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GEOTHERMAL ENERGY UTILISATION

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ABSTRACT

Geothermal energy is energy derived from the natural heat of the earth. The earth's temperature varies widely, and geothermal energy is usable for a wide range of temperatures from room temperature to well over 300°C. Geothermal energy can be used for both electricity generation and direct uses depending on the temperature and chemistry of the resources. High to medium resources are used for electricity generation while medium to low resources are is mainly used for direct application. For efficient utilization of resources, geothermal energy is being utilized for combined heat and power. Since geothermal energy is renewable, indigenous and environmentally benign, and can be used as base load, its will be the future source of energy in Kenya and most of the Eastern African countries especially those that are located within the east Africa Rift. This will reduce uses of fossil fuels and hence address global warming.

1. INTRODUCTION

The word geothermal was developed from two Greek words, "*geo*", meaning earth, and "*thermos*", meaning heat since it is power extracted from heat stored in the earth. This geothermal energy originates from radioactive decay of minerals, and from solar energy absorbed at the surface. Geothermal heat, is estimated to be about 5,500°C at the Earth's core – about as hot as the surface of the sun. This energy been used for bathing since paleolithic times and for space heating since ancient roman times. Nowadays, it is used commercially for both generating electricity and direct uses. Worldwide, geothermal plants have the capacity to generate about 10 GW of electricity as of 2007, and in practice supply 0.3% of global electricity demand. An additional 28 GW of direct geothermal heating capacity is installed for district heating, space heating, hot spas, industrial processes, desalination and agricultural applications (Fridleifsson et. al, 2008).

Because of the near limitless ability of the earth to produce magma, and the continuous transfer of heat between subsurface rock and water, geothermal energy is considered a renewable resource. It is also cost effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels.

2. UTILISATION OF GEOTHERMAL ENERGY

The heat from the earth's own molten core is conducted to the adjacent rocks and eventually is transferred to underground water reservoirs through convection. Steam/water heated by the geothermal heat can be tapped using different technologies and channeled to various uses. Utilisation of geothermal fluid depends heavily on its thermodynamic characteristics and chemistry. These factors are determined by the geothermal system from which the fluid originated. Geothermal fluids have been classified differently by different authors. Some authors have done so by using temperatures while others have used enthalpy (Dickson and Fanelli, 2004). The most common criterion is that based on enthalpy. The resources are divided into low, medium and high enthalpy resources. Table 1 shows the classifications proposed by a number of authors.

TABLE 1: Classification of geothermal resources (°C) (Dickson and Fanelli, 2004)

	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	< 90	<125	<100	≤150	≤190
Intermediate enthalpy resources	90-150	125-225	100-200	-	-
High enthalpy resources	>150	>225	>200	>150	>190

a) Muffler and Cataldi (1978); b) Hochstein (1990); c) Benderitter and Cormy (1990);
d) Nicholson (1993); e) Axelsson and Gunnlaugsson (2000).

Depending on the enthalpy, geothermal fluid can be utilised either for electricity generation or direct applications. Electricity generation is the most important form of utilization of high-temperature geothermal resources while low to medium resources are better suited for non-electric (direct) application (Table 2).

TABLE 2: Basic technology commonly used for geothermal energy

Reservoir temperature	Reservoir fluid	Common use	Technology commonly chosen
High temperature, >220°C	Water or Steam	Power generation Direct use	Flash steam; Combined (flash and binary) cycle Direct fluid use; Heat exchangers; Heat pumps
Intermediate temperature, 100-220°C	Water	Power generation Direct use	Binary cycle Direct fluid use; Heat exchangers; Heat pumps
Low temperature, 30-150°C	Water	Direct use	Direct fluid use; Heat exchangers; Heat pumps

2.1 Electricity generation from geothermal energy

Geothermal energy is utilized in many parts of the world especially those that are located on plate boundaries or tectonically active regions (Figure 1). In 2005, 24 countries generated a total of 56,786 GW-hours (GWh) (204 PJ) of electricity from geothermal power, accounting for 0.3% of worldwide electricity consumption. Output is growing by 3% annually because of a growing number of plants and improvements in their capacity factors, development of binary cycle power plants and improvements in drilling and extraction technology. Since geothermal power does not rely on variable sources of energy, unlike, for example, wind or solar, its capacity factor can be quite large – up to 96% has been demonstrated (Lund, 2003). The global average was 73% in 2005 (Fridleifsson et. al, 2008).

Geothermal power plants are categorized in three main ways depending on the fluid temperature, pressures and chemistry.

- Condensing power plants (dry steam, single or double flash systems)

- Back-pressure turbines (release to the atmosphere)
- Binary plants (for lower temperature or separated brine).

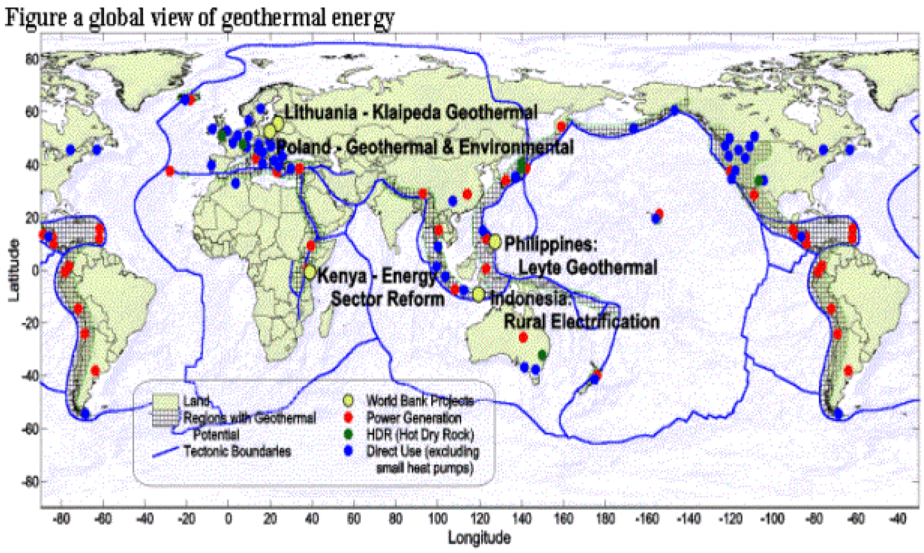

FIGURE 1: Plate and tectonic boundaries

The largest group of geothermal power plants in the world is located at The Geysers, field in California, United States As of 2004, five countries (El Salvador, Kenya, the Philippines, Iceland, and Costa Rica) generate more than 15% of their electricity from geothermal sources (WEA, 2004).
Geothermal resources vary in temperature from 30-350 ^{o}C, and can either be dry steam, two-phase (a mixture of steam and water) or just liquid water. In order to extract geothermal heat from the earth, water is the transfer medium. Naturally occurring groundwater is available for this task in most places but more recently technologies are being developed to even extract the energy from hot dry rock resources. The temperature of the resource is a major determinant of the type of technologies required to extract the heat and the uses to which it can be put. Table 3 lists the basic technologies normally utilised according to resource temperature and fluid availability.

TABLE 3: Geothermal energy applications

Electricity production	Wells drilled into a geothermal reservoir produce hot water and steam from depths of up to 3 km. The geothermal energy is converted at a power plant into electric energy, or electricity. Hot water and steam are the carriers of the geothermal energy.
Direct use	Applications that use hot water from geothermal resources directly. Examples: space heating, crop & lumber drying, food preparation, aquaculture, industrial processes, etc. Historical traces back to ancient Roman times, e.g. for baths
Geothermal heat pumps	Taking advantage of relatively constant earth temperature as the source and sink of heat for both heating and cooling, as well as hot water provision. One of the most efficient heating and cooling systems available.
Hot Dry Rock Deep geothermal/EGS (both not commercial yet)	Extracts heat by creating a subsurface fracture system to which water can be added through injection wells. Water is heated by contact with the rock and returns to the surface through production wells. Energy is then converted at a power plant into electric energy as in a hydrothermal geothermal system.

High temperature geothermal reservoirs containing water and/or steam can provide steam to directly drive steam turbines and electrical generation plant. More recently developed binary power plant technologies enables more of the heat from the resource to be utilised for power generation. A combination of conventional flash and binary cycle technology is becoming increasingly popular.
High temperature resources commonly produce either steam, or a mixture of steam and water from the production wells. The steam and water is separated in a pressure vessel (Separator), with the steam piped to the power station where it drives one or more steam turbines to produce electric power. The separated geothermal water (brine) is either utilised in a binary cycle type plant to produce more power, or is disposed of back into the reservoir through deep (injection) wells. The following is a brief description of each of the technologies most commonly used to utilise high temperature resources for power generation.

2.1.1 Dry steam power plants

Power plants using dry steam systems were the first type of geothermal power generation plants built. They use steam from the geothermal reservoir as it comes from wells and route it directly through turbine/generator units to produce electricity (Figure 2). An example of a dry steam generation operation is at the Geysers in northern California.

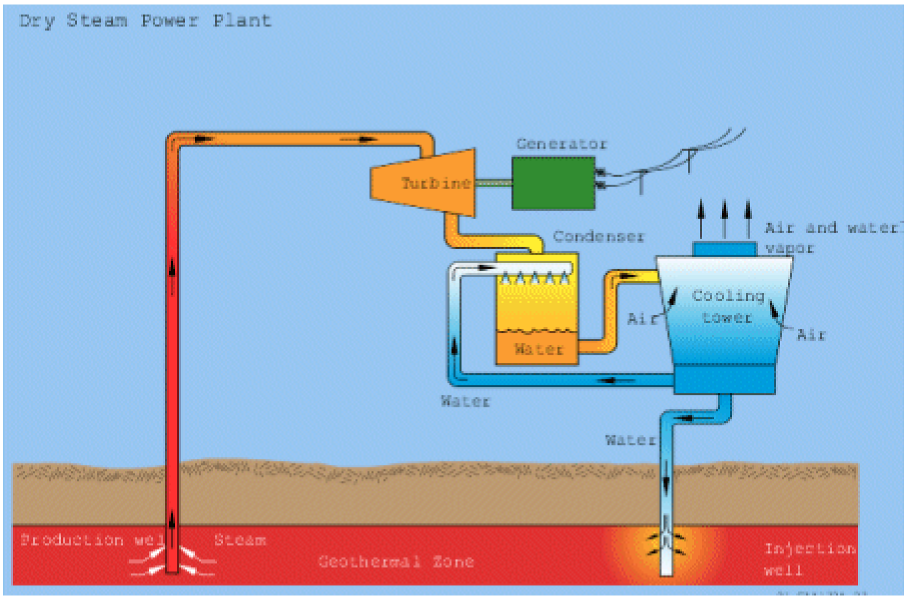

FIGURE 2: Schematic of a dry steam power plant.

2.1.2 Flash Steam Power Plant

Flash steam power plants (Figure 3) are the most common type of geothermal power plant. The steam, once it has been separated from the water, is piped to the powerhouse where it is used to drive the steam turbine. The steam is condensed after leaving the turbine, creating a partial vacuum and thereby maximizing the power generated by the turbine-generator. The steam is usually condensed either in a direct contact condenser, or a heat exchanger type condenser. In a direct contact condenser the cooling water from the cooling tower is sprayed onto and mixes with the steam. The condensed steam then forms part of the cooling water circuit, and a substantial portion is subsequently evaporated and is dispersed into the atmosphere through the cooling tower. Excess cooling water called blow down is often disposed of in shallow injection wells. As an alternative to direct contact condensers shell and tube type condensers are sometimes used, as is shown in the schematic below. In this type of plant, the condensed steam does not come into contact with the cooling water, and is disposed of in injection wells.

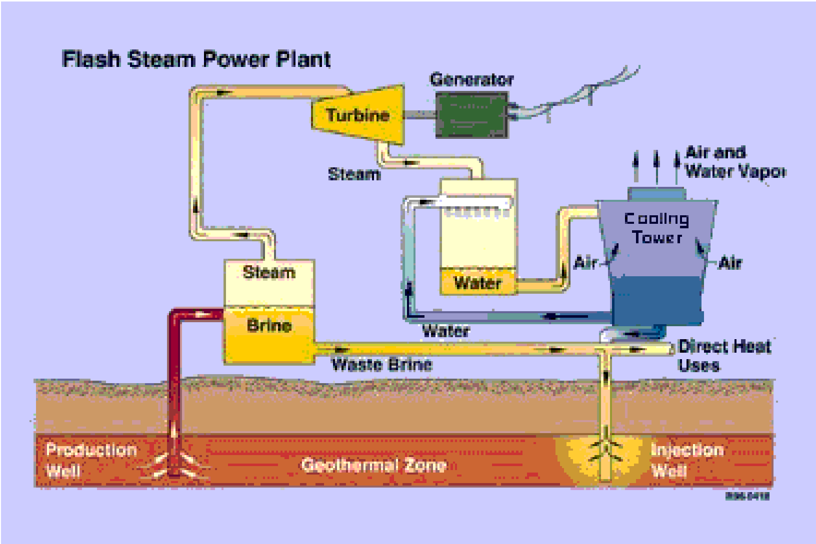

FIGURE 3: Schematic of a single flash steam power plant

Typically, flash condensing geothermal power plants vary in size from 5 MW to over 100 MW. Depending on the steam characteristics, gas content, pressures, and power plant design, between 6000 kg and 9000 kg of steam each hour is required to produce each MW of electrical power. Small power plants (less than 10 MW) are often called well head units as they only require the steam of one well and are located adjacent to the well on the drilling pad in order to reduce pipeline costs. Often such well head units do not have a condenser, and are called backpressure units. They are very cheap and simple to install, but are inefficient (typically 10-20 tonne per hour of steam for every MW of electricity) and can have higher environmental impacts.

2.1.3 Binary cycle power plants

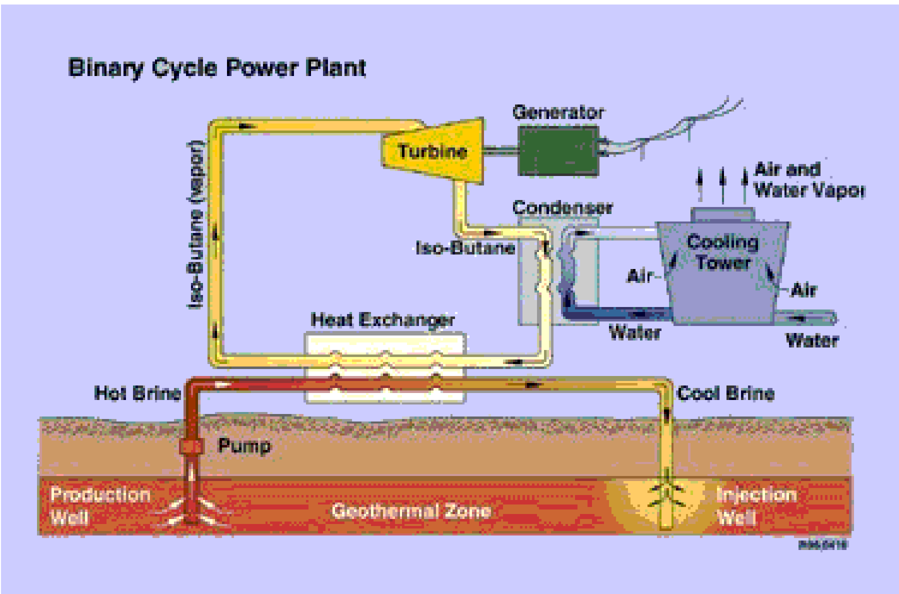

FIGURE 4. Power schematic of a binary cycle power plant

In reservoirs where temperatures are typically less than 220° C. but greater than 100° C binary cycle plants are often utilised. The illustration (Figure 4) shows the principal elements of this type of plant. The reservoir fluid (either steam or water or both) is passed through a heat exchanger which heats a secondary working fluid (organic) which has a boiling point lower than 100° C. This is typically an organic fluid such as Isopentane, which is vaporised and is used to drive the turbine. The organic fluid is then condensed in a similar manner to the steam in the flash power plant described above, except that a shell and tube type condenser rather than direct contact is used. The fluid in a binary plant is recycled back to the heat exchanger and forms a closed loop. The cooled reservoir fluid is again re-injected back into the reservoir.

Binary cycle type plants are usually between 7 and 12 % efficient, depending on the temperature of the primary (geothermal) fluid. Binary Cycle plant typically vary in size from 500 kW to 10 MW.

2.2 Direct uses of geothermal energy

Low to medium temperature geothermal resources are utilized for direct uses or binary power plants. The oldest and probably best known direct application of geothermal energy is in baths and spas, used during Roman times. Other more coordinated and commercial uses include district heating systems, like those found in Iceland which are the largest geothermal district heating system in the world, tourist centres thermal baths in Hungary and China; geothermally heated fish farms and food processing and de-hydration in Greece and the USA. Furthermore the possibility to utilize ground source (geothermal) heat pumps to either heat homes directly or through energy efficiency programs, allowing savings in energy costs, has vast possibilities for individual or industrial use.

All those "direct use" applications utilize geothermal energy produced from lower temperature water of less than 150 degrees centigrade that is being derived from wells of 100-3,000 m deep wells. Today, around 73 nations utilize geothermal energy directly, with an overall energy output of 75.9 TWh thermal per year. The number of nations using geothermal heat is growing constantly.

Approximately 70 countries made direct use of a total of 270 PJ of geothermal heating in 2004. More than half of this energy is being used for space heating, and another third for heated pools. The remainder supported industrial and agricultural applications. The global installed capacity was 28 GW, but capacity factors tend to be low (30% on average) since heat is mostly needed in the winter. The above figures are dominated by 88 PJ of space heating extracted by an estimated 1.3 million geothermal heat pumps with a total capacity of 15 GW. Heat pumps for are the fastest-growing means of exploiting geothermal energy, with a global annual growth rate of 30% in energy production. Most of these new heat pumps are being installed for home heating.

Direct heating in all its forms is far more efficient than electricity generation and places less demanding temperature requirements on the heat resource. Heat may come from co-generation with a geothermal electrical plant or from smaller wells or heat exchangers buried in shallow ground. As a result, geothermal heating is economical over a much greater geographical range than geothermal electricity. Where natural hot springs are available, the heated water can be piped directly into radiators. If the ground is hot but dry, earth tubes or downhole heat exchangers can collect the heat. But even in areas where the ground is colder than room temperature, heat can still be extracted with a geothermal heat pump more cost-effectively and cleanly than it can be produced by conventional furnaces (Lund, 2006). These devices draw on much shallower and colder resources than traditional geothermal techniques, and they frequently combine a variety of other functions, including air conditioning, seasonal energy storage, solar energy collection, and electric heating. Geothermal heat pumps can be used for space heating essentially anywhere in the world.

Geothermal heat supports many applications. In Iceland, Reykjavík and Akureyri pipe hot water from geothermal plants below pavement to melt snow. District heating applications use networks of piped hot water to heat buildings in whole communities. Geothermal desalination has been demonstrated. Some of the main direct uses of geothermal energy are

3. GEOTHERMAL UTILISATION IN KENYA

Kenya has a large potential of geothermal energy estimated to be more than 4000 MWe (Omenda and Simiyu, 2006). Currently, only 4% of this energy is being exploited primarily for electricity generation. Other non electric applications have not been given the necessary attention (Mwangi, 2005). There are a number of potential applications of geothermal energy in Kenya.

3.1 Electricity generation using geothermal energy in Kenya

Geothermal energy exploitation in Kenya has been primarily for electricity generation and it constitutes 14 % of the country's electricity. KenGen generates 89% of this energy from two power plants. Olkaria I power plant was commissioned in the year 1981 while Olkaria II (Figure 5) was commissioned in the year 2003. Drilling for a third power plant, Olkaria IV is currently ongoing for a 140 MWe power plant expected in 2012.

FIGURE 5: Olkaria II power station, commissioned in 2003

OrPower 4, Inc., an independent power producer (IPP) is currently generating 48 MWe, 12 MWe from an Ormat binary plant commissioned in the year 2000 and 36 MWe is from a single flash plant commissioned in 2009. Oserian Development Company, (Oserian), constructed a 1.8 MWe binary plant Ormat OEC in 2004 and 2MWe from a back pressure turbine commisioned in 2007. Both of these plant use wells leased from KenGen (Knight et al, 2005).

3.2 Direct utilisation of geothermal energy for in Kenya

The only commercial application of geothermal energy for other uses other than electricity generation (direct applications) in Kenya is at Oserian. Since 2003, the firm has been utilising energy from a geothermal well OW-101 leased from KenGen for greenhouse heating. The system started by heating 3 hectares and has been expanded to 50 hectares (Figure 6). Other minor geothermal direct uses are at Lake Borogia hotel, where a naturally occurring geothermal hot spring is being used to warm a swimming pool and at Eburru geothermal resource where the local community use geothermal energy for drying pyrethrum products (Mwangi and Mburu, 2005). Other potential applications include greenhouse farming, domestic hot water supply, animal husbandly, and balneology among others.

Hot springs have been used to heat spas in tourist hotels for example in Borogia hotel which is located near the Bogoria prospect The Local community at Eburru geothermal resource condenses the steam from fumarole and uses the water for domestic purposes. They also use geothermally heated driers to dry their pyrethrum products. A study carried out in 2008 (Mburu, 2008) revealed potential market for direct utilisation in Kenya. Some of the main potential uses.

Although there is great potential for both electricity generation and direct utilisation of geothermal energy in the Kenyan Rift valley, geothemal energy has been primarily used for electricity generation

(Mwangi, 2005). Investigations into possible applications of this energy for direct applications show potential in swimming pools and spas, balneology, drying of farm produce and greenhouse heating (Lagat, 2006). This study will also investigate the feasibility of some of these applications together with domestic hot water supply and space cooling.

FIGURE 6: Geothermal greenhouse heating at Oserian Company, Kenya.

3.2.1 Greenhouse heating

Heating of greenhouses using geothermal energy has been practiced in many countries in the world with encouraging economic, social and environmental benefits (Lund and Freeston, 2000).
In 2003, Oserian Development Company Ltd, a private firm growing rose flowers for export leased a geothermal well from KenGen for use in greenhouse heating. Steam and brine from this well are being used in a heat exchanger to supply hot water to heat 50 hectares of the greenhouses. In Kenya and other warmer countries,greenhouse heating is done primarily for humidity control since, increase in humidity results in mutiplication of fungus affecing the crops. Heating also enhances growth and saves on fuel costs that would be incured if heating is to be done using fossil fuels (Hole and Mills, 2003).

3.2.2 Domestic hot water uses

District heating and domestic hot water supply using geothermal energy is dominant in many cold European countries. Though most of them use ground source heat pumps, those which have large geothermal resources like Iceland use geothermal energy (Fridleifsson, 2001).

The various uses for domestic hot water include dish washing, laundry, bathing and hand washing. Hot water consumption depends on uses and application temperature (Yao et. al., 2003). According to BRE, 2008, domestic hot water should be supplied at 60°C to avoid multiplication of Legionnaire bacteria (Figure 7) and to avoid scalding.

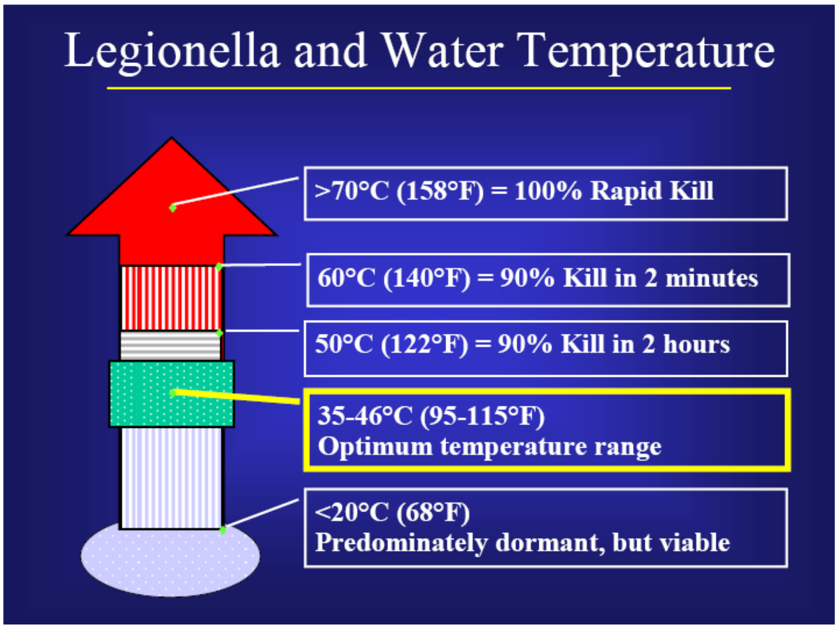

Figure 7: Safe temperature for domestic hot water (AWT, 2003)

3.2.3 Leisure therapeutic hot water uses

Water at elevated temperatures has been used for leisure and for its therapeutic potential for many centuries. Geothermal waters have in particular been used widely for this purpose. In Iceland for example, many tourist centres have geothermally heated pools, spas and steam bath. Blue lagoon, which uses geothermal brine from Svatsengi geothermal power plant, is a major tourist attraction with about 300,000 per year (Sigurgeirsson and Olafsson, 2003).

For safety and hygiene of swimmers, swimming pool water requires continuous cleaning and filtering at a circulation rate of between 4-8 hours. This depends on size and usage of the pool. A conventional commercial swimming pool 25m length, 10m width and average height of 1.5 m requires a circulation time of 6 hours (Dayliff, 2006). Water temperature at the swimming pool ranges between 26-30^{o}C (Seneviratne, 2007). Saunas temperature must be between 80^{o}C and 100^{o}C while steam baths are requires water from 43-60^{o}C (Hillingdon, 2008).

3.2.4 Crop drying

Geothermal energy has been used to dry vegetables, fruits wheat and other cereals (Lund et al, 2005). Due to high solar radiation in Kenya, crops have been traditionally dried using solar energy but farmers incur heavy crop losses due to these unreliability of solar energy during rainy and cold seasons and at night. Alternative energy sources have to be used during such times. Farmers in Eburru Kenya, use geothermal energy to dry pyrethrum flowers (Mwangi, 2005). However, this is uncoordinated and is on a very small scale. When such activities are co-ordinated, they can be a major benefit to the farmers of the area and to the environment.

4. CONCLUSIONS

Geothermal energy has been utilized for direct uses for along time in human history especially where the energy has been occurring naturally for example in Romans, Chinese, Ottomans and the Japanese. This was mainly in bathing and on small-scales. Currently, direct uses are on commercial level and are replacing fossil fuels in uses of low heat applications such as district heating, processing of agricultural products, therapeutic uses as well as in aquaculture.

The earliest industrial exploitation began in the 19th century with the use of geyser steam to extract boric acid from volcanic mud in Larderello, Italy. In the 20th century, demand for electricity led to the consideration of geothermal power as a generating source. In 1904, at the same Larderello dry steam field where geothermal acid extraction began, electricity generation was begun. Cierro Prietto in Larderello is the world's first commercial geothermal power plant. It was the world's only industrial producer of geothermal electricity until New Zealand built a plant in 1958. These two plants are operational to date.

Depending on the temperature, pressure and chemistry of geothermal resources, geothermal energy can be used in electricity generation using either conventional or binary power plants. In Kenya for example, 167 MWe is used for electricity generation using condensing, binary and back-pressure turbines.

The African Rift has a geothermal potential of more than 10,000 MWe and much more thermal energy. This energy if utilized can go a long way to replacing uses of fossil fuels and hence address the global warming.

Where temperature and pressure allow, combined heat and power should be adopted in all future geothermal developments. This will enhance efficient utilization of geothermal resources. This calls for research to explore potential direct uses especially among the communities living in geothermal resource area.

Geothermal energy has been used for direct applications in many parts of the world such as Iceland, USA, Turkey, China and many European countries. This has proved to be very economical and reliable since geothermal energy is has very high availability (>90%). In Africa, geothermal energy has not been widely used for direct uses mostly due to absence of cold seasons which requires applications low heat. This is however changing as the prices of fossil fuels continue to increase and as more and more focus goes to the utilisation of renewable energy sources to address the climate change. Geothermal energy can be used to replace fossil fuels in greenhouse heating, aquaculture and crop drying as well as in leisure and therapeutic uses. 16 MWt is used for direct applications in greenhouse heating and a limited amount of thermal energy is used for low heat energy applications in crop drying and swimming.

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