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EXPERIMENTAL MODEL INVESTIGATING POTENTIAL OF GEOTHERMAL HEAT ENERGY IN RECYCLING POLYETHYLENE TEREPHTHALATE: CASE STUDY OF OLKARIA

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ABSTRACT

Geothermal energy is one of the clean, sustainable and renewable resources which provide heat energy that is derived from radioactive decay elements within the earth's crust. The non-electric utilization (direct use) of geothermal heat has been reported in various domains that have a need for sustainable supply of heat energy. Adoption and direct use of geothermal energy in Kenya is one way which can enable waste control to enhance environmental protection and optimize the use of energy. In this research, heat energy from the geothermal well was simulated using an experimental model in which polyethylene terephthalate (PET) pieces were melted and moulded into usable products under suitable pressure conditions. The objective of this study was to investigate the potential of using geothermal heat energy in recycling PET plastics through an experimental model. The ground plastic waste material was exposed to heat and the resulting molten medium was subjected to selected polymer processing techniques to obtain desired products. The suitability of geothermal conditions in recycling PET was investigated through numerical analysis. In the design, the study performed experiments on three controlled factors temperature, velocity and pressure. The data collected was analyzed by use of MATLAB. This study established through experimental model that geothermal heat energy conditions in Olkaria are viable in recycling PET plastics. These findings, will enhance control of environmental pollution and create job opportunities in the recycling process. The study recommends that KenGen should explore the utilization of geothermal energy in the recycling of PET plastics.

Key words: *experimental model, geothermal heat energy, recycling and polyethylene terephthalate*

1.0 Introduction

Plastics are carbon-based polymeric materials comprising of hulk organic molecules. These materials can be designed in different shapes through assorted methods such as extrusion, moulding, artifact or gyrating (Arena *et al,* 2016). Modern plastics retain a quantity of awfully desirable physiognomies; enough strength to mass proportion, superb thermal properties, electrical insulation, resistance to acids, alkalis and solvents. These polymers are made of a chain of repeating units identified as monomers (Achou, 2016). The construction and degree of polymerization of a given polymer govern its physiognomies (characteristics).

There are six major plastic polymers that have found application in different spheres of life. These include polyethylene terephthalate, high flux of polyethylene, least density polyethylene, polypropylene and polystyrene. The most common applications for these materials include the manufacture of household items such as kitchen cutlery, car body parts, soft drink bottles, plumbing fittings, greenhouses and grocery store trays among other uses. This illustrates the wide range of application of the plastics in our daily lives. Among the highest worth end-uses for secondhand PET plastic is the production of novel PET bottles and vessels. Though, renewed PET can be completed into many other goods (Abugri, 2012).

According to United Nations Environmental Program (2018) report, it is projected that one to 5 trillion PET plastics are consumed worldwide each year. Five trillion is virtually 10 million plastic bags per minute. If tied together, all these plastic bags could be spread around the world seven times every hour. Plastic containers accounts for close to half of all plastic discarded globally, and much of it is thrown away within just a few minutes of its first use. Most plastics are possibly single-used, but that does not depict that they are easily disposable as shown in

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Figure 1.1. When discarded in landfills or in the environment, plastic can take up to a thousand years to decompose.

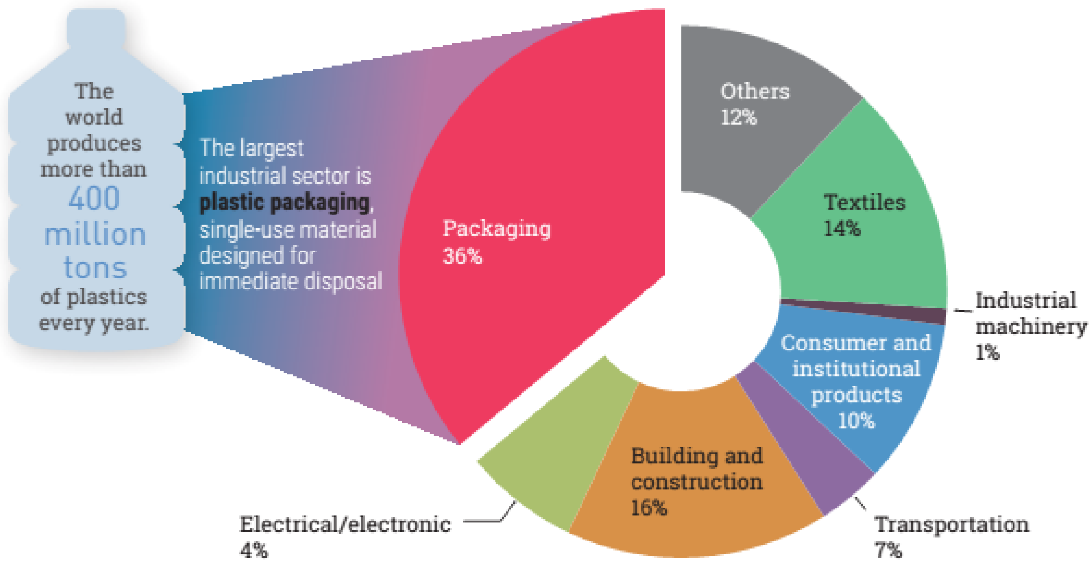

Figure 1.1: Global uses of PET packaging in million metric tonnes (Geyer, Jambeck, and Law, 2017)

According to Applied Market Information (AIM, 2018) report, Africa represents one of the least technologically advanced continents. However, it's one of the most stirring markets for polymers in the world today. It is an unlimited continent with a very hefty, growing and youthful population currently highly concentrated in urban areas. Development is not only engineered by its ordinary resources and minerals but also by its escalating consumer markets giving upswing to a growing demand for an extensive range of products using plastics from automotive to mobile phones, building and packaging industry. While much of this is still presently imported, there is now substantial investment going on in PET plastics processing set-ups motivating double digit evolution in polymer plea.

In Kenya, the use of PET plastics is a common practice, day in day out. It is worth noting that the estimated amount of plastic packaging from trade and manufacturing is approximately 270,000 tonnes per year while the figure based on South Africa data is approximately 240,000 tonnes per year (Elliott *et al.* 2018). Most of these plastics, after use are discarded to the environment willingly or unwillingly. Once they enter into the environment, plastics can stay for a prolonged period of time. According to Bashir (2013), plastic bags take over 1,000 years to photo-degrade.

The degradation process introduces poisonous (toxic) waste products into the environment. These products in turn pollute the vital pillars of various ecological niches. On the other hand, hundreds of these bags are inhaled or consumed by various animals at various levels in Kenya as shown in Figure 1.2

Figure 1.2: Poor waste management in an urban set-up in Kisii County (Courtesy of research 2017 Kisii County)

Geothermal energy is a form of heat energy produced naturally and stored in the Earth. This energy is obtained from the formation of the planet and from radioactive decay of materials within the crust. The formation of its reservoir depends on three parameters; source of heat, recharge (fluids) and the permeable zones as shown in Figure 1.3. These parameters are determined through the exploration process with the aid of geophysics, geology and geochemistry information.

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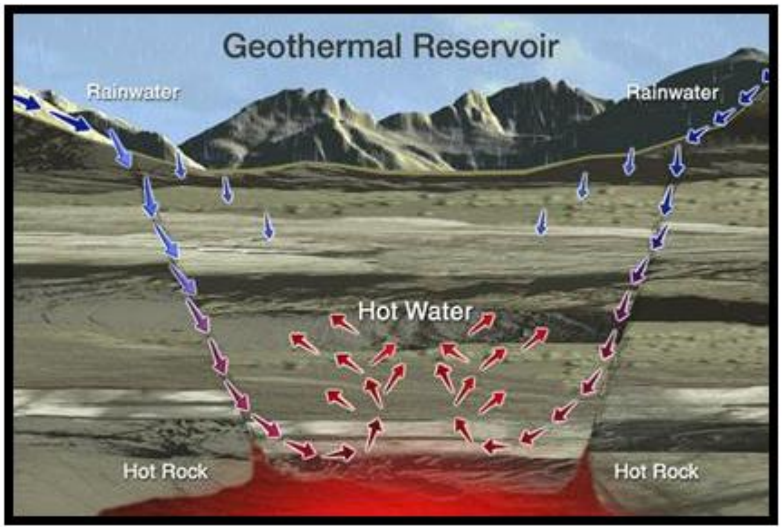

Figure 1.3: Illustration of the formation of a geothermal reservoir (Geothermal Energy Association, 2014)

Geothermal energy is endowed with a variable temperature gradient. This form of energy has a big influx of uses that result in multidimensional impact towards economic growth and development (Geothermal Energy Association, 2013). Kenya, as a developing country, has this important resource along the Rift Valley. Proper utilization of this resource provides a stable channel which can open more sources of income and job opportunities to its population. According to Kiruja (2011), geothermal resources are classified as low, medium or high enthalpy depending on the thermodynamic conditions of the reservoir. High enthalpy sources are used for production of electricity, while low and medium enthalpy sources are mainly for direct applications.

2.0 Statement of the problem

Use of plastics is a common phenomenon for all people in various aspects of life. Conferring to the United Nations Environment Program (2015), the production of PET plastics globally exceeded 311 million metric tonnes. Plastics Europe report (2016), indicates that the production of plastics since 2013 has been on an upward trend. After use, most of these plastics end up being disposed through the wrong channels. This results in environmental pollution since they do not decompose; they photodegrade instead. The process of photo degradation takes a long period of time and this escalates the effect of pollution. This prompted the study to design an experimental model to investigate the possibility of using geothermal energy in the recycling of PET plastics to reduce the side effects to the environment.

2.1 Main objective

To establish a mathematical model to analyse the potential of using geothermal heat energy in Olkaria for recycling PET plastics through experimental approach.

3.0 Methodology

This study adopted an integrated methodology that involved the assessment of an experimental model to investigate geothermal conditions through numerical analysis. The methodology was classified into six blocks (I-VI) with the activities carefully designed to establish the use of experimental and geothermal data to achieve stated objective.

- Using an experimental model to investigate the potential of using geothermal energy in recycling PET plastics.

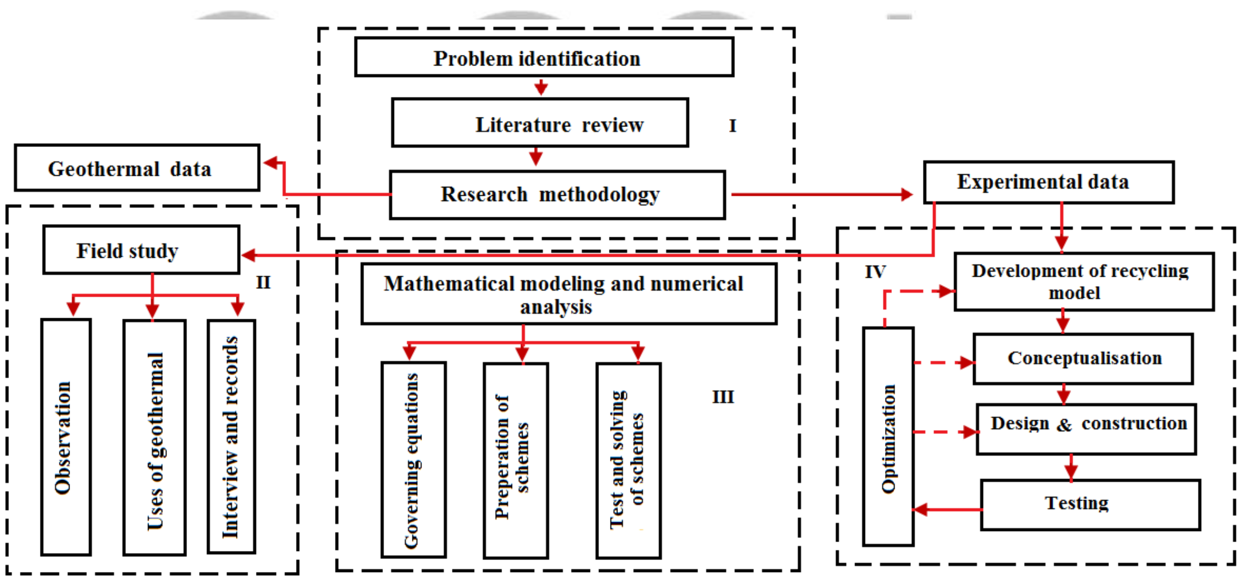

Figure 1.4: Schematic representation of the integrated research methodology

Figure 1.4 depicts how the research conducted the study to gather geothermal data from Olkaria, engineering design and laboratory studies for recycling PET plastics. The research employed the engineering concepts in design, pure, applied and social science at given levels to meet the needs of objectives of the study. The levels used were: collection of data, mathematical modeling, analysis, design, construction, testing and optimization by using experimental approach to investigate the potential of using geothermal energy in recycling PET plastic. The optimization process involved various construction, laboratory evaluation and statistical analysis as show in Figure 1.5.

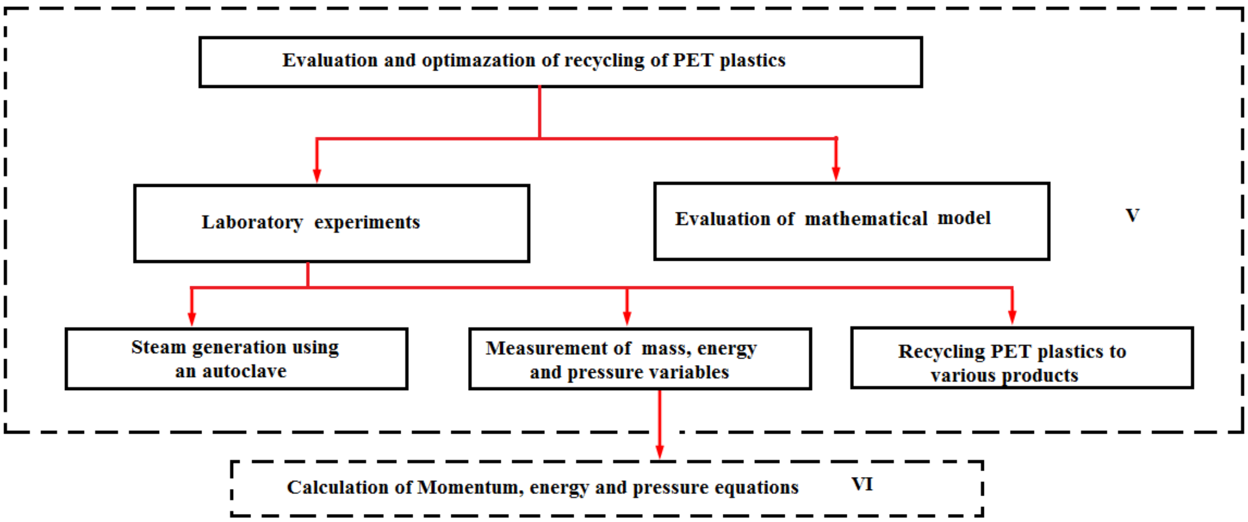

Figure 1.5: Optimization stages for recycling PET plastics

The Olkaria volcano complex is situated to the south of Lake Naivasha within the Great Rift Valley of Kenya. It is geothermally dynamic area and is being used to produce clean electric power. The area has an estimated potential of 2,000 MW. The geothermal fields and power plants lie within the Hell's Gate National Park. The area is about 120 kilometres (75 miles) from Nairobi. It is to the south of Ol Doinyo Eburru multifaceted and north of the Suswa volcano; it is east of the rift valley's western margin and west of Mount Longonot, a stratovolcano. The volcanic field covers 240 square kilometres (93 square miles). The geographical coordinates of Olkaria Geothermal complex are 0°53'27.0"S, 36°17'21.0"E (Latitude:-0.8908; Longitude:36.2892). Major economic activities carried out in this area include; dairy farming, crop farming, nomadic pastoralism and geothermal power development. It is endowed with geothermal prospects along the East African Rift Valley as shown in Figure 1.6.

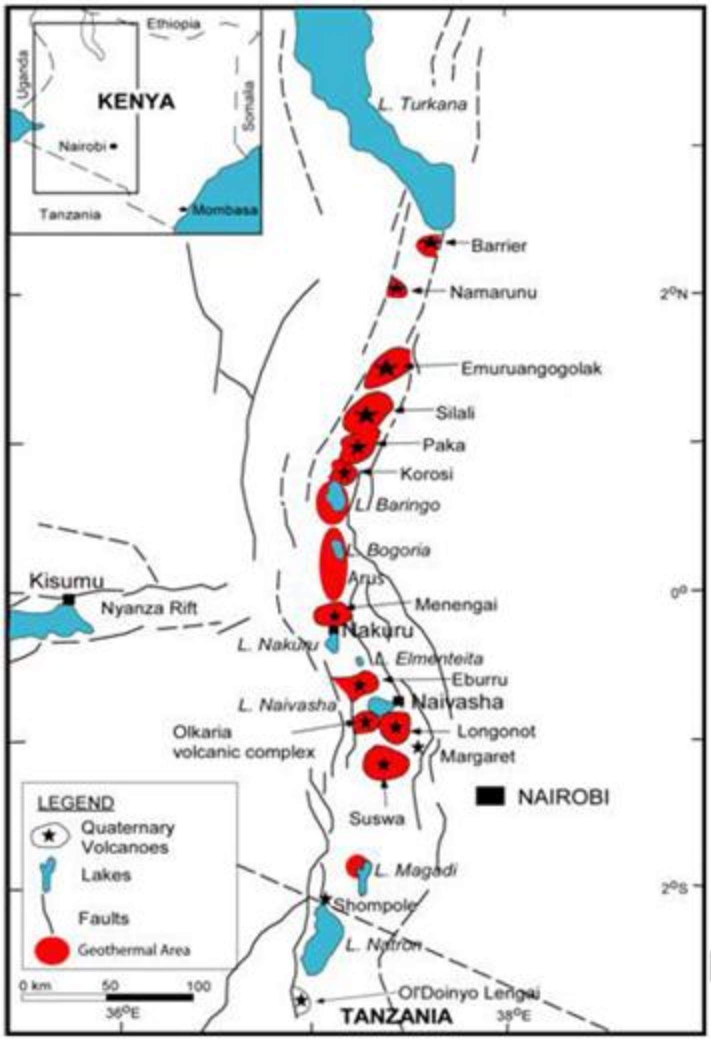

Figure 1.6: Map showing Olkaria geothermal volcanic complex (KenGen, 2016)

4.0 Results and Discussion

The results of the study are presented below.

The study obtained Olkaria Domes well reports which are displayed in Table 1.1. This data was compared with experimental data using MATLAB to meet the objectives of the study.

Table 1.1: Olkaria well parameters derived from the official KenGen reports

Well name	**Type (vertical or directional)**	**Depth TVD (m)**	**Measured BHT ^{0}C**	**Massflow (t/hr.)**	**Whp (bar)**	**Steam (t/h)**	**Enthalpy (KJ/kg)**
OW-1	Vertical	1000	126	240	4.5	108.6	1350
OW-801	Vertical	2000	215	280	5.75	93.2	2389
OW-801 R1	Vertical	600	85	75	4.2	35.0	1496
OW-802	Vertical	3000	220	230	3.4	57.9	2080
OW-804A	Directional N145E	2900	285	270	4.9	102.8	1640
OW-802A	Directional N137E	2855	150	120	5.3	50.7	2290
OW-804	Vertical	3000	300	290	4.87	115.2	2530
OW-907A	Directional	2870	285	105.3	5.28	58.3	1801
OW-911A	Directional	2987	298	77.2	3.6	20.2	1192
OW-909	Vertical	3120	294	143.7	7.3	84.6	1950
Mean		**2433.2**	**225.8**	**183.12**	**4.91**	**72.65**	**1871.8**

Table 4.1, shows the well depth, temperature conditions at bore head, mass flow, head pressure, steam velocity and enthalpy in which various conditions were obtained. The temperature, pressure and velocity conditions of this data was used for analysis. This was done in relation to experimental findings using the mathematical model.

4.1 Energy equation

The change in heat is governed by an equation that is very similar to the second Navier-Stokes equation seen earlier. The heat diffusion equation (Equation 4.1) that gives the change in temperature θ:

$$\frac{\partial\theta}{\partial t} = k\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right) - u\left(\frac{\partial\theta}{\partial x} + \frac{\partial\theta}{\partial y}\right) \tag{4.1}$$

This equation has two right-hand terms: the diffusion of heat and heat convection. The parameter *k* is called the *thermal diffusion constant*, and it takes on a small value for those materials that we simulate. The research investigated both temperature of molten plastic in the flow channel. For the Hybrid scheme (HS), the values θ_t θ_{yy} θ_{xx} θ_x and θ_y in Equation (4.2) were replaced by central difference approximation, the study found out that:

$$\left[\frac{\theta_{i,j}^{k+1} - \theta_{i,j}^{k}}{\Delta t}\right] = k\left[\frac{\theta_{i+1,j}^{k} - 2\theta_{i,j}^{k} + \theta_{i-1,j}^{k}}{(\Delta x)^2} + \frac{\theta_{i,j+1}^{k} - 2\theta_{i,j}^{k} + \theta_{i,j-1}^{k}}{(\Delta y)^2}\right] - u\left(\frac{\theta_{i+1,j}^{k} - \theta_{i-1,j}^{k}}{2\Delta x} + \frac{\theta_{i,j+1}^{k} - \theta_{i,j-1}^{k}}{2\Delta y}\right) \tag{4.2}$$

The effect of Re on the fluid horizontal velocity was then investigated. Taking $\Delta x = \Delta y = 0.25$ and $\Delta t = 0.01$, k = 0.196 and u = 100, the scheme was obtained.

$$3.775\theta_{i+1,j}^{k} + 4.1\theta_{i,j}^{k} - 1.225\theta_{i-1,j}^{k} = 1.225\theta_{i,j-1}^{k} - 2.775\theta_{i,j+1}^{k+1} \tag{4.3}$$

Taking i = 1, 2, 3…….10 and k = 0, j = 1 the study found out the following systems of linear algebraic equations:

$$\begin{aligned}
3.775\theta^1_{2,1} + 4.1\theta^1_{1,1} - 1.225\theta^1_{0,1} &= 1.225\theta^0_{1,0} - 2.775\theta^0_{1,2} \\
3.775\theta^1_{3,1} + 4.1\theta^1_{2,1} - 1.225\theta^1_{1,1} &= 1.225\theta^0_{2,0} - 2.775\theta^0_{2,2} \\
3.775\theta^1_{4,1} + 4.1\theta^1_{3,1} - 1.225\theta^1_{2,1} &= 1.225\theta^0_{3,0} - 2.775\theta^0_{3,2} \\
3.775\theta_{5,1} + 4.1\theta_{4,1} - 1.225\theta^1_{3,1} &= 1.225\theta^0_{4,0} - 2.775\theta^0_{4,2} \\
3.775\theta^1_{6,1} + 4.1\theta^1_{5,1} - 1.225\theta^1_{4,1} &= 1.225\theta^0_{5,0} - 2.775\theta^0_{5,2} \\
3.775\theta^1_{7,1} + 4.1\theta^1_{6,1} - 1.225\theta^1_{5,1} &= 1.225\theta^0_{6,0} - 2.775\theta^0_{6,2} \\
3.775\theta^1_{8,1} + 4.1\theta^1_{7,1} - 1.225\theta^1_{6,1} &= 1.225\theta^0_{7,0} - 2.775\theta^0_{7,2} \\
3.775\theta^1_{9,1} + 4.1\theta^1_{8,1} - 1.225\theta^1_{7,1} &= 1.225\theta^0_{8,0} - 2.775\theta^0_{8,2} \\
3.775\theta^1_{10,1} + 4.1\theta^1_{9,1} - 1.225\theta^1_{8,1} &= 1.225\theta^0_{9,0} - 2.775\theta^0_{9,2} \\
3.775\theta^1_{11,1} + 4.1\theta^1_{10,1} - 1.225\theta^1_{9,1} &= 1.225\theta^0_{10,0} - 2.775\theta^0_{10,2}
\end{aligned} \tag{4.4}$$

When θ (x, 0) = θ (x, 2) = 180 °C, gave the matrix-vector Equation 4.11 below.

$$\begin{bmatrix}
-4.1 & 3.775 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1.225 & -4.1 & 3.775 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1.225 & -4.1 & 3.775 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1.225 & -4.1 & 3.775 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1.225 & -4.1 & 3.775 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1.225 & -4.1 & 3.775 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1.225 & -4.1 & 3.775 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1.225 & -4.1 & 3.775 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.225 & -4.1 & 3.775 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.225 & -4.1
\end{bmatrix}
\begin{bmatrix} \theta_{11} \\ \theta_{21} \\ \theta_{31} \\ \theta_{41} \\ \theta_{51} \\ \theta_{61} \\ \theta_{71} \\ \theta_{81} \\ \theta_{91} \\ \theta_{101} \end{bmatrix}
=
\begin{bmatrix} 2.718 \\ 7.389 \\ 20.08 \\ 54.59 \\ 148.41 \\ 403.43 \\ 1096.63 \\ 2980.95 \\ 22026.47 \\ 43076.43 \end{bmatrix} \tag{4.5}$$

4.2 Experimental results

The study performed the experimental processes as shown in Figure 1.7

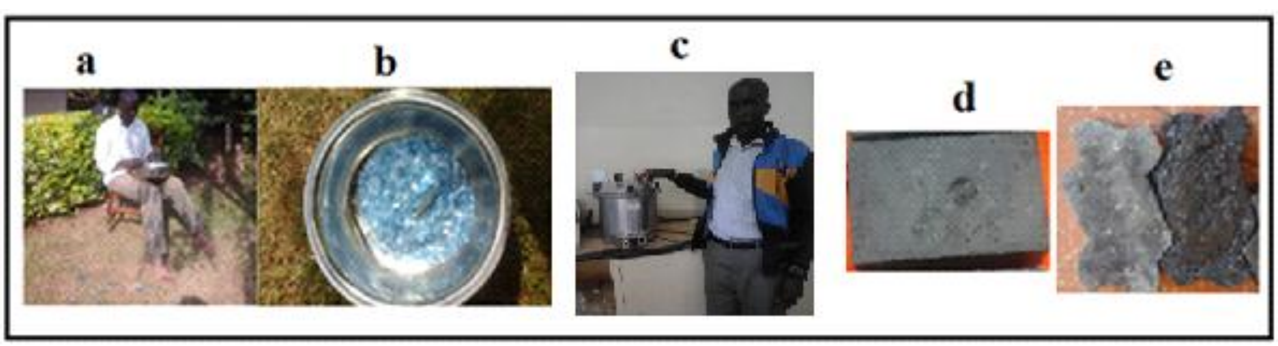

Figure 1.7: Experimental processes in recycling of PET

In the collection unit, wastes of PET plastics were collected from dust bins. In this unit, cleaning was done using warm water at 80 ^{0}C to remove any grease and labels as shown in Figure 1.7 (a). After cutting the plastics, the samples were placed inside the autoclave. The drying was done using heat from the sun as shown in Figure 1.7 (b). The study took a sample of 0.5 kg of PET which was weighed using a beam balance; the sample was placed inside a clean pan which was in turn placed in the grid basket of the autoclave. The autoclave was set at the required operating conditions and closed for melting process as shown in Figure 1.7 (c). It was thereafter placed inside the fume chamber to control pollution to the surroundings. It was at this stage that experimental data were taken. After melting, the sample was removed under controlled conditions and poured into a container with the given dimensions under pressure to produce the required products for various uses as shown in part (d) and (e) of Figure 1.7. The study conducted experiments at various temperatures between 140 ^{0}C to 220 ^{0}C using a sample of 0.5 kg of PET with the aid of an autoclave at a pressure of 1 bar and yielded the results shown in Table 1.2.

Table 1.2: Experimental results obtained using an autoclave

Heating temp. (^{0}C)	**Time for melting (s)**			**Mean time (s)**	**SD**	**Velocity of molten long channel at 1 m (m/s)**			**Mean (m/s)**	**SD**
	Trial 1	**Trial 2**	**Trial 3**			**Trial 1**	**Trial 2**	**Trial 3**		
140	129.96	130.03	130.01	**130.00**	$\pm$ **0.04**	0.125	0.123	0.125	**0.124**	$\pm$ **0.001**
160	120.40	120.41	120.45	**120.42**	$\pm$ **0.03**	0.153	0.151	0.152	**0.152**	$\pm$ **0.001**
180	110.44	110.45	110.40	**110.43**	$\pm$ **0.03**	0.180	0.177	0.180	**0.179**	$\pm$ **0.002**
200	104.46	104.48	104.50	**104.48**	$\pm$ **0.02**	0.214	0.217	0.214	**0.215**	$\pm$ **0.002**
220	99.11	99.13	99.15	**99.13**	$\pm$ **0.02**	0.233	0.233	0.236	**0.234**	$\pm$ **0.002**

Table 1.2 indicates that the study investigated the time for melting PET and the velocity of the molten material at specific temperatures under constant pressure. In each heating temperature, three trials were conducted of which their respective means and standard deviation are shown in

the table. The time taken for PET to melt in each of the trials was recorded immediately when steam was released from the valve which was connected to the fume chamber. At the chamber, observations were made on the changes in the universal indicator once it was in contact with fumes from melting PET plastics. Further, the study analysed the melting temperature against time take and obtained the results depicted in Figure 1.8.

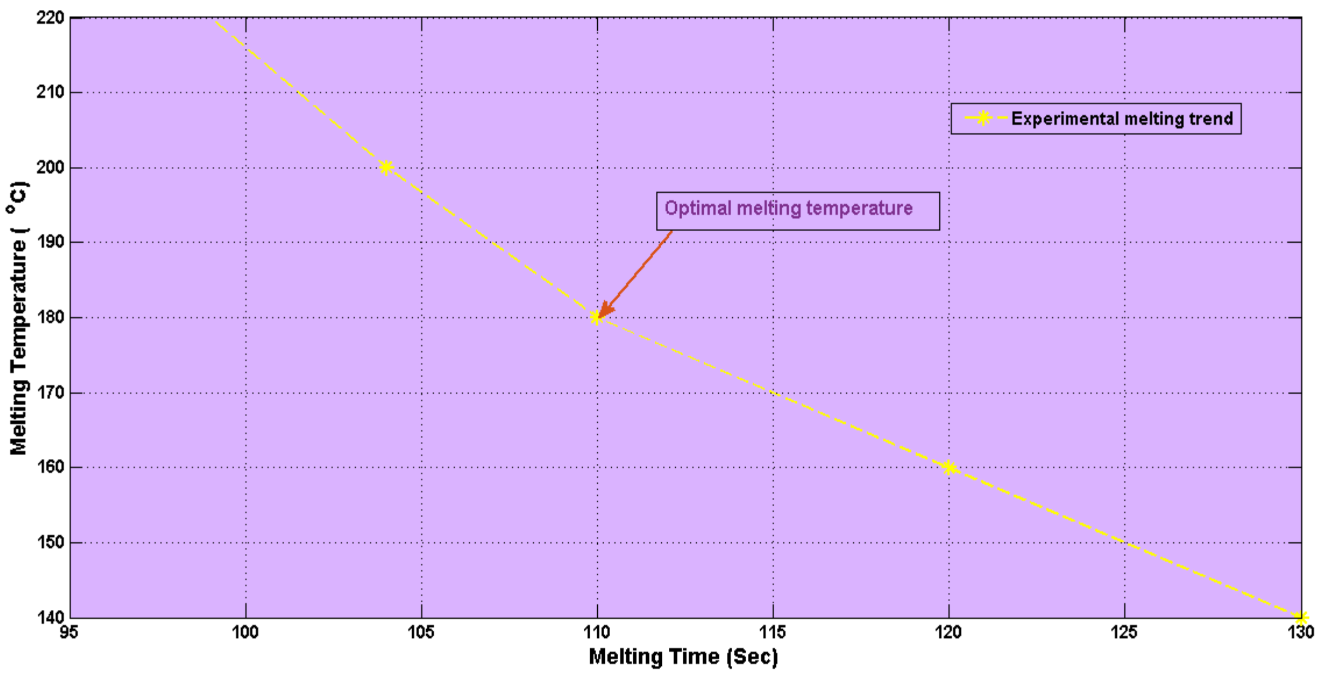

Figure 1.8: Experimental melting temperature against time

From Figure 1.8, the study noted that the melting temperature and time displayed an inversely proportional trend. Along the graph, at 180 ^{0}C a distinctive change was noted. This temperature depicts the most optimal melting temperature of PET under required conditions. According to Wong (2010), PET consists of polymerized units of the monomer ethylene terephthalate, which is frequently recycled at optimal temperature of 180 ^{0}C.

The research also established that geothermal and experimental temperature along the channel of flow have a positive linear correlation (Figure 1.9). This depicts that geothermal has got sufficient temperature conditions for recycling PET plastics. Rop (2012), established that Olkaria well domes field is a high temperature zone ranging from 200 ^{0}C to 360 ^{0}C at -500 m above sea level.

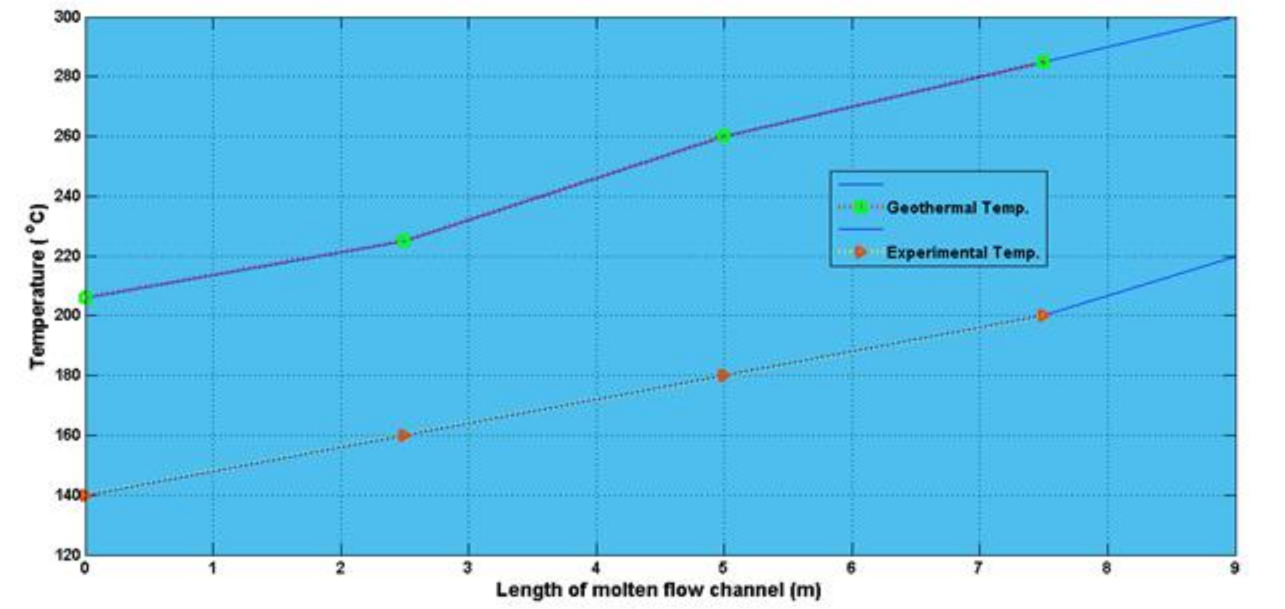

Figure 1.9: Geothermal and experimental temperature from Table 1.1 and 1.2 respectively against length of molten plastic flow channel.

In addition, the study investigated geothermal enthalpy using the data shown in Table 1.1 through analysis along the flow channel and obtained a summary shown in Figure 1.10.

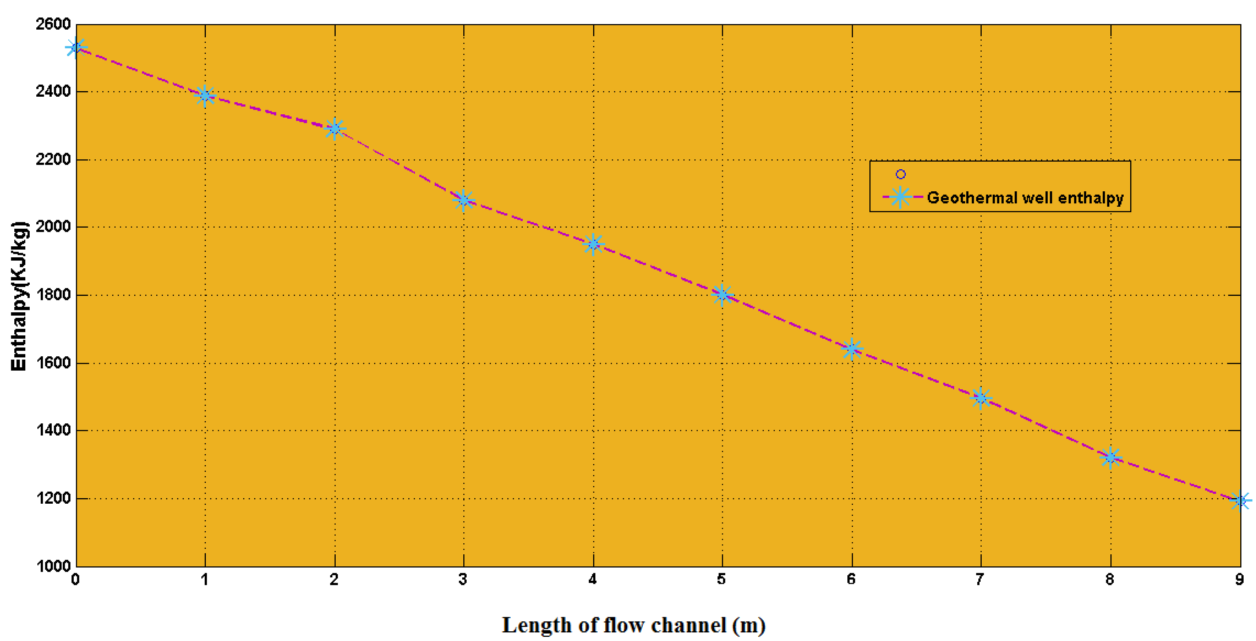

Figure 1.10: Geothermal enthalpy against length of molten plastic flow channel

From Figure 1.10, the study revealed that geothermal wells have varying enthalpies depending on location. The graph depicts that the enthalpy along the channel of flow decrease with an increase in length. Rop (2012), established that Olkaria Domes field is a high enthalpy zone with down-hole temperature profiles between 200 ^{0}C to 360 ^{0}C at -500 m above sea level as shown in Figure 2.10. Olkaria Domes wells indicate an average dryness fraction of 0.54. This means that Olkaria domes wells are not dry wells and, therefore, they have a longer lifetime.

5.0 Conclusions

Recycling of plastic wastes in a wide field of view has some benefits to the country and the world at large. These benefits are coupled into environmental, social, and economic domains of all forms of lives. This will enable to keep the water bodies clean, since the wastes in the landfills can seep dangerous chemicals into water towers. At the same it will reduce landfills, total eyesores and the smell. Economically, it will open more windows for job opportunities. This process will convey a cost-effective benefit to all groups by creating a true win-win locus to Kenyan development.

5.1 Recommendation

This study recommends the following;

i. KenGen should explore the use of geothermal heat energy as a source of recycling PET plastics.

ii. KenGen to establish the use of steam temperature in recycling process of PET plastics.

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