4 the analysis of 7 samples from different sampling locations in A3 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 A3 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 bar a) 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. And between 600 m and the wellhead, the diameter reduction was around 15 mm. At low pressure in surface equipment the main deposition was FeSiO3 and at high pressure (i.e. down in the well) it was galena PbS.

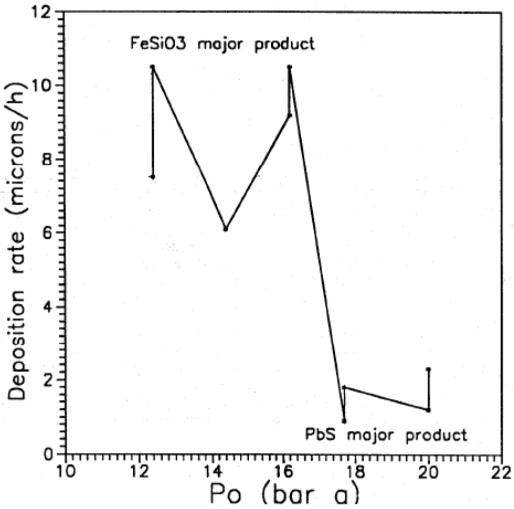


**FIGURE 4 : Thickness of scales on coupons at different pressures (Ármannsson and Hardardóttir, 2010).**

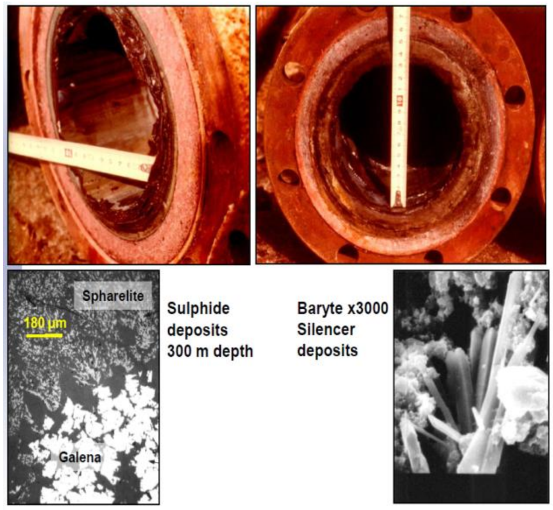


**FIGURE 5: Scale deposits in 6 inch production Liner Asal 1 geothermal well**

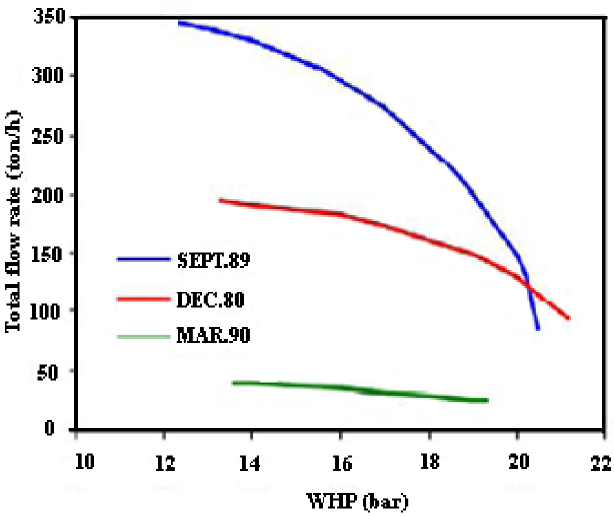


**FIGURE 6: Output characteristic curves for different test well Asal 3 (Jalludin, 2009).**

### 2.2 Scale prevention and recommendation

As has been observed the extent of iron silicate scaling in Asal is small above 16 bars 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 scales may be dealt with by inhibition, the iron silicate scales 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.

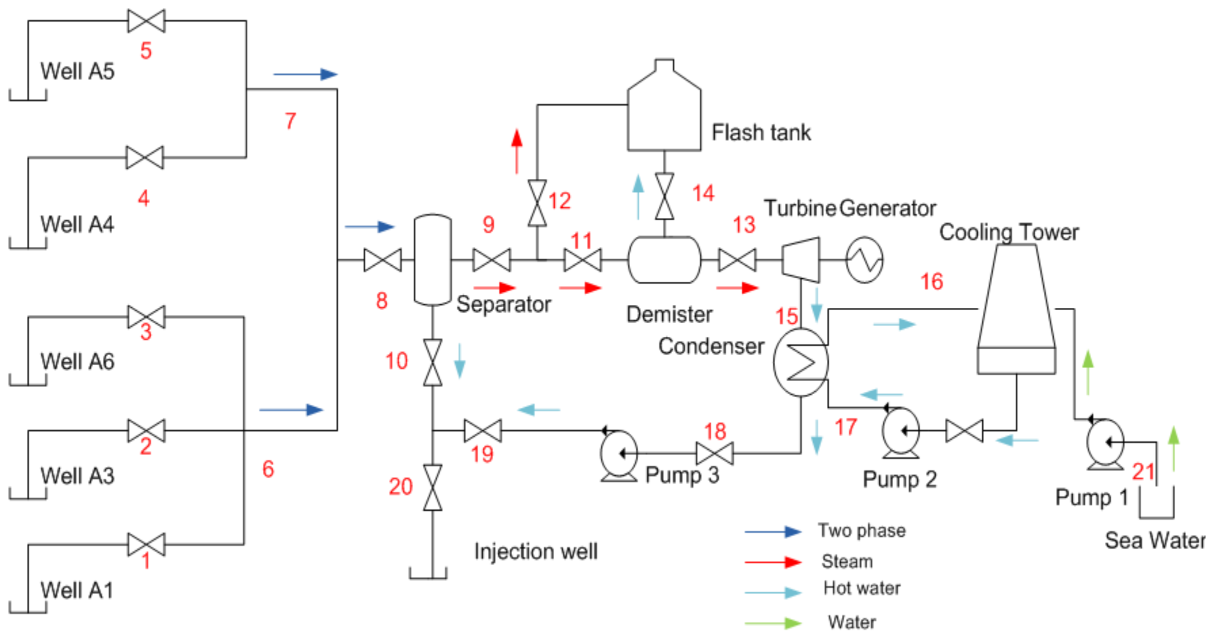


**FIGURE 7: Flow diagram of Asal geothermal power plant**

### 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 bars; 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 temperature are shown in Figure 14. 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 bars. The 9 bars 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 and you have not decrease 30-40% in flowrate in three month (like Figure 7). The power output (51643 kWe) generated with 17.7 bars is lower than which calculated with 9 bars 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).

**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 |

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

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

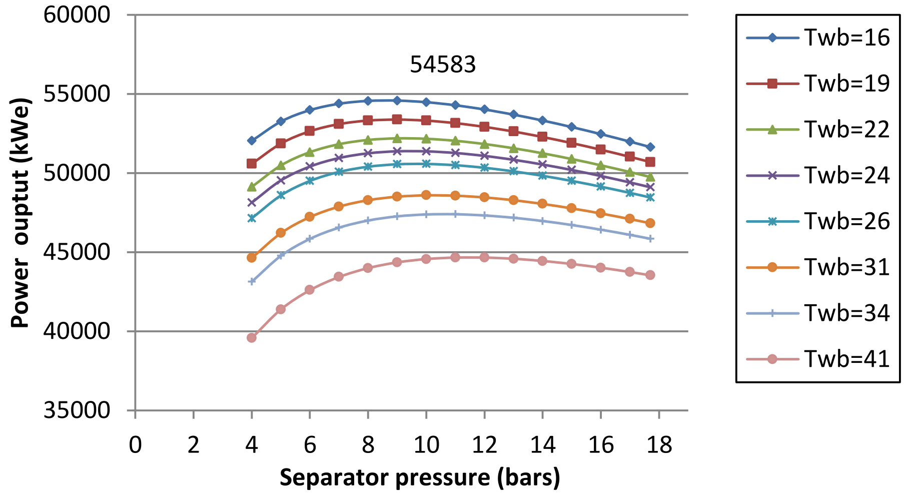


**FIGURE 8: Separator pressure Vs Power output**

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 to 42 degrees Celsius 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 function of fan power, vacuum pump and water pump. The fan power and the vacuum pump power decrease when the wet-bulb temperature increases.

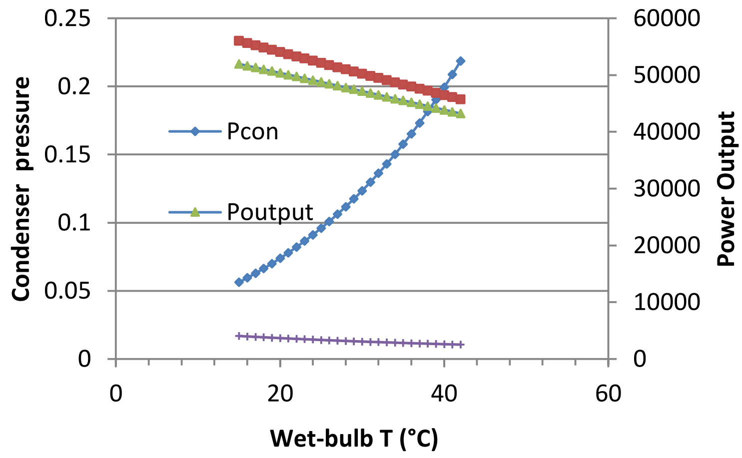


**FIGURE 9: Wet-bulb temperature versus Poutput and condenser pressure**

## 4. CONCLUSION

The government of Djibouti is committed to development the environmental sound geothermal energy to overcome the growing energy demands of the country and to support the economical development. The energy strategy of the government is willing 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 modelling of a geothermal power plant. In order to see the effect of the outside temperature (wet-bulb temperature) on the system and how it reacts. When the wet-bulb temperature increases, the condenser pressure increases also. The increase of the pressure in the condenser involves the 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 attain 55.6 MW and power output of 51.6 MW. The auxiliary power for pumping, cooling tower fan and others is 4 MW.

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