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# EFFECT OF CASCADING DURING DIRECT UTILIZATION OF GEOTHERMAL ENERGY

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**ABSTRACT**

Energy bearing fresh water is used to supply direct use applications with thermal energy. The water can be cascaded from process to process or industry to industry, whereby at each stage, some energy is extracted from the water. Four different sources of energy and three scenarios were used to demonstrate the effect of cascading of energy. The result was a 60% approximate reduction in the amount of water required to carry the energy.

## 1. INTRODUCTION

Energy for direct use is in the form of heat. Fresh water is the medium required to transport the heat from the well to the industries which require it. The energy is extracted from geothermal brine into the fresh water by the use of heat exchangers. A case study for Menengai was conducted and considered four options as the possible sources for the energy: Separated brine from power generation, MW-07, MW-17 and MW-17A as shown in Table 1 (Kiruja, 2017).

TABLE 1: Sources of energy for direct use in Menengai

| Source of thermal energy | Energy available (MWt) | Fresh water mass flow rate (kg/s) | Fresh water temperature (°C) |
|---|---|---|---|
| Separated brine | 22.6 | 47.8 | 135 |
| MW-07 | 8.8 | 21.4 | 120 |
| MW-17 | 3.3 | 9.0 | 110 |
| MW-17A | 10.4 | 21.9 | 135 |

For each of the options, the available energy is indicated as well as the amount of fresh water required to extract the energy and the temperature of that fresh water after heat exchange.

A number of industries were identified and the energy demand of their thermal processes estimated. This estimate was based on an assumed size for each of the industries and an estimate of the energy consumed by the thermal processes in those industries as shown in Table 2.

For each of the thermal processes, the required temperature of the hot water as it enters and exits the process is indicated.

TABLE 2: Industries and their thermal energy requirements

| **Industry** | **Process** | **Thermal energy requirement** | **Inlet temp. (°C)** | **Outlet temp. (°C)** |
|---|---|---|---|---|
| Greenhouse | Greenhouse heating | 300/1000 kWth/ha | 55 | 40 |
| Aquaculture | Aquaculture heating | 1260 kWth/ha | 40 | - |
| Drying | Onion drying | 35000 kJ/kg | 120 | 80 |
| | Grain drying | 350 kJ/kg | 90 | 75 |
| Milk processing | Cleaning | | 80 | |
| | UHT milk processing | 0.35 kWth/litre | 130 | 100 |
| | Milk pasteurisation | 0.056 kWth/litre | 100 | 90 |
| Abattoir | Cleaning | 1.5 m3/bovine carcass | 90 | |
| | Precooking and canning | | 120 | - |
| | Equipment sterilisation | | 120 | - |
| Tannery | Chemical processes | 12 kWth/m2 of leather | 65 | - |
| | Drying | | 100 | 55 |
| Textile | Chemical processes | 10 kg of hot water/kg of fabric | 100 | - |
| | Drying | | 110 | 90 |
| Recreation | Water heating | | 40 | |
| Water treatment | Water heating | 180 kWth/kg of water | 80 | 65 |

The size of the industries was estimated based on the studies that have been conducted by GDC in collaboration with its partners as well as the size of similar industries in Kenya. The thermal energy which is to be used in these industries will be transported using water and therefore, the hot water flow rate into each thermal process was analysed. This flow rate depends on the temperature required by the thermal processes as well as the per unit energy requirement for each of those processes.

The effect of cascading the energy bearing fresh water from one thermal process to the next and from one industry to the next was investigated as follows.

## 2. CASCADING OF ENERGY

The identified industries have different energy requirements. Some processes have high temperature requirements while others have lower temperature requirements. Exchange of energy among these processes results in better energy utilisation because a single stream of hot water can meet the energy needs of several processes as shown in Figure 1.

The thermal processes in the industries were categorised into six temperature bands. 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 and deodorizing have the highest temperature requirement while aquaculture, some wet processes in textile manufacture and recreation facility 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. In case the hot water stream gets into direct contact with a product that is being processed or is used in cleaning of equipment, then that stream cannot be cascaded down to any other process but is discarded.

The industries requiring temperature above what can be obtained from geothermal brine, i.e. above 130°C can be supplied with steam. Cold storage requires at least 140°C to operate at a reasonable coefficient of performance when using water/ammonia refrigeration equipment in order to achieve freezing conditions. Edible oils processing requires at least 200°C for the deodorizing process in order to evaporate the volatile impurities from crude palm oil.

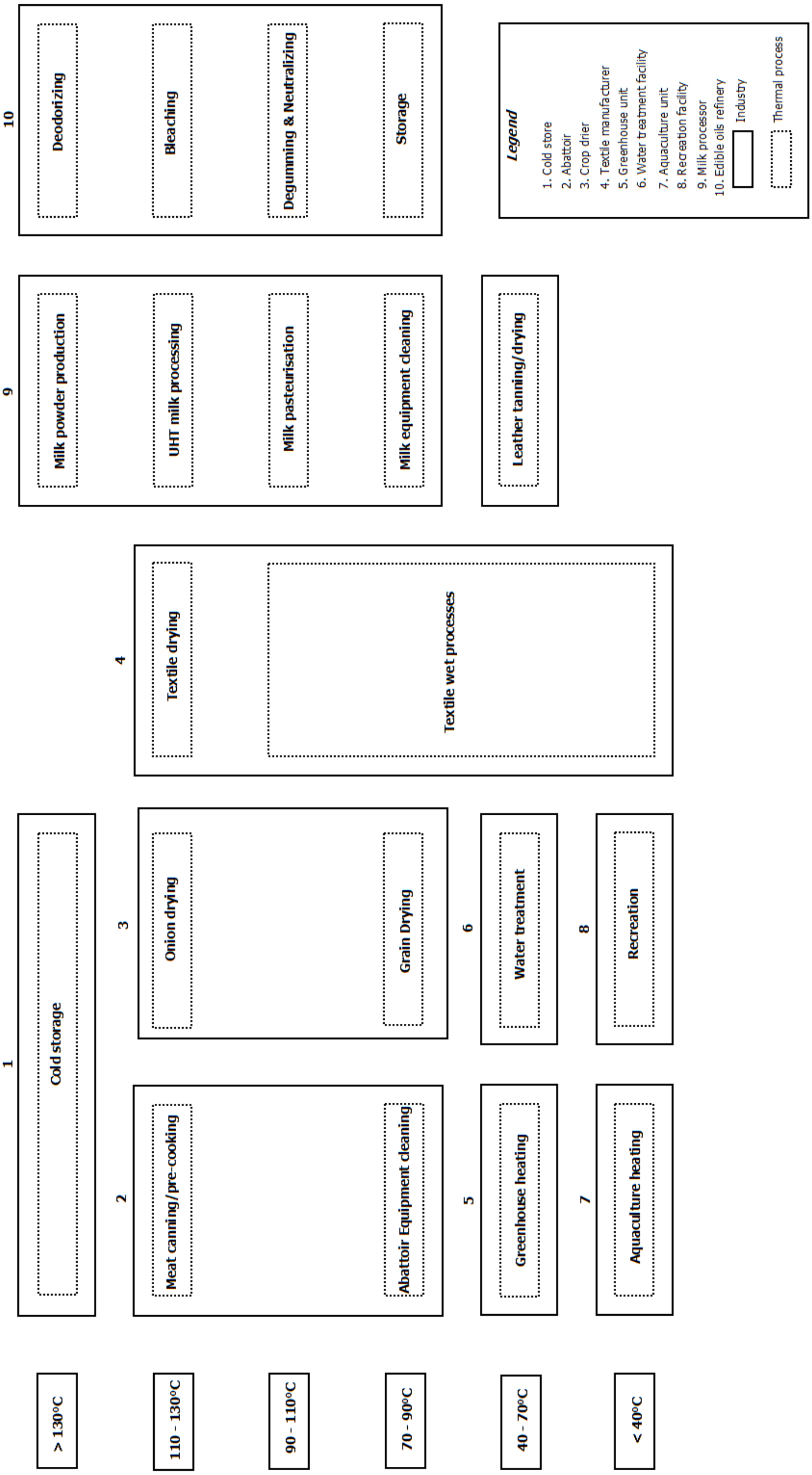


FIGURE 1: Cascading of energy

### 2.1 Energy demand scenarios

Since the energy demand was based on estimates of the thermal energy requirements for each process as well as an estimate of the capacity of the industries, scenarios were created to analyse the effect of any variations from the base case scenario. In scenarios where the energy available from a single source was not sufficient, then a combination of sources was considered. When more than one source of brine was used to provide the energy, it was assumed the energy bearing water from those sources would be combined and transported using a single pipeline to the industries.

#### 2.1.1 Scenario 1

This is the base case scenario and the energy requirements for the industries considered in Scenario 1 are shown in Table 3.

TABLE 3: Scenario 1 energy requirements

| **Industry** | **Process** | **Thermal energy requirement** | **Capacity** | **Hot water requirement (kg/s)** |
|---|---|---|---|---|
| Greenhouse | Greenhouse heating | 300/1000 kWth/ha | 10 ha | 7.41 |
| Aquaculture | Aquaculture heating | 1260 kWth/ha | 4.7 ha | 4.44 |
| Drying | Onion drying | 35000 kJ/kg | 150 kg/h | 8.1 |
| | Grain drying | 350 kJ/kg | 5 ton/h | 5.4 |
| Milk processing | Cleaning | | 250,000 litres/day | 5.21 |
| | UHT milk processing | 0.35 kWth/litre | | 18.81 |
| | Milk pasteurisation | 0.056 kWth/litre | | 18.75 |
| Abattoir | Cleaning | 1.5 m3/bovine carcass | 200 heads of cattle and 200 heats of goats and sheep | 9.26 |
| | Precooking and canning | | | |
| | Equipment sterilisation | | | |
| Tannery | Chemical processes | 12 kWth/m2 of leather | 620 $m^2$ of skins and hides/day | 2.92 |
| | Drying | | | |
| Textile | Chemical processes | 10 kg of hot water/kg of fabric | 1 ton of fabric/day | 0.12 |
| | Drying | | | |
| Recreation | Water heating | 180 kWth/kg of water | 2,000 $m^2$ | 4.63 |
| Water treatment | Water heating | | | 7.99 |

10 hectares of greenhouse have been considered, where 2 hectares are for floriculture propagation while 8 hectares are for various fruits and vegetables. 7.41 kg/s of hot water at 55°C will supply the greenhouses with sufficient energy.

Aquaculture production will require 4.44 kg/s of hot water at 40°C to maintain 4.7 hectares of aquaculture ponds at 29°C. The constant temperature of 29°C can only be maintained if the heated water is allowed to flow through the aquaculture unit. This size of the aquaculture unit was selected by matching the flow from the aquaculture unit to the irrigation needs of the greenhouse. The water flowing from the aquaculture unit is used for irrigation in the greenhouse to prevent wastage of water.

An onion dryer with a capacity of 150 kg of dry onion per hour and a cereals dryer of 5 tons/h were considered. The onion dryer would require 8.1 kg/s of 120°C water to dry onions to 4% moisture content while the cereals dryer would require 5.4 kg/s of 90°C hot water to achieve a moisture content of 13% in maize.

A milk processing facility with a capacity of 250,000 litres of milk per day was considered. Between 20%-30% of the milk will undergo high temperature short time pasteurisation and be marketed either as fresh ultra-heat treated (UHT) milk or cultured milk while the remaining 70%-80% will undergo low temperature long time pasteurisation. These processed milk products are popular in the Kenyan market. 18.81 kg/s of 130°C water and 18.75 kg/s of 100°C water will be required to process both products respectively. Since hygiene is critical in a milk processing facility, 5.21 kg/s of hot water at 80°C will be required to clean the equipment and the space used for milk processing.

An export level abattoir with a capacity to slaughter 200 heads of cattle and an equal number of goats and sheep was considered. The abattoir will have refrigeration equipment which can keep the meat refrigerated for at least 24 hours at a temperature of minus 10°C. In addition, equipment for meat canning will be installed in the abattoir. In order to maintain the required hygienic standards and meet the thermal energy requirements of meat canning, 9.26 kg/s of water at 80-120°C will be required. This is based on the assumption that $1.5m^3$ of water is required per a bovine caucus and that 3 ovine caucuses are equivalent to one bovine.

If all the hides and skins produced in the abattoir are treated into leather in a tannery located at the geo-industrial park, then 631 $m^2$ of hides and skins will be processed daily assuming that a bovine hide is 2.3 $m^2$ and an ovine skin is 0.8 $m^2$. Hot water at 65-100°C with a flow rate of 2.92 kg/s will be required to meet the thermal energy needs of such a tannery.

A textile manufacturer with a capacity to make 1 ton of fabric daily will require 10 $m^3$ of water daily to accomplish the wet processes. This water at a temperature range of 60-100°C will be required at a flow rate of 0.12 kg/s assuming the factory will operate for 24 hours every day.

A recreational facility consisting of a swimming pool, hot tabs and steam bath and occupying an area of 2,000 $m^2$ with the average water depth of 1m was considered. The water in this facility will be treated, reheated and recirculated. However, about 10% of the water will be lost daily through evaporation and cleaning operations and should be replaced. About 4.63 kg/s of water at 50-70°C will be required for this purpose.

The water used in the aquaculture unit and for irrigating crops many contain harmful microorganisms. It is important to sterilise this water in order to get rid any microorganisms which might be harmful to the fish and the crops. 7.99 kg/s of water at 80°C would be required to sterilise the water at a temperature of 60°C in order to kill any disease causing organisms.

Cleaning of equipment and working areas is important for hygiene in the factories. Washing off the fats from foods such as milk, meat and fish requires hot water at 80°C.

In total, 12MWt would be required to meet the energy requirements of the discussed thermal processes. This would require 93 kg/s of 130°C water. However, none of the analysed sources of energy could generate enough hot water flow rate to meet this demand.

A cascaded model of the thermal processes revealed that the same amount of energy can be supplied using 36 kg/s of 130°C water. This is because a stream of hot water can be used to supply energy to more than one process, provided that the temperature requirement of the downstream process is lower than that of the preceding processes.

Two sources of energy were found to contain sufficient energy and hot water flow rate to meet the demand of the industries as shown in Table 4.

TABLE 4: Proposed sources of energy for Scenario 1

| | **Source of thermal energy** | **Energy available (MWt)** | **Hot water temp. delivered at the park (°C)** | **Available flow rate (kg/s)** | **Required flow rate (kg/s)** | **Proportion of un-utilised flow rate** |
|---|---|---|---|---|---|---|
| Option 1 | Separated brine | 22.6 | 131 | 47.8 | 36.17 | 24% |
| Option 2 | Combined MW-07 and MW-17A | 19.2 | 123 | 43.2 | 41.89 | 4% |

In this scenario, cascading reduces the demand for hot water by 61% when the energy is supplied from Option 1 and by 58% in the case of Option 2.

### 2.1.2 Scenario 2

In this scenario, the capacity of the industries was reduced by half in comparison to the base case scenario. This is shown in Table 5.

TABLE 5: Scenario 2 energy requirements

| **Industry** | **Process** | **Thermal energy requirement** | **Capacity** | **Hot water requirement (kg/s)** |
|---|---|---|---|---|
| Greenhouse | Greenhouse heating | 300/1000 kWth/ha | 5 ha | 3.7 |
| Aquaculture | Aquaculture heating | 1260 kWth/ha | 2.33 ha | 2.22 |
| Drying | Onion drying | 35000 kJ/kg | 75 kg/h | 5.83 |
| | Grain drying | 350 kJ/kg | 2.5 ton/h | 2.7 |
| Milk processing | Cleaning | | 125,000 litres/day | 2.08 |
| | UHT milk processing | 0.35 kWth/litre | | - |
| | Milk pasteurisation | 0.056 kWth/litre | | 8.89 |
| Abattoir | Cleaning | 1.5 m3/bovine carcass | 100 heads of cattle and 100 heats of goats and sheep | 4.84 |
| | Precooking and canning | | | |
| | Equipment sterilisation | | | |
| Tannery | Chemical processes | 12 kWth/m2 of leather | 310 m$^2$ of skins and hides/day | 1.46 |
| | Drying | | | |
| Textile | Chemical processes | 10 kg of hot water/kg of fabric | 0.5 ton of fabric/day | 0.06 |
| | Drying | | | |
| Recreation | Water heating | 180 kWth/kg of water | 2,000 m$^2$ | 4.63 |
| Water treatment | Water heating | | | 5.33 |

This resulted in a 50% reduction in the amount of energy required by the industries to about 6 MWt. When this energy is cascaded through the thermal processes, only about 20 kg/s of hot water will be required. The sources of energy which can supply this energy are shown in Table 6.

When the source of energy for Scenario 2 is Option 1, only 39% of flow rate would be required when compared to the case without cascading. Option 2 would require 42% of the water demanded in the absence of cascading.

TABLE 6: Proposed sources of energy for Scenario 2

| | Source of thermal energy | Energy available (MWt) | Hot water temp. delivered at the park (°C) | Available flow rate (kg/s) | Required flow rate (kg/s) | Proportion of un-utilised hot water |
|---|---|---|---|---|---|---|
| Option 1 | MW-07 | 8.8 | 115 | 21.4 | 19.93 | 7% |
| Option 2 | MW-17A | 10.4 | 129 | 21.9 | 19.56 | 11% |

### 2.1.3 Scenario 3

In this scenario, the capacity of the industries under consideration was doubled in comparison to the base case scenario as shown in Table 7.

TABLE 7: Scenario 3 energy requirements

| Industry | Process | Thermal energy requirement | Capacity | Hot water requirement (kg/s) |
|---|---|---|---|---|
| Greenhouse | Greenhouse heating | 300/1000 kWth/ha | 20 ha | 14.81 |
| Aquaculture | Aquaculture heating | 1260 kWth/ha | 9.33 ha | 8.88 |
| Drying | Onion drying | 35000 kJ/kg | 300 kg/h | 16.20 |
| | Grain drying | 350 kJ/kg | 10 ton/h | 10.80 |
| Milk processing | Cleaning | | 500,000 litres/day | 10.42 |
| | UHT milk processing | 0.35 kWth/litre | | 37.62 |
| | Milk pasteurisation | 0.056 kWth/litre | | 37.50 |
| Abattoir | Cleaning | 1.5 m3/bovine carcass | 400 heads of cattle and 400 heats of goats and sheep | 18.53 |
| | Precooking and canning | | | |
| | Equipment sterilisation | | | |
| Tannery | Chemical processes | 12 kWth/m2 of leather | 1,240m$^2$ of skins and hides/day | 5.83 |
| | Drying | | | |
| Textile | Chemical processes | 10 kg of hot water/kg of fabric | 2 ton of fabric/day | 0.23 |
| | Drying | | | |
| Recreation | Water heating | 180 kWth/kg of water | 2,000 m$^2$ | 4.63 |
| Water treatment | Water heating | | | 5.33 |

This scenario requires 22 MWt of energy to meet the energy demand of the thermal processes. A flow rate of 170 kg/s of water at 130°C would be required to supply each of the processes with adequate energy but after cascading, only 72.34 kg/s will be required. Since no single source of energy considered can generate this energy, a combination of separated brine, MW-17 and MW-17A was proposed to supply the energy as shown in Table 8.

Due to cascading of energy, the need for hot water by the industries is reduced by 58% in this scenario.

TABLE 8: Proposed sources of energy for scenario 3

| Source of thermal energy | Energy available (MWt) | Hot water temp. (°C) | Available flow rate (kg/s) | Required flow rate (kg/s) | Proportion of un-utilised hot water (%) |
|---|---|---|---|---|---|
| Separated brine plus Combined MW-17 and MW-17A | 36.4 | 129 | 78.7 | 72.34 | 8% |

## 3. CONCLUSION

Cascading results in better utilisation of resources such as energy and water. In the considered scenarios and options, the effect of cascading can be summarised as shown in Figure 2.

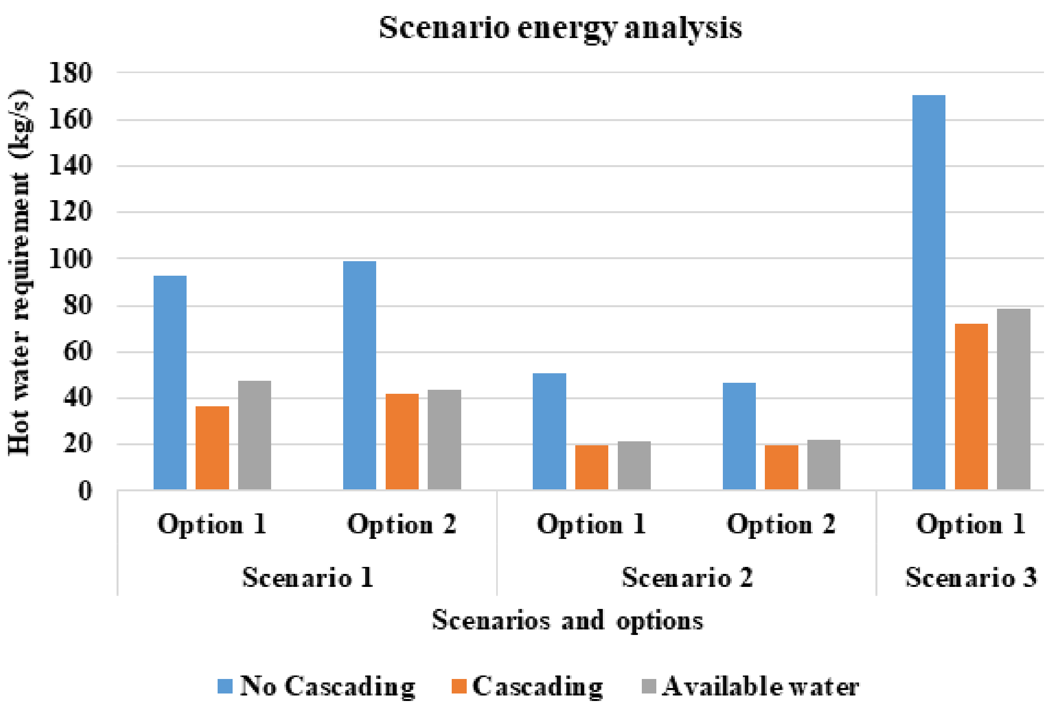


FIGURE 2: Summary of the effect of cascading

Due to cascading, the amount of water required by the industries is reduced by approximately 60%. In addition, some excess water remains un-utilised after cascading.

## REFERENCES

Kiruja, J., 2017: *The viability of supplying an industrial park with thermal energy from Menengai Geothermal Field, Kenya.* United Nations University Geothermal Training Programme and University of Iceland, Reykjavík, Iceland, MSc thesis, 64 pp.