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Geothermal Fluid for Industrial Use in the KenGen Green Energy Park, Kenya

Irene Jepkorir Ronoh

Reykjavik University, Menntavegur 101, Iceland

irene18@ru.is; ironoh@kengen.co.ke

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ABSTRACT

Despite the huge success in electricity generation in Kenya, there is limited direct use applications of the country's vast geothermal energy potential. Studies have shown that Kenya has thermal energy capacity of 22.40 MWt, an annual energy use of 50.70 GWh/year with a capacity factor of 0.26 but boasts of few successful direct use applications compared to other parts of the world. The Oserian Greenhouses using geothermal resource for the cut flower farming and the geothermal spas in Olkaria and Bogoria areas are the most successful direct use applications. However, KenGen is setting up an industrial park within the Olkaria Geothermal area to utilize available and abundant geothermal resources for industrial purposes to tap environmental, economic and social benefits for KenGen, private sector and the community. These geothermal resources include cheap electricity generated from the geothermal power plants, more than 2000t/h of brine from several separator stations at 130°C, steam from low to medium enthalpy wells, wells with unique characteristics e.g. cyclic wells, CO_2 or SiO_2 rich wells and also drilled wells that are located far from the existing power plants.

The identified industrial applications within the park include textile, steel and glass manufacturers, eco-friendly fertilizer production, milk processing plants and crop drying facilities. These industries have different energy needs hence a design to promote an exchange of resources among these processes in a cascade approach will result in better resource utilisation and enhance sustainability. The use of Combined Heat and Power (CHP) technologies make more efficient use of the geothermal resources by cascading the geothermal fluid to successively lower temperature applications, thereby improving the economics of the entire system dramatically. The main aim is to assess the possibility of circular economy by optimizing the use of materials, energy and wastes in sustainable circular approach. By promoting the industrial symbiosis concept between firms ensures the wastes of one industry becomes the raw materials for another industry hence minimizing waste and enhancing resource use efficiency. These innovative technologies will upscale the KenGen Green Energy Park into an Eco-Industrial Park.

The Green Energy Park aims to increase sustainability in utilisation of geothermal resources and operate under the following principles: integrated utilisation of the steam, brine and electricity from geothermal energy; by-product sharing hence minimizing of waste; job creation resulting from an improved economy and social progress due to development of innovation.

1. INTRODUCTION

Kenya is naturally endowed with enormous potential of geothermal energy that is a clean indigenous environmentally benign source of renewable energy used for electric and non-electric uses (Mangi, 2013). Studies have estimated that the geothermal resource potential in Kenya is about 7,000-10,000 MWe along fourteen (14) prospective resource areas in Kenya (Omenda, 2012; Ogola, 2013). With Olkaria geothermal area currently in an advanced development phase, Kenya is ranked at position eight (8) globally with an installed capacity of about 840 MWe from geothermal generation (ThinkGeoEnergy Research, 2019). Menengai, Eburru, Barrier and Paka-Silali geothermal fields are currently in different stages of development with a plan to deliver a total of 5,000 MWe by 2030. According to worldwide geothermal direct use data (Lund & Boyd, 2015), Kenya has an energy capacity of 22.40 MWt, an annual energy use of 50.70 GWh/yr with a capacity factor of 0.26.

Unfortunately, there is limited utilization of the country's geothermal energy potential for direct use applications despite its huge potential. However, direct utilization of geothermal energy is continuously gaining popularity due to its economic, environmental and energy efficiency benefits. In Kenya, a few direct use applications exist with health spas operating in Olkaria and Bogoria, crop dryers at Eburru, greenhouse heating and carbon dioxide enrichment at Oserian flower farms and water harvesting for domestic purposes both at Eburru and Suswa geothermal areas. A demonstration centre with four direct use projects in Menengai geothermal area was set up in 2015 to test the technical and economic viability of a geothermal energy cascade design. The projects include a milk pasteurizer, a heated green house, heated aquaculture ponds and a laundry unit (Nyambura, 2016).

Geothermal energy in Kenya has primarily been used for electricity generation while the separated brine is normally reinjected back into the ground while still containing huge amounts of thermal energy. In addition, no other by-products of geothermal energy such as mineral extracts or gases are extracted for useful purposes. As a result, there is inefficient utilization of the geothermal resource.

It is expected that the establishment of a geothermal industrial park will address some of these problems to a large extent. In addition, thousands of jobs will be created for the local population and businesses through employment and provision of services to the industries in the park.

The utilization of geothermal energy depends on the resource temperature with high temperature resource (>150°C) mainly used for electricity generation in condensing power plants. Low to medium temperature geothermal resources (<150°C) are utilized for direct uses or binary power plants (Mburu, 2009). An innovative use of geothermal heat is a cascade utilization for power generation and sequential use of geothermal heat for various direct uses, or by use of thermally activated technologies. The concept of cascading can be effective method to maximize the use of geothermal resources of low to medium enthalpy as shown in the Lindal diagram in Figure 1. The use of Combined Heat and Power (CHP) technologies make more efficient use of the geothermal resources by cascading the geothermal fluid to successively lower temperature applications, thereby improving the economics of the entire system dramatically (Lund & Chiasson, 2007). The geothermal steam, after being used for power generation, can be used for milk pasteurization, greenhouse heating, aquaculture pond and swimming pool heating before reinjecting it back to the reservoir.

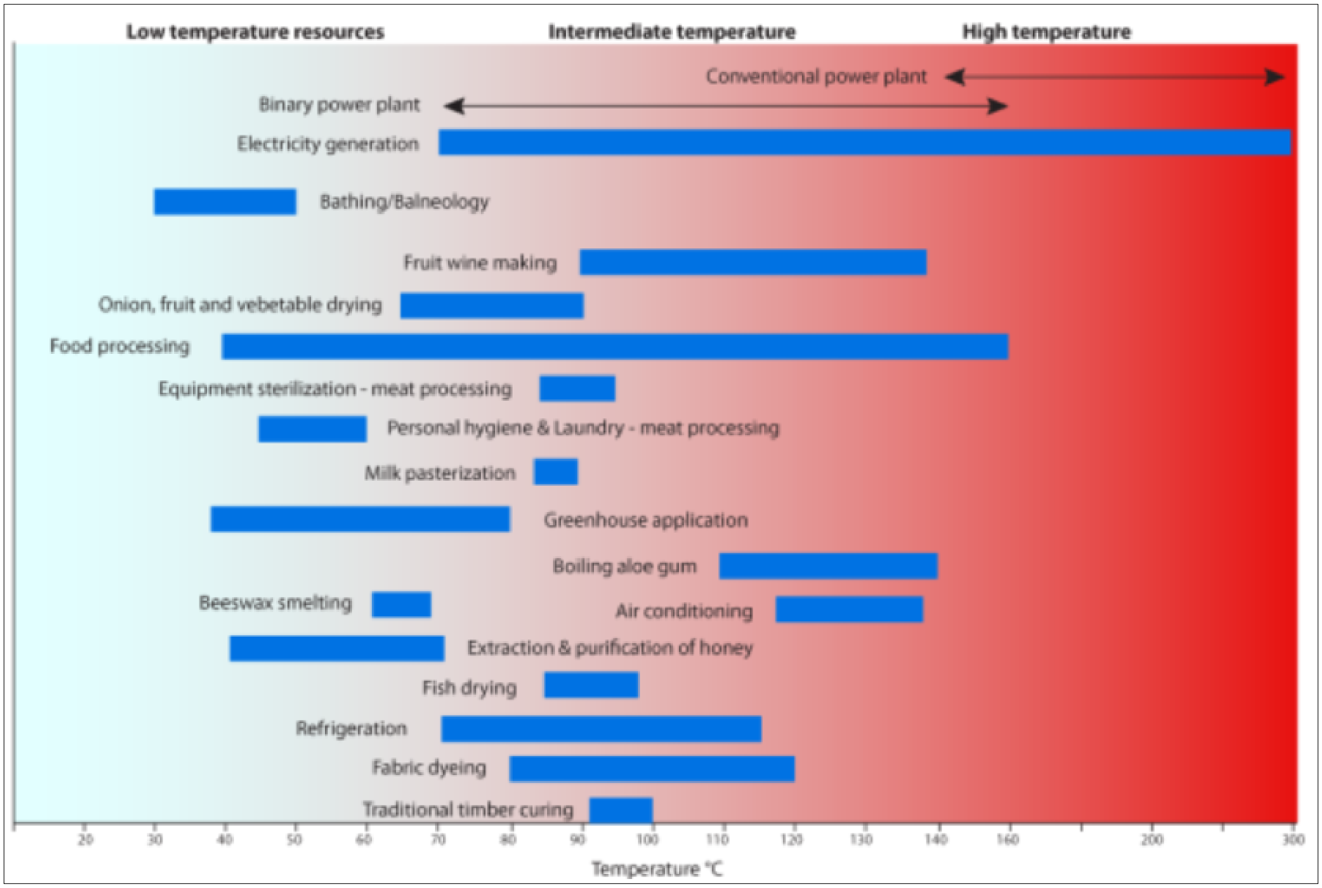

Figure 1: Modified Lindal diagram of potential uses of geothermal energy

Industrialization in Kenya has faced challenges due to the high cost of energy and its unreliability. Electricity from the grid costs about USD 0.22/kWh (Regulus, 2020). Power outage is a common occurrence in Kenya due to routine rationing and unstable grid which forces most industries to incur an extra cost of installing and running standby diesel generators for several hours every month (VEGA, 2014). Similarly, most industries which require steam for their operations normally use industrial diesel oil or furnace oil to fire boilers. These sources are known for emission of greenhouse gases. Besides, their prices are usually volatile and in most cases high, which eats into the manufacturers' margins and makes it difficult to predict profits accurately. Geothermal energy on the other hand is cheaper, cleaner and more reliable than the other sources of energy currently being used. In addition, direct use of geothermal energy presents an opportunity to eliminate the use of fossil fuels to generate thermal energy for industries.

In this regard, plans are underway at the Olkaria Geothermal area to set up a green energy park to utilize geothermal resources to tap environmental, economic and social benefits for KenGen and the community. A feasibility study conducted in Olkaria in 2016 identified the available geothermal resources to be utilized in the park. These include cheap electricity generated from the geothermal plants, more than 2,000t/h of brine from several separator stations at 130°C, steam from low to medium enthalpy wells, wells with unique characteristics e.g. cyclic wells, CO_2 or SiO_2 rich wells and also drilled wells that are located far from the existing power plants. According to the Geothermal Development Prioritization Task Force Report (2018), there are more than sixteen geothermal wells that are currently not assigned to any future electricity generation project due to the aforementioned reasons. These wells have been earmarked for connection to the industrial park. The identified industrial and service applications to be developed within the park range from mineral extraction from geothermal brine, textile, steel and glass manufacturers, eco-friendly fertilizer production, milk processing plants and recreation facilities. These industries have different energy needs hence a design to promote an exchange of resources among these processes in a cascade approach will result in better resource utilization and sustainability.

The concept of energy parks within/near the geothermal resource areas is currently gaining momentum with Suðurnes Resource Park in Iceland as a succesful example. The resource park is located next to Svartsengi and Reykjanes geothermal power plants, which are owned and operated by HS Orka hf (Albertsson and Jónsson, 2010). Besides economic considerations, the geothermal resource park is based on the concept of waste reduction due to sharing of by-products. Albertsson (2013), indicates that the geothermal energy parks are built on the following values; integrated utilization of the various resources available from geothermal energy; sustainable development resulting in an ecological balance due to minimizing of waste through by-product sharing; economic prosperity due to creation of jobs in various disciplines; and social progress due to development of innovation, new job opportunities and environmental awareness; better collaboration between different professions and companies resulting in sharing of equipment, machinery and manpower as well as increased sustainability in utilization of geothermal resources due to increased efficiency within the resource area.

2. COMMERCIAL DIRECT GEOTHERMAL APPLICATIONS

2.1 Olkaria and Bogoria Geothermal Spa

One of the revenue generation projects for KenGen is the Geothermal Health Spa in Olkaria field which was commissioned in 2015 and has been in successful operation attracting about 45,000 people annually. The Spa utilizes brine estimated at 5 MWt and 40 TJ/yr from a re-injection pipeline before reinjected to well OW-X1. It is comprised of three cascaded lagoons; The first lagoon is a receiving pond for the hot brine at 90^{o}C, the second lagoon at 50°C, the third and largest bathing lagoon, 70 m in diameter, whose temperature is maintained at 30-35°C and a fourth children's pond, 10 m wide (Mangi, 2012). The success in the operation of the geothermal health spa has opened ways for more direct applications within the KenGen´s Olkaria geothermal area.

Figure 2 illustrates the spa in Olkaria and Bogoria hotel. The Lake Bogoria spa has hot spring providing fluid into the spa pool with thermal energy of 0.4 MWt and 6 TJ/yr (Omenda and Simiyu, 2015).

Figure 2: Geothermal Spa in Olkaria and Bogoria

2.2 Oserian Flower Farms

A 50-ha greenhouse heating remains the leader at the Oserian Flower Farms for growing roses that are air-freighted daily to Europe and other world-wide locations. The installed capacity for these greenhouses is estimated at 16 MWt and annual energy use of 126.62 TJ/yr (Omenda and Simiyu, 2015). Heat is only required normally from around 2:00 AM to 7:00 AM, but the heat also provides a dry environment that limits fungus growth.

Figure 3: Roses in Oserian's greenhouses in Kenya (source: Oserian)

2.3 Menengai Demonstration centre

In 2015, a Direct Use Demonstration Project was launched in Menengai geothermal area to showcase other direct applications of geothermal energy. The four direct use pilot projects showcase the applicability of direct use of geothermal energy in various sectors including a milk pasteurizer, a heated green house, heated aquaculture ponds and a laundry unit. The project demonstrates a cascade utilization by re-directing the water already used for milk pasteurization through the geothermal heated dryer and finally to the fish pond (Nyambura, 2016). These projects however have not reached a commercial scale.

Figure 4: Geothermal Direct utilization in Menengai; Milk pasteurizer and heated fish pond (Nyambura, 2016)

2.4 Eburru Geothermal Dryer

At Eburru, the local community uses geothermal heat from a shallow geothermal well to dry pyrethrum at a plant constructed in the 1920s. According to Omenda and Simiyu, (2015), the energy is estimated at 1.0 MWt and 10 TJ/yr. With proper harnessing of the geothermal steam, the local community can greatly benefit from the drying of other plants like vegetables and maize. Figure 5 shows pyrethrum drying at using geothermal steam at Eburru.

Figure 3: Geothermal energy being used by the local community at Eburru for grain and pyrethrum drying

3. SUITABILITY OF KENGEN GREEN ENERGY PARK

3.1 New Policy Framework

Kenyan Government has identified the KenGen Green Energy Park as one of the Special Economic Zones (SEZs) to spur economic growth by providing incentives and policies to promote and attract investment. Policies governing the Special Economic Zones in Kenya are incorporated in the draft SEZ policy and the SEZ Act No. 16 of 2015. The Act highlights integrated infrastructure facilities, access to business and economic incentives as well as removal of trade barriers and impediments as being key benefits accorded through the SEZ regime. The major selling point of SEZs in Kenya are the tax shields offered within the confines of an SEZ (GOK, 2015). Licenced SEZ enterprises, developers and operators benefit from various tax rebates such as exemption from excise duty, customs duty, value added tax and stamp duty. Further incentives include; advantageous corporate income tax rates and preferential withholding tax rates, especially in relation to profit repatriation.

3.2 The KenGen Green Energy Park Location

The park is located within the Olkaria Geothermal Area and is expected to tap direct energy produced within the resource area (Figure 2). The large amounts of thermal and electrical energy will be provided cheaply for utilisation by industries. The close proximity of the industrial park to the Olkaria geothermal field means that energy will be transported for a short distance to the industries that need it increasing efficiency. The sorrounding farming community provide source for raw materials to be processed in the park.

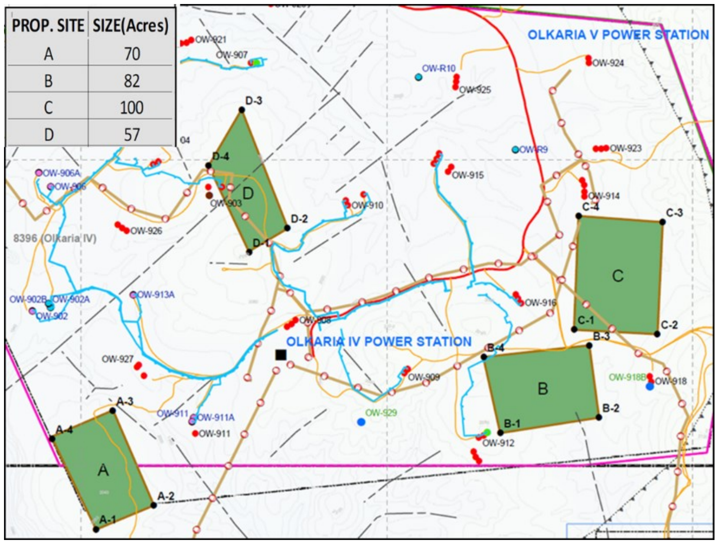

Figure 2: Location of the proposed sites for the KenGen Green Energy Park in relation to Olkaria IV (140 MWe) and Olkaria V (165 MWe) power plants (Source: KENGEN)

2.3 Infrastructure development

The park is connected both by railway and road to major sea port and airports and supported with the necessary logistical installations making it ideal for transportation of raw materials and valuable products to various markets. The Standard Gauge Railway from Mombasa to Naivasha is a key major installation that connects several existing and proposed industrial parks providing a gateway into East Africa making it a regional economic hub hence reducing time to market for the industrial products.

2.4 Geothermal Center of Excellence

The need to provide training and research on advancing technologies, the high international quality standards, the quality of the products, health and safety or environmental protection will be facilitated by the existing training centre within Olkaria. The linkages between the academia and research and development institutions and other related industries will reduce technical barriers often associated to lack of information of the changing technologies.

2.5 Water supply

Olkaria is a water scarce area, however ongoing groundwater surveys within the resource area have confirmed that the reservoir volumes are estimated to be 16,964,640 m3 and 7,121,914.8 m3 to the East of the Olkaria Domes Field around well pad OW-922 and within the Olkaria Domes field around well pad OW-919 respectively (KenGen Hydrological Report, 2016). These viable zones have been earmarked for drilling for fresh water supply to the industrial park. However, other sources are from the Rift Valley Water Service Board which will connect the park with water from Ewaso Nyiro in Narok. Five boreholes have been drilled for this purpose.

3. PROPOSED INDUSTRIES

Manufacturing firms expressed interest to work within the park and after evaluation thee following companies were identified as early locators in the park;

- Textile and apparel industry
- Steel manufacturer
- Glass manufacturer
- Fertilizer manufacturer
- Leather industry
- Milk processor/pasteurizer
- Food processing and packaging (Grain dryers)

4. ENERGY REQUIREMENTS

Each industry requires thermal energy as shown in the Table 1 below. Steel and glass producers are energy intensive industries and require electricity directly from the power plants. Fruehan et al. (2000) reports that raw steel production from iron ore to steel using a basic oxygen furnace will require approximately 6.8MWh per ton of steel produced. For the glass production, raw materials are combined into a specific mixture and heated to in a furnace to about 1500-1600°C based on the desired properties of the product (Schmitz et al. 2011).

Table 1: Thermal energy requirements for various industries in the park (Kiruja, 2017)

Industry	Thermal Energy (°C)
Milk pasteurisation and sterilization	100-130, 200[1]
Garment manufacturing	60-100
Grain Drying	55-95
Leather processing	35-65, 80[2]
Fertilizer manufacturing	55

[1]: Powder milk, cheese making; [2]: Drying the treated leather

4.1 Mass available

The industrial park will utilize electricity from the power lines within the Olkaria geothermal area and in close proximity to the Olkaria IV and V power plants hence reducing the distance that the energy is transported to the industries. The energy intensive industries will benefit from the cheap power and also thermal energy from brine and low pressure wells in the field. In Olkaria Domes geothermal field, steam for electricity generation is obtained from separator stations at a pressure of 10 bar absolute. Therefore, any well that discharges geothermal fluid at a pressure less than 5 bar is considered unsuitable for electricity generation. The geothermal production wells are connected to various separator stations as shown in Table 2. The separated steam from all the separator stations are gathered and directed to the power plant for electricity generation. The brine collected will be chanelled through the manufacturing zones for provision of thermal energy before reinjectin it back the geothermal reservoir.

Table 2 illustrates the mass of brine available for each proposed site and the reinjection wells available for disposal after thermal energy extraction. Some sites are conveniently located in close proximity to the reinjection pipelines.

Table 2: Mass flow allocated to each proposed industrial site

Proposed Site	Separator station	Reinjection Wells	Brine available (t/hr)
A	SD2 & SD3	OW-911, OW-911A, OW-902, OW-913	1076.2
B	SP912	OW-912B	110
C	SP924 & SP923	OW-928	140
D	SD1 & SD4	OW-901, OW-906, OW-906A, OW-921B	801.1

4.2 Fluid chemistry

Olkaria field well water discharges are low in total dissolved solids when compared to most high-temperature geothermal fields in the world. A general rise in solutes is probably due to steam loss and increase in water-rock interaction. Most wells in Olkaria Domes field are under-saturated with respect to calcite and amorphous silica. The minimum pressure the wells like OW-910 can be separated safely at ~3.4 bar-g (146°C) before running silica scaling risk (Figure 3). Other wells require a higher separature pressure of more than 5.4 bar-g to avoid clogging of pipeline. The current practice to minimize silica scaling is to operate the wells at temperatures above that of amorphous silica saturation to avoid the risk of scaling. Care should be taken during the extraction of heat from brine to ensure that the temperature of the brine does not drop below the silica saturation temperature for the given concentration of silica. For the low-pressure wells, steam and brine are not separated and therefore, the concentration of silica remains constant during cooling until precipitation begins.

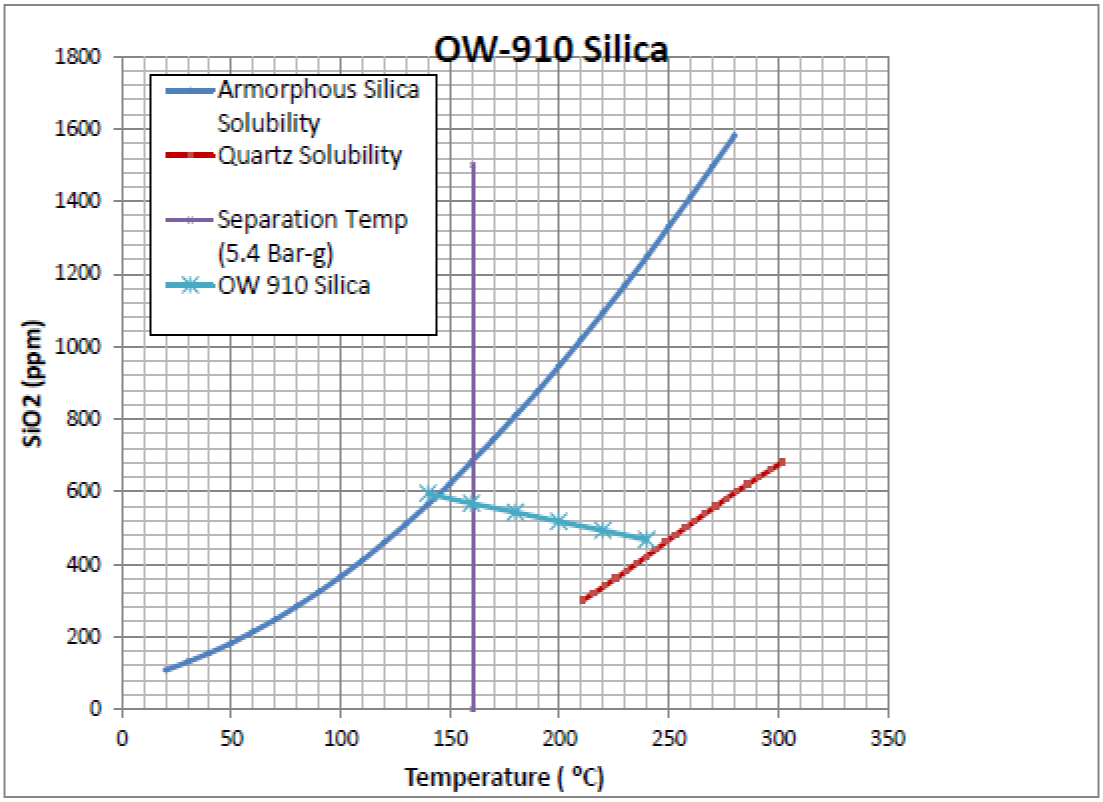

Figure 3: Boiling curve for amorphous silica saturation for OW-910

4.3 Heat exchangers

Due to inherent impurities of geothermal fluids and the possibility of corrosion or scaling, a proper material and equipment selection is mandatory to enable a relatively easy and economical equipment maintenance. The principal reason for having heat exchanger in geothermal systems is to efficiently extract the heat from the brine. In this regard, only fresh water is used to transport the energy for utilisation to the industries It must be remembered that there will be a temperature differential between the primary and secondary fluids any time the heat exchanger is used. Approach temperatures of less than 6ºC are often uneconomical but depend on heat exchanger type and particular application (Lund, 2018).

The counter-current flow and high turbulence achieved in plate heat exchangers makes them popular in geothermal direct use applications as they provide for efficient thermal exchange in a small volume. In addition, they have the advantage when compared to shell-and-tube exchangers, of occupying less space, can easily be expanded when additional load is added, and cost about 40% less (Geo-Heat Centre, 1997).

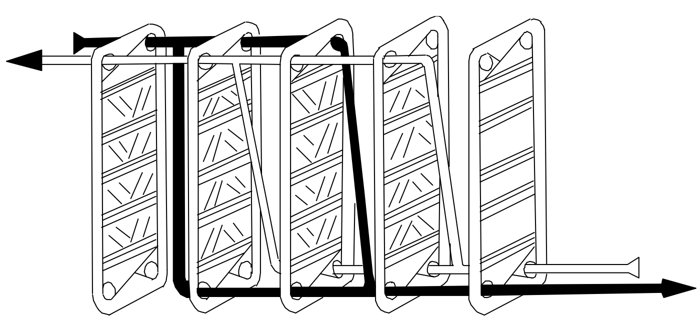

Figure 4: Plate heat exchanger (Lund, 2018).

5. CASCADE AND CIRCULAR ECONOMY

The industries which are to be located within the green energy park have different energy needs. Some processes have high temperature requirements while others processes utilize energy at lower temperatures. Figure 5 illustrates how cascading of thermal energy downstream the processes results in better energy utilisation because a single stream of hot water can meet the energy needs of several processes.

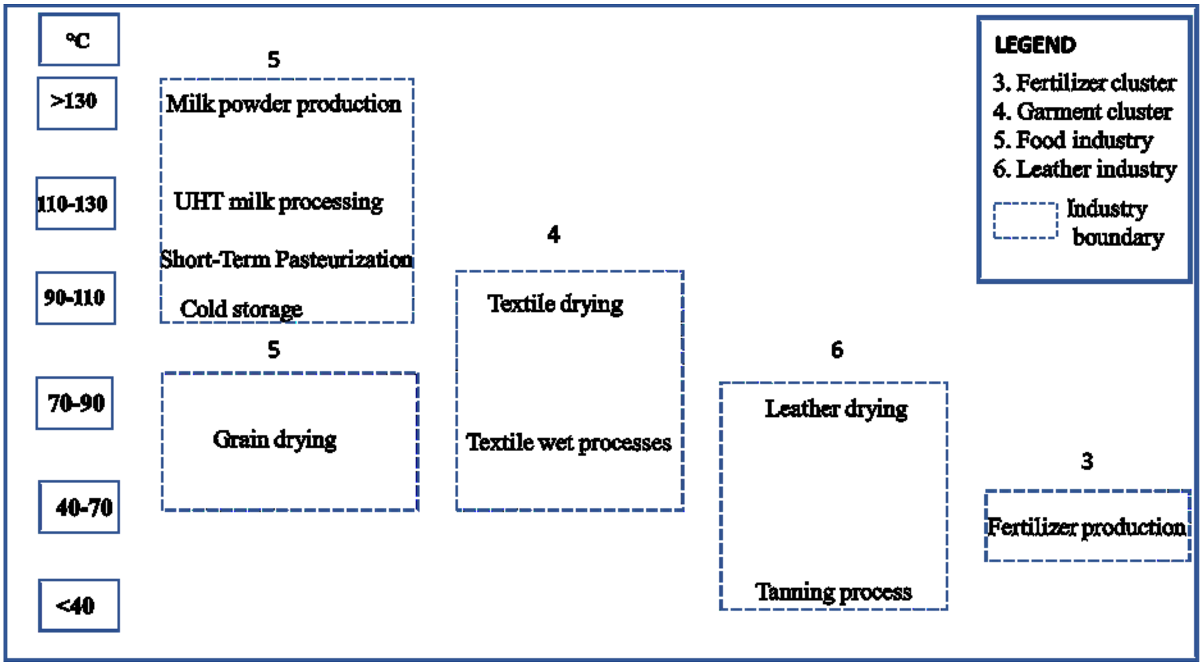

Figure 5: Energy cascade within the KenGen Green Energy Park

The thermal processes in the industries were categorised into six temperature bands with each band having a temperature range of 20°C. The highest temperature band comprises of processes, which require more than 130°C while the lowest temperature band processes require less than 40°C. Cold storage, milk powder processing and deodorizing have the highest temperature requirement while tanning processes in textile manufacture and fertilizer production have the lowest temperature requirements. A stream of hot water can be utilised by as many processes as possible of subsequently lower temperature requirements, where each process extracts some energy from the stream. Water below the temperature of 40°C is reinjected back to the Olkaria geothermal reservoir for sustainability forming a closed loop system of production.

5.1 Industrial Clusters for symbiosis

Eco-industrial clusters are geographic concentrations of interconnected industries in a specialized field that cooperate and coordinate to efficiently share resources and information. They emerge as a central concept to furthering innovation and competitiveness and advancing sustainable development strategies. The fostering of industrial clusters has become a focus of regional development, industrial, and environmental policies

Cluster zonation needs to be included in the master planning and detailed design of the park to enable infrastructural layout that facilitates resource sharing. The anchor tenant should be strategically located to allow other companies to be built around it. Similarly, companies should establish mutual trust and be ready to engage in active pooling of sustainability knowledge and know-how. The anchor company should be able to help develop joint internal and external communication networks that will aid the coordination of zone wide cluster activities.

For resource efficiency and waste monitoring to be effective within the KenGen Green Energy Park, a material flow model should be simulated to show the symbiotic relationship between industries and possible future incorporation of spin off companies to utilize the remaining co-products and wastes. Two important factors are to be considered when developing a material flow model; system boundary and the flows. The total industrial area represents the system and coincides with the geographical boundaries of the industrial park. Each company represents a subsystem and are defined by the territorial limits of companies. To summarize classification of different exchanges amongst firms and industries in the form of synergies, the flows are characterized by three attributes imports, exports and outputs as illustrated in Figure 17. Domestic extraction are the resources used extracted inside the system (e.g. steam), whereas raw materials and products from other businesses, bought or extracted outside the industrial area, are treated as imports. Exports are the products and materials used or sold outside the system boundaries, while emissions to air, wastes and wastewater are outputs to the environment. The industrial cluster is composed by six industries and their material symbiosis. The circles represent the boundaries for each company (subsystem). To analyse interconnection among companies, material flow analysis of each subsystem should be evaluated. Possible use of co-products by various processes, for example slag from steel manufacturers can be sold to a cement manufacturer, sludge to be channelled for fertilizer production and fabric off-cuts can be used in making bags and for other profitable craft projects.

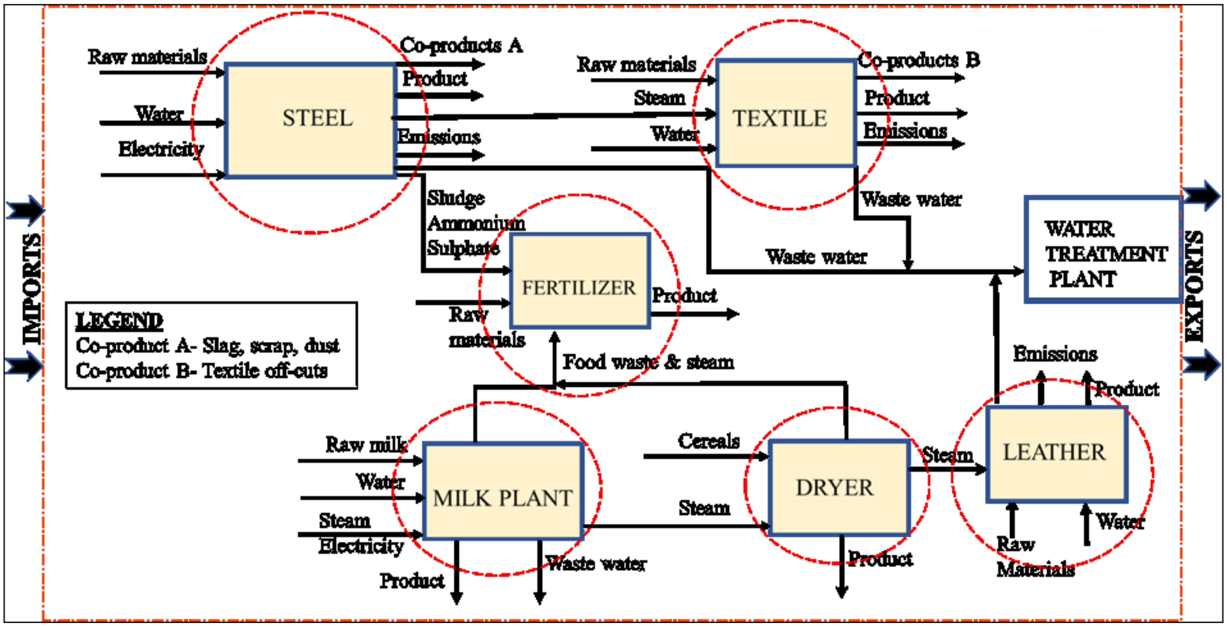

Figure 6. Summary of the input and output flows for each industry and the symbiotic relationships among different industries

A circular economy feeds back into its own development and thus closes the loop (Jørgensen and Pedersen, 2018). It is a regenerative economic model aimed at minimising waste and reducing resource dependency. This sustainable economic approach uses a 'repair, reuse, recycle' model of production is more beneficial than the traditional linear model of 'take, make, dispose'. Other benefits of circular economy include reduction of environmental footprint, increased economic growth, creates a greater collaboration between companies, improving the products and saving on production costs, enhancing the business competitiveness and creating more jobs. Circular economy concept within the KenGen Green Energy Park will be the main agenda to promote sustainable development mainly by enabling the wastes fluids from geothermal electricity generation to be utilized for direct use processes before reinjecting it back to the geothermal reservoir as demonstrated in the closed loop illustration in Figure 7.

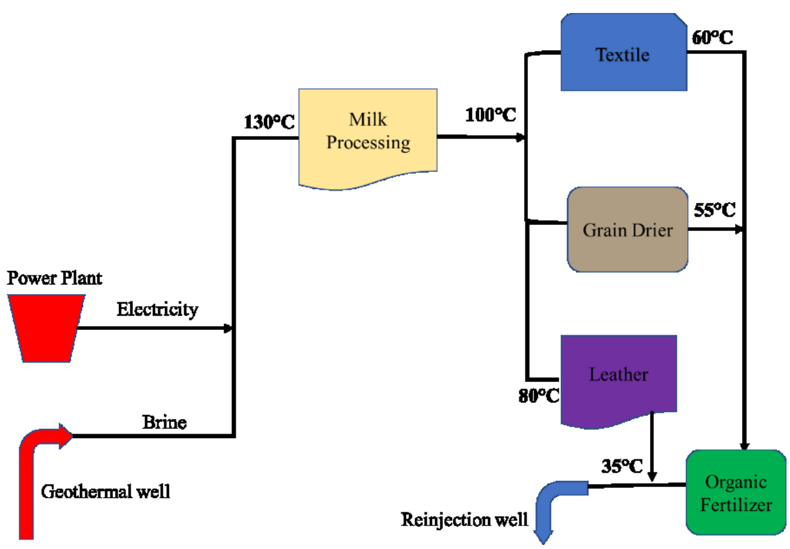

Figure 7: Closed loop system indicative of a sustainable circular economy model

6.0 CONCLUSION

The KenGen Green Energy Park has been identified as one of the revenue stream apart from electricity generation within the Olkaria Geothermal Resource Area. The park will utilize cheap electricity from the geothermal power plants and thermal energy harnessed from separated brine and steam from low pressure / low enthalpy wells within the geothermal field. The first co-located firms have been identified and initial phases of infrastructure development has begun. The firms are manufacturers of steel, glass, organic fertilizer, textile, leather and food processing industries.

From the application of the Lindal concept, it is evident that it is possible to enhance the feasibility of geothermal projects with cascading and combined uses. The possible utilization depends on the resource temperatures, available flow rate, the chemistry of the geothermal fluid and the type of application. Use the geothermal brine first for industrial utilization and thereafter for food drying and recreational purposes will continue being a recent research focus in Olkaria (cascade uses). Other innovative ideas like industrial clustering and industrial symbiosis will enable energy resource efficiency. Future plans for Combined Heat and Power – CHP production will be viable as Olkaria is surrounded by many hotels and facilities that are interested in hot water for their daily domestic use.

The industrial symbiosis and circular economy approaches within the park will bring numerous gains including environmental, economic, and social advantages. The environmental benefit is the result of the potential reduction in wastes, emissions, primary inputs, and energy. The economic convenience comes from the savings due to reduced costs for both wastes disposal and primary inputs purchase and the social benefits focuses on the creation of new firms and new jobs from the emerging spin off companies and small to medium scale enterprises that benefit from wastes and co-products of the major companies. The green energy park needs to encourage the incorporation of start-up and research companies that will scale up the research and innovation and create a platform for new ideas. By ´´greening´´the KenGen Green Energy Park and operating it as an Eco-Industrial Park, it will achieve sustainability and benefit from competitiveness within the region.

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