UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

ANALYSIS OF ENERGY COST SAVINGS BY INSULATION OF ACCUMULATOR HEATER IN PLASTIC BLOW MOULDING PROCESS A CASE STUDY OF KENTAINERS LIMITED, EMBAKASI

BY CHARLES K. KOMEN

F56/64111/2010

RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE IN ENERGY MANAGEMENT

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

NOVEMBER, 2019

DEDICATION

To the Late Prof. Felix Makau Luti, Thank you for your support and inspiration in my pursuit of Master of Science Energy Management. Your legacy shall live on. Rest in peace Professor.

DECLARATION

Student Declaration

I **Charles Komen** declare that this report is my original work, and except where acknowledgements and references are made to previous work, the work has not been submitted for examination in any other University.

Signature.........................Date.................

Approval by supervisors

I confirm that the study was carried out under my supervision and has been submitted for examination with my approval as University supervisor.

Dr. A. Aganda: Signature.................................. Date.........................

Dr. R. Kimilu: Signature.................................. Date………………...

ACKNOWLEDGEMENT

To start with, is my profound gratitude to my family members for the sleepless nights I had to burn the midnight oil to ensure that this particular study is successful in the pursuit of knowledge. I equally place on record my appreciation to Dr. Richard Kimilu and Dr. Alex Aganda for the guidance on the completion of the project.

I equally place on record my appreciation to all my classmates and friends for their support and invaluable contributions throughout the course. I also acknowledge and thank Kentainers Limited Embakasi especially Kennedy Wanjala and Joseph Nzimbi for their support during my data collection. To all of you, God bless.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

ECM	Energy Conservation Measures
ERC	Energy Regulatory Commission
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
PETE	Polyethylene Terephthalate
IRR	Internal rate of return
Kwh	Kilowatt Hour
Kg	Kilogram
NPV	Net Present Value
ROI	Return on investment
KES	Kenya Shillings

LIST OF APPENDICES

ABSTRACT

Blow moulding process of plastic tank production makes use of electricity to heat the band heaters to attain optimal temperature for melting the plastic pellets which are the raw materials used in the process. Based on an analysis of the process, the major electricity consumer was found out to be the accumulator. This project investigated how much savings are gained by the insulation of the accumulator in the plastic blow moulding process. Ceramic fibre, cellular glass, calcium silicate and fibre glass were the different insulation materials analysed. Based on the comparison, fibre glass was found out to be the most cost effective, available and easy to handle hence used for this research project. This research was guided by five main objectives, namely: determination of energy consumption for existing system, identify energy losses in the existing accumulator, evaluation of different insulation materials then estimation of energy savings after insulation and finally carry out the economic analysis of the project to determine the viability of the insulation. From the research findings based on the real time data collected and recorded, there was a significant change in energy consumption per kilogram of product manufactured through the process. Estimation of energy savings was based on heat losses from the surface of the accumulator. There was an overall reduction in convective and radiative heat losses returning 4.452 kW representing a heat loss gain of 40.83% hence the insulation was a success. This is evidence to the fact that more energy is lost when the accumulator is not insulated than when insulated. The cost benefit analysis returned a positive net present value of Kes. 900,040.57 and the IRR was calculated to be 110 %. This was an indicator that the change was worth. Again, the simple payback period was 8 months and return on investment was 139.16 %. Using these four methods of capital budgeting, which are, NPV, IRR, Simple payback period and ROI the undertaking was worthwhile venture**.**

CHAPTER ONE: INTRODUCTION

1.0 Background of the Study

Energy conservation is a very important aspect globally due to increasing population and subsequently the rise in demand for power across industries due to urbanization. This has resulted into initiatives focused on looking into ways and means of reducing this demand and identification of areas where energy can be saved. Demand for energy in Kenya has been increasing at a rate faster than available supply, leading to a shortage of primary sources of energy as well as depletion of natural resource capital. The cost of electricity in relation to energy efficiency and conservation has long been a critical element of the energy policy dialogue but took on renewed importance as concerns about global climate change and energy security intensified (Mutua et al, 2015). The ensuing debate is important for developing countries such as Kenya that have ratified the Kyoto protocol and are adopting energy management and conservation measures. Owing to the interest in energy conservation, a significant amount of literature has developed over the past 30 years that provides a framework for addressing the issue (Mutua et al, 2015). The load forecast indicates an increase in demand for power. Thus, in Kenya, initiatives through the Energy Regulatory Commission are meant to engage companies to conduct energy audits every three years and identify areas of energy savings. Based on an energy audit conducted in Kentainers Limited plant in Kenya, areas of energy savings were identified.

This study was based at the Kentainers Limited Plant in Embakasi. The plant is about 18km from Nairobi Central Business District along the North Airport Road and opposite the Kenya Airways Pride Centre, Embakasi. The plant belongs to the Kentainers Limited who are manufacturers of plastic tanks. On average the plant produces 200 tonnes monthly of plastic products consuming on average about 177,260 kWh of electrical power for the various processes. The main installed energy consuming equipment includes electric extruders, electric motors and lighting. The extrusion blow moulding process consists of two machines with a total rating of 406 kW and is the highest power consumer. Liquefied petroleum gas is also consumed in ovens and rock and roll machines for manufacture of much larger diameter tanks with minimal power consumption.

The processes are mainly manual considering the plant is about 30 years old. Based on energy audit of the plant, there are a number of operational and technical improvements that can be done to improve on production with a positive improvement on energy use. Continuous increase in costs, narrowing margins due to increasing prices of raw materials on the market and a growing number of competitors in the market in recent years have encouraged all the polymer processing industries to improve and optimize the entire production process. These initiatives have been applied through a systemic approach to reducing energy consumption on every place possible, from material selection, the geometry of the moulded part to the basic equipment for blow moulding. This is in order to increase the possibilities of achieving multiple energy savings.

This study focused on blow moulding process where thermoplastics are converted into hollow objects of desired shape and size. This is a batch process, involving a cyclic sequence of operations. The cycle is repeated automatically or semi-automatically with a short cycle time for mass production of a stream of moulded parts. The properties of plastic materials and the methods by which they may be processed are significantly affected by the chemical structure and the nature of the constituent materials from which the polymer is created. All polymers are formed by the chemical linking of small molecules, or monomers to form very large molecules in polymerization reaction. The polymerization reactions are applicable for creating thermoplastic and thermosetting polymers. Thermoplastics have mostly linear molecules and therefore soften and flow when heat and pressure are applied and re-solidify on cooling. On the other hand, thermosetting resins undergo an irreversible chemical reaction or cure during the moulding process. (Kent, R., 2005).

The extrusion blow moulding process is a heat intensive procedure where solid resins are mixed at a specified ratio with fillers then taken through a melting process to activate cross-linking reaction which starts with thickening of the melt and finalizes in rigid cured thermoplastic polymer. The source of power in this process is primarily electricity. The main installed energy consumers include electric extruders, electric motors and heaters. There are three main types of blow moulding processes which are extrusion blow moulding, injection blow moulding and stretch blow moulding (Charles, A. H., 2005). This study specifically focused on extrusion blow moulding process.

1.1 Extrusion Blow Moulding Process

Extrusion blow moulding in Kentainers Limited is used in the manufacture of plastic tanks ranging from 1000 to 3500 litres. The size of the mould is adjusted by a torpedo in the accumulator with a total power rating of 200 kilowatts. The process starts with melting of the plastic raw materials components in an extruder to a temperature of 195°C. The melted polymer is then fed into the accumulator which is at a set maximum temperature of 220°C and a minimum of 215°C controlled by thermostats. The melted polymer leaves the accumulator as a parison into the open mould cavity which immediately closes and compressed air is pumped in; which then forces the parison to form a hollow article in the shape of the mould cavity, and thereafter the mould opens to allow cooling of the tank (Allied Way India, 2016). This process is illustrated in Figure 1.1.

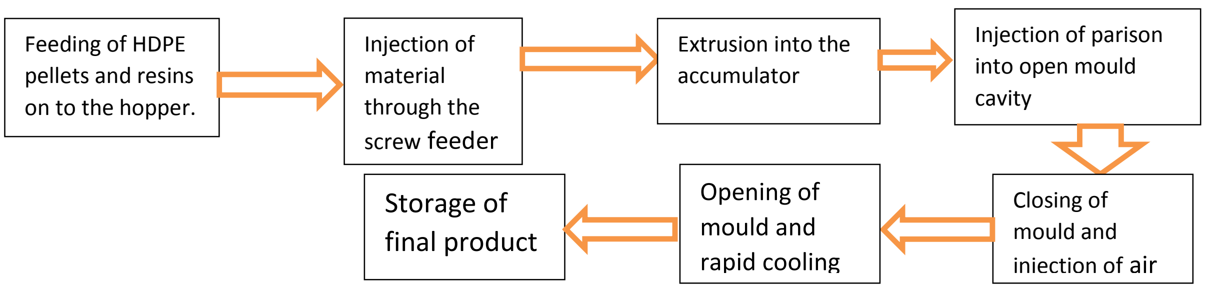

Figure 1.1 Extrusion blow moulding process flow

Electric band heaters are used at the extruder section and at the accumulator. This is in order to achieve the required process temperatures to ensure fillers and other additives completely mix up to form the moulding compound. The process is energy intensive, the main energy consumers being the extruder, accumulator and the motor. Figure 1.2 gives a summary of energy use in the blow moulding process. Detailed description of blow moulding process is described in Appendix A.

Figure 1.2 Equipment power rating in kW

1.1.1. Accumulator

The accumulator receives the melted product from the extruder through a connecting channel within the machine chamber. The accumulator has a die head incorporated in its design which is a tubular extrusion die as shown in Figure 1.3. Its purpose is to ensure delivery of a straight parison in the correct diameter, length and thickness. Before being clamped in the mould, the parison is suspended freely vertically downwards in order to avoid undue twisting. The parison should carry as little evidence as possible of the weld line formed when the melt stream from the extruder flows around the torpedo. Accumulator heads are employed for containers ranging from 10 litres up to several cubic meters. A parison programming or profiling system is advisable to obtain finished product with constant wall thickness, even though it may have a variable cross section (Lee, N.C., 1998).

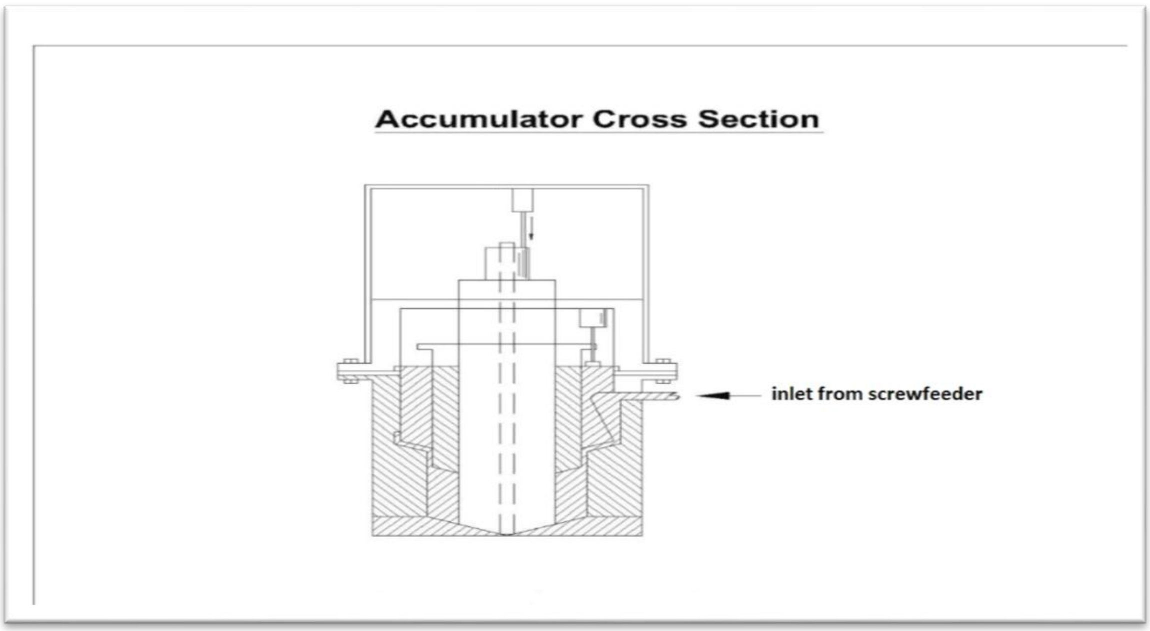

Figure 1.3 Accumulator Cross Section

The accumulator is kept at a constant temperature of between 215°C and 220°C by the temperature control system of thermostats. This is to ensure the melted polymer is uniform at the time when the parison exits the accumulator. The electric energy consumption profile is on average 20 minutes interval of turning on and off of the thermostats due to the loss of heat. The temperature on the accumulator surface is normally between 60°C and 65°C. This also presents an area of potential energy savings through additional lagging. The temperature of the accumulator in this study was maintained by ten electric ceramic heaters rated at 20kW each giving a total of 200kW. The equipment also provides that the initial melt leaves when the ram empties the cavity; the aim is to have the cavity totally emptied by each stroke. When the parison exits the die and reaches the set dimension, a split cavity mould closes around it and squeezes one end of it. The blow mould is the last stage of this process after which we have the finished product and this is further described in detail in Appendix B.

1.2 Problem Statement

Electric power is the main source of power in blow moulding process. The results of a recent energy audit suggest high energy losses due to high external temperatures on the accumulator surface leading to loss of revenue. The research study sought to work towards quantifying energy loss through selection of the best insulation material and therefore improve the overall competitiveness of the blow moulding plant at Kentainers Limited.

1.3 Objectives of the Study

1.3.1 General Objective

To quantify and mitigate for energy loss in the extrusion blow moulding process.

1.3.2 Specific Objectives

i. To determine the current energy consumption of the accumulator.
ii. To identify energy losses in the existing accumulator without insulation.
iii. To evaluate different insulation materials available and cost effectiveness.
iv. To estimate energy savings when the accumulator is insulated.
v. To carry out the economic analysis of the insulation project.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of the Blow Moulding Process

Plastics are an important component in the world and are commonly used in many sectors from construction, electrical applications, transport to domestic plastic tanks used in homes and industries. Plastics are produced in medium capital-intensive production plants generally located close to major cities which provide an easy market due to the construction projects in these areas that use these products. In Kenya there are 28 plastic tank manufacturing companies in the plastics and rubber sector (Kenya Association of Manufacturers, 2016). These companies have different processes for manufacturing the thermosetting and thermoplastics products as per the market requirements, but the most common process is the blow moulding process of plastic tanks. The raw material is readily available from many suppliers and comes in form of small pellets or granules. The parts made from blow moulding are hollow plastics which are thin-walled, such as bottles and containers that are available in a variety of shapes and sizes. Small containers may include bottles for water, liquid soap, shampoo, motor oil, and milk, while larger ones include plastic drums, tubs, and storage tanks.

According to Kent, (2005), Energy efficiency measures can improve profits significantly for minimum effort and costs. Taking a case of a plastics company with an annual turnover of £10 million per year and a net profit of 10% then the profit will be £1 million. The average electricity bill will be approximately British Pounds, £200,000 which is between 1 and 3% of turnover. A Simple no-cost or low-cost energy reduction practices can reduce this by a minimum of 10% (and up to 20%) and increase profits by at least 2%. This is the equivalent of adding sales of £200,000 to turnover and is a worthwhile investment by any standards. Therefore, focus should be given on the reduction of energy and energy related environmental emissions locally and globally. Plastic manufacturing being an energy intensive industry, energy costs accounts for 50–60% of the total production costs. The average electrical load capacity of a modern plastic manufacturing plant normally ranges from 1300 kW to 6000kW, with bulk of the consumption going to the various blow moulding machines installed.

World demand for plastics is always on upward trend according to Zion Research (2016). Global demand for plastic packaging was valued at $270 billion in 2014, and is expected to reach $375 billion in 2020, growing at a compound annual growth rate of 4.8% between 2015 and 2020. In terms of volume, the global plastics packaging market stood at 81,750 kilo tons in 2014. Figure 2.1 shows the world plastic production 2009 by region and main countries involved in plastic production. This has a big impact on energy needs and hence the importance of coming up with energy saving measures.

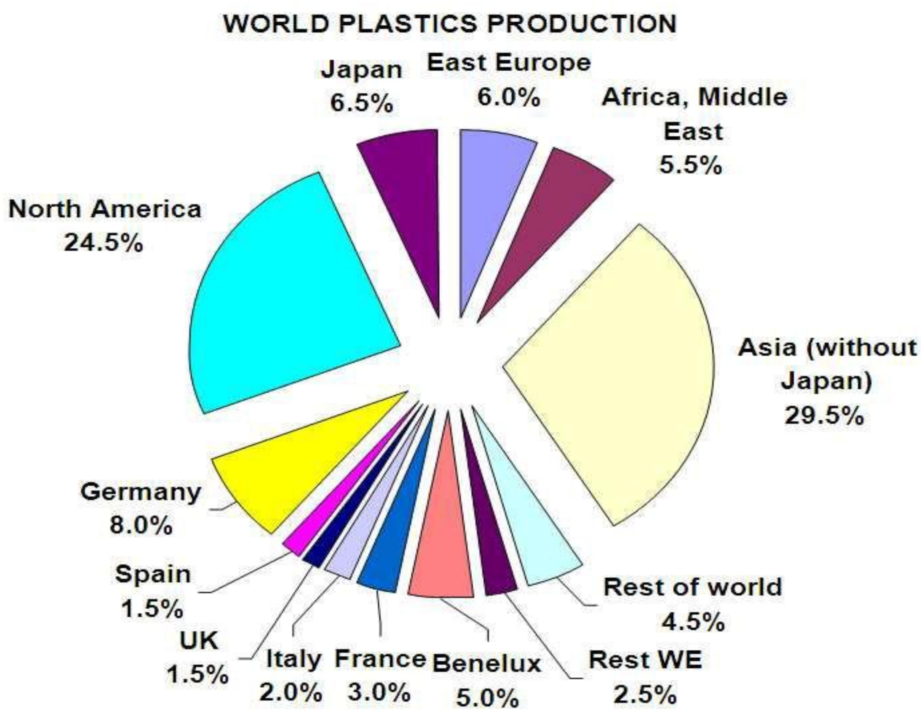

Figure 2.1 World Plastic Production 2009, by Region and Main Countries (Plastic Europe, 2010)

From Figure. 2.1, it can be observed that plastics are heavily used across the globe hence by insight the number of industries that uses the technology. Thermoplastics account for more than 70 per cent of all polymers produced and blow moulding is the main process in production. The various variables in the plastic blow moulding process and the energy saving opportunities are hereby presented.

2.2 Variables in Blow Moulding Process

Various efforts have been made to improve the efficiency in blow moulding process in order to reduce on energy consumption, directly resulting into improvement on production costs thereby increasing profitability. The different areas in the process from beginning to end are covered below. They include screw rotational speed, extruder heating, and accumulator heating.

2.2.1 Screw Rotational Speed

Efforts have been made to improve electricity consumption in the motor area that drives the mechanical screw by use of variable speed drive motors to achieve control of energy use. Extensive research by designers has been done in establishment of load profiles for several resin types. It is desirable to identify the starting and running torque requirements for extruders under different resin conditions. Some of the heat necessary to melt the plastic material is generated by rotating the screw. The faster it is rotated the higher the temperature. As the screw rotates during its metering stroke it has a shearing action on the melt and faster screw speed produce more frictional heat. Excessive screw speeds can cause the material to degrade (Elsheikhi and Benyounis, 2016)

The change in screw rotational speed may influence key physical properties such as shear, viscosity and glass fibre properties in the matrix. An increase in the screw speed causes an increase in the melt temperature of the polymer owing to viscous heat generation. Thus, at higher screw speeds, higher temperature and lower viscosity may result in lower shear stress acting between the glass fibre and the polymer matrix at the interface. Consequently, the length may decrease less than proportionally to the screw speed as observed by some investigators (Elsheikhi and Benyounis, 2016). However, it is important to ensure that the correct speed is being used otherwise process instability could occur. Higher flow rate resins permit faster extrusion speeds while the extruder is expected to run at very low speeds for extended period of time for some resins. Table 2.1 shows the extrusion speeds for various resins.

Table 2.1 Extrusion Speed for Various Materials (Allied Way India, 2016)

TYPE OF RESIN	EXTRUSION SPEED IN RPM
Polyethylene terephthalate (PET or PETE)	1100
High-density polyethylene (HDPE)	1000
Polyvinyl chloride (PVC)	700
Low-density polyethylene (LDPE)	100
Polypropylene (PP)	1200
Polystyrene (PS)	1200

A number of initiatives have been done in this area of screw feeder speed to ensure product quality and energy savings which have been adopted in the current machine designs. In the study done on screw rotation analysis results have shown to provide a better understanding of the flow mechanism in the extruder, a better estimate of viscous dissipation and temperature increase in the extruder resulting to a better prediction of the melting characteristics. Several other methods are available for estimating the flow components in the metering section of a screw, but they can be more complicated and time consuming (Rosato, D., 2003).

2.2.2 Extruder Heating

There are different types of heaters used in extruders which include mica barrel band heaters, coil heaters, and ceramic band heaters. As per the incorporated design for the purpose of this research, an analysis of the ceramic band heaters which are installed in the extruder barrel and accumulator at the Kentainers Limited equipment is done. The array of band heaters creates an opportunity of variability during extruder heating. The ceramic band heater has incorporated ceramic fibre insulation for longer heat retainance as shown in Figure 2.2.

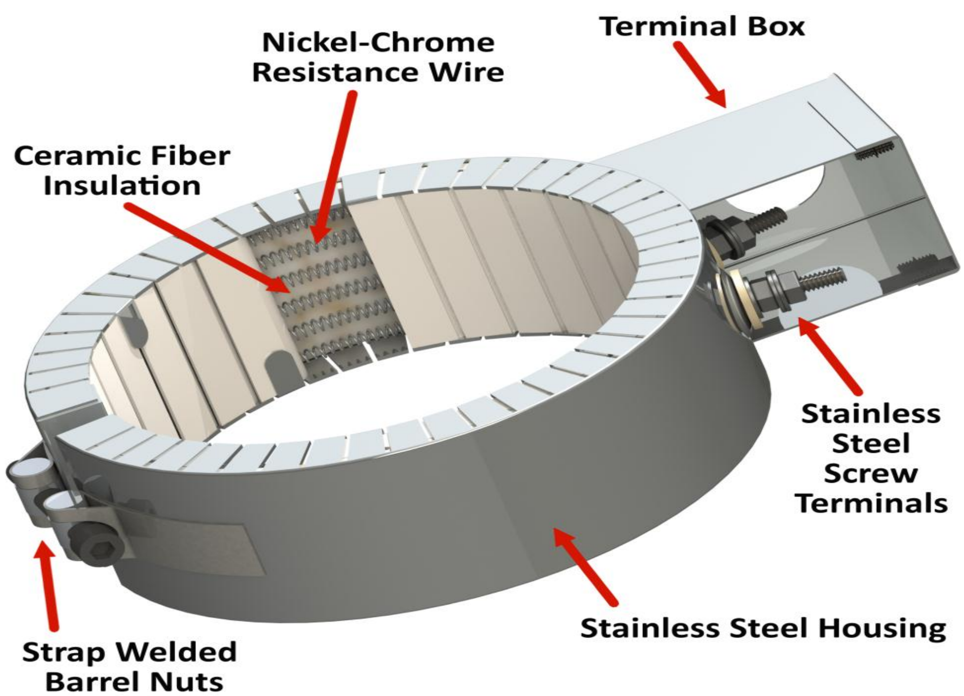

Figure 2.2 Ceramic band heaters (Source: www.heatandsensortech.com)

The ceramic heaters are made of insulated ceramic tiles beneath a stainless steel serrated edges as shown in Figure 2.2. The heat of the ceramic band heaters originates from the inner coils that conduct heat at maximum temperatures. The heated coils evenly deliver heat through ceramic tiles which radiate energy to the barrel depending on wattage requirements designed for the machine. Mahajan, et al (2016) carried out performance comparison on different insulation options in the design of band heaters and the results were as indicated in Table 2.2.

Table 2.2 Comparison of Mica, Ceramic and Mineral Insulated Band Heaters (Mahajan et. al, 2016)

	MICA	**CERAMIC**	**MINERAL**
Electric Insulation	Mica	Ceramic	Mica
Thermal Insulation	No	Ceramic Fibre	Minerals
Wattage (W/In^2)	10 To 40	20 To 45	45 To 100
Temperature Range (°C)	150- 450	150-650	340-760
Cost	low	High	High
Durability	less	Good	Better

From Table 2.2 above, the mica insulated band heaters and ceramic insulated band heaters give maximum watt density of 40 and 45 W/in^2 respectively, whereas the mineral insulated band heaters have a maximum watt density of 100 W/in^2. A detailed study of the three types of band heaters indicate that band heaters without thermal insulation results to heat loss to the atmosphere through convection, which increases the cost of energy. Comparative results show that the mineral insulated band heater gives better watt densities (up to 100 W/in^2) and lesser heat loss. Therefore, mineral insulated band heaters are better band heaters for higher temperature ranges but for the blow mouldings process the temperature range of ceramic band heaters are favourable since the range of temperature is between 150°C - 650°C.

This has informed the incorporation of ceramic band heaters in the extrusion process which has a temperature range within the requirements of the plastic tank manufacturing. Further improvements with regards to energy savings in this process can be done. Another aspect of prevention of heat loss is the option of additional insulation with fiberglass and according to Thermal Insulation Association of South Africa handbook, the minimum and maximum allowable thickness of on cylindrical insulation with fibre glass are shown in Table 2.3.

The recommendations in Table 2.3 should be regarded as a general guide dependent on relative electricity cost and cost of applied insulation, where the indicated thickness need not necessarily be the most economic insulation thickness.

Table 2.3 Recommended Fiberglass Thickness of hot insulation (TIASA, 2013)

Operating temperature range (°C)	Nominal bore range (mm)	Insulation Thickness (mm)
0 to 100		15
101 to 200		20
201 to 250		25
251 to 300	15 - 32	40
0 to 100		20
101 to 200		25
201 to 250		40
251 to 300	40 - 100	50
0 to 200		25
201 to 250		40
251 to 300	125 - 200	50
301 to 350		70*
0 to 200		35
201 to 250		40
251 to 300	225 - 400	50
301 to 350		70*

Remarks: * Non-standard thickness

2.2.3 Accumulator Heating

The accumulator head is the processing tool that shapes the parison. This is the tool that determines shape, properties, structures and dimensions of the parison as well as mutual position of the elements in the extrusion process. The accumulator head is the tool with an open forming cavity (the extrusion die). The accumulator head has to ensure the occurrence of proper physical and chemical processes in the polymer during its flow through the flow channels. In accumulator head machines, the melt accumulates in the head and pushes up a ram cylinder as it is filling the head.

When sufficient material has accumulated in the head to form the parison, the cylinder rams down, forcing the melted plastic between the die and pin. A variety of head designs are used to obtain a uniform wall thickness in the parison. If the wall thickness is not uniform, the parison will bend or hook to one side or the other. The die can be adjusted from side to side to compensate for this action. Accumulator heads allow a slight amount of leakage out of the top of the head to provide a thin layer of polymer as a lubricant for the ram parts. Reciprocating screw machines do not have a ram cylinder, since the melt accumulates in the barrel of the extruder and the extruder screw does the ramming. Continuous extrusion machines do not have ram cylinders, since the flow is continuous through the head and pressure to exit the head is provided by the extruder. Accumulator head machines are classified by the shot size of the head when filled with High Density Polyethylene material. Thus, a 5-lb (2.3-kg) machine can extrude 5-lb (2.3-kg) of HDPE material (including flash) in one cycle or shot. Reciprocating screw machines are classified by the shot size of the machine in terms of the volume available in the barrel and head for melt accumulation. Continuous machines are classified by the size of the extruder, the number of heads, and the size of the press (Harper, C. A., 2015).

A number of initiatives have been done in the area of energy savings in the accumulator by making sure the process is optimized with a number of controls. Sanghani et al, (2016) investigated on how to reduce overall cost of production in plastic injection moulding process. Performance of heater was tested in running production line using different insulating materials like ceramic, mineral fibre, fibre glass, glass wool, perlite and combination of ceramic and glass wool. According to Sanghani, the results showed that combination of ceramic and glass wool had the highest heat retaining capacity compared to other materials. During the start of injection moulding process, certain temperature was required to achieve melting of raw material. The starting time was also noted and it was found that combination of ceramic and glass wool had the lowest starting time of 18 min and 16 sec while fibre glass had the highest starting time of 29min and 7 sec. These results can be useful in selection of proper insulating material for heater in injection moulding machine. The accumulator formed the critical part of the study and it was lagged in the process, and the study covered the insulation of the accumulator by use of fibre glass to retain heat in the process.

2.3 Insulation for Energy Saving

The concept of energy management is relatively new to the plastics processing industry, but is now being strongly driven by the recent rises in energy costs and the rising insecurity of supplies for the future. Ten years ago, energy management was a 'minority sport' and it was difficult attracting the interest of industry in energy management. This is no longer the case and for most companies, energy management is now a real business issue. Energy costs generally represent the third largest variable cost (after materials and direct labour) and in some companies are even the second largest variable cost (Robin, K., 2005).

The one benefit of the plastics processing sector being a major user of energy responsible for 4% of global energy consumption, according to some estimates, is that there is a lot of scope for reducing its energy use. That, at least, is what the European Commission and the U.S. governments think; both of them have introduced initiatives aimed at greatly reducing energy consumption by the plastics sector (Fosco, A., 2013).

The energy consumer for blow moulding process is mainly the ceramic heaters. Energy consumption in plastic manufacturing is mainly attributable to the following actions; melting of raw materials, cooling (mould, gauges, oil among others), and driving peripheral equipment such as grinders, compressors, pumps and mixers among others. At Kentainers, the lack of insulation of the machine based on the last energy audit report is a great contributor to the energy losses in the process. The electric motors compared to the ceramic heaters consume much lower power since most of the motors used are energy efficient.

2.4 Insulation materials

Insulation materials are available in different types from bulky fibre materials such as fiberglass, rock and slag wool, cellulose, and natural fibres to rigid foam boards and sleek foils. Bulky materials resist conductive and to a lesser degree convective heat flow in different areas in manufacturing industries. Rigid foam boards trap air or another gas to resist conductive heat flow. Highly reflective foils in radiant barriers and reflective insulation systems reflect radiant heat away from living spaces, making them particularly useful in cooling climates. Other less common materials such as cementations and phenolic foams, vermiculite and perlite are also available.

A number of initiatives have been considered by different researchers in this area and according to Leavesuch (2003), heater elements are embedded in the underside of sections of vacuum-cast ceramic-fibre insulation, which reduces heat escape to the plant floor, thereby increasing worker comfort and reducing the cost of plant air conditioning. The insulated heater modules cover 100% of the barrel's surface unlike standard heaters. Prewired sections are held together by stainless-steel and velcro style fasteners. Unlike with heater bands, processors need not be concerned about obtaining a tight fit around the barrel to prevent heater burn-out. Heat distribution across the barrel to prevent heater burn-out is key from whichever insulation that is used in this process.

Based on the studies done, a number of insulation proposals have been done in the process improvements resulting to energy savings. Insulation materials are available in a wide range and a number of factors were important in selection of the specific material to be used in this process. The most important aspect was performance in addition to considering the ease of installation. The consideration of the right insulating material is important and there are different hot insulation materials used that are applicable in the process. They include fibre glass, cellular glass, calcium silicate and ceramic fibre.

2.4.1 Fibre Glass

Fibre glass is available in a wide range of forms ranging from flexible rolls, rigid slabs and preformed pipe sections. It is particularly suitable for thermal insulation in steam pipeline, hot water line and other industrial applications such as high-performance insulation in the aircraft industry. It is generally used for high temperature insulations as it is cost effective and steady in performance.

Fibre glass as an insulating material is available with relatively high density and 15 to 150 mm thickness. The thermal conductivity is 0.031 to 0.042 W/mK depending on the range of temperatures. The density of the insulation material ranges from 10 to 80 kg/m^3 with service temperature range of 200°C to 450°C. The compressive strength of the fibre glass is 1 to 8 kN/m^2, the water vapour transmission is 346 to 417 µgm/Nh and it is non-combustible by nature, which is acceptable for high temperature applications (Volovirta, I. and Vinha, J., 2004).

The thickness of the insulation can be varied and the cost saving with minimum insulation thickness can be calculated at a working temperature based on the average working temperatures of both the accumulator and heater. Cost considerations have also to be done in such an analysis based on standard manufactures sizes.

2.4.2 Cellular Glass

Cellular glass insulation is composed of crushed glass combined with a cellulating agent. These components are mixed, placed in a mould, and then heated to a temperature of approximately 510^{o}C. During the heating process, the crushed glass turns to a liquid. Decomposition of the cellulating agent will cause the mixture to expand and fill the mould. The cellular creates millions of connected, uniform, closed-cells and form at the end a rigid insulating material. The typical areas of use of this material for insulation are tank bases, vessels, piping and equipment, cold stores and marine applications. Cellular glass as an insulating material is available with relatively high density and 40mm to 160 mm thickness. The thermal conductivity ranges from 0.034 to 0.081 W/mK with the service temperature of -260°C to 430°C. The water vapour transmission is zero with a compressive strength of 700 kN/m^2. It is a non-combustible insulation material (Westman, M. P., et al, 2010).

As in the case of use as an insulating material, the thickness of the insulation can as well be varied and the minimum insulation thickness calculated. Cellular glass comes at specific sizes which have to be considered based on working temperatures of the specific application. This will therefore have an impact on cost and selection of it as a choice insulating material.

2.4.3 Calcium Silicate

Calcium silicate is used to insulate high temperature pipes and equipment and to achieve fire endurance. It is manufactured and sold in three different forms: preformed block; preformed pipe; and board. It is also used in furnace or boiler insulation. It is generally available in 240kg/m^3 density and a thickness ranging from 25mm to 100 mm. The thermal conductivity of the material ranges from 0.054W/mK to a maximum 1.73 W/mK. The maximum service temperature of calcium silicate is 1000°C with no water vapour penetration under normal conditions. It is a non-combustible material and has a compressive strength of 600 kN/m^2 (Bynum, R. T., 2001).

2.4.4 Ceramic Fibre

Ceramic fibre is a refractory grade material suitable for use up to 1400°C. It is generally used for thermal insulation within dairy and food processing industries such as in the boilers. The density of the ceramic fibre is in the range of 64 to 192 kg/m^3 with a thickness of 6mm to 50 mm. The thermal conductivity is from 0.030 to 0.079 W/mK with the water vapour transmission of zero. The compressive strength is 2.5 kN/m^2 and it is non-combustible (Westman, M. P., et al, 2010).

2.5 Economic Thickness for Insulation

The addition of insulation on to the accumulator increases the surface area. Adding insulation up to the optimum thickness is dominated by increase in surface area. Conduction is the direct flow of heat through a material resulting from physical contact. The transfer of heat by conduction is caused by molecular motion in which molecules transfer their energy to adjoining molecules and increase their temperature. Heat transfer in the above analysis is governed by the equation below.

$$Q = \frac{T_W - T_\infty}{R_{insul} + R_{conv}} + \frac{T_W - T_\infty}{\frac{In(r_1/r_2)}{2\pi Lk} + \frac{1}{h(2\pi r_2 L)}} \qquad (1)$$

Where T_w is the surface temperature, L is cylinder length, r_1 and r_2 are inner and outer radius respectively, and the cylinder is insulated by a material of thermal conductivity *k*. Heat is lost from the insulated accumulator surface to the surrounding medium at temperature T_∞, with a convective heat transfer coefficient of *h* as illustrated in Figure 2.3.

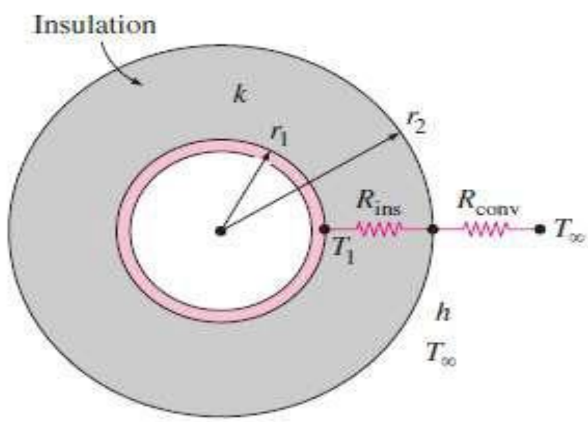

Figure 2.3 Schematic Presentation of Insulation Losses

An insulated cylindrical pipe is exposed to convection from the outer surface and the thermal resistance network associated with it. Sahu et al, (2015) states that it should be realized that insulation does not eliminate heat transfer; it merely reduces it. The thicker the insulation, the lower the rate of heat transfers but also the higher the cost of insulation. Therefore, there should be an optimum thickness of insulation that corresponds to a minimum combined cost of insulation and heat lost.

2.6 Mass and Energy Balance

In every process that uses energy there is always the amount of energy that actually goes into the process and energy that is lost. The basic raw material added in the extruder comprises of HDPE pellets form. Table 2.4 shows the product weight and the average time through the accumulator.

Table 2.4 Product Weight and time through the extruder (Allied Way India,2016)

Round Tank Capacity (Litres)	Weight (kg)	Time (Seconds) through accumulator	Seconds/Kilogram
1000	35	9	0.257
1500	45	11	0.244
2000	55	13	0.236
2500	65	15	0.231
3000	75	17	0.226
3500	85	25	0.294

The energy required into the material to produce the tank when the accumulator is full of the material melt can be calculated versus the actual energy used in order to quantify the percentage of energy loss and possibility of saving energy. The conservation of energy can be stated as:

$$Q_{input} = Q_{melting} + Q_{lost} \quad (2)$$

The energy required for melting $Q_{melting}$ we consider the melting temperature, heat capacity and heat of fission of HDPE as below.

$$Q_{melting} = Q_1 + Q_2 + Q_3$$

Where $Q_1 = Mc_p\Delta T$ (where $\Delta T = T\infty - T_{melting}$) (3)

$Q_2 = M\mathbf{H_f}$ (where $\mathbf{H_f}$ = heat of fission of HDPE) (4)

$$Q_3 = Mc_p\Delta T \text{ (where } \Delta T = T_{melting} - T_{\text{fission}}) \quad (5)$$

Where the parameters for the high-density polyethylene material are used. This is also in consideration of specific product weight and time through the accumulator as per the Table 2.4 above from the equipment manufacturer. Using the information retrieved from the raw materials data sheets and using the full capacity of the accumulator, the actual heat energy that goes into the material can be actually calculated. The energy lost which is the most important for energy savings identification can also be measured.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

The plastic blow moulding process at Kentainers Limited was analysed and areas of high energy consumption identified and measured using energy meters. Energy losses were calculated and calculation of energy savings done. Different insulation materials were also analysed and an insulation using fibre glass was done in order to determine the feasibility of the project. Data was collected for a period of 120 days where different performance parameters were measured for several hours of running the accumulator. The parameters were power consumption, production volume and surface temperature. Cost benefit analysis was also conducted for the purposes of differentiation and drawing of conclusion on the viability of this project on the equipment before installation and after installation of insulation. This was done as follows;

3.2 Determining the Energy Consumption at the Accumulator

Before the identification of areas on high energy consumption in the process, data readings on the energy consumption was collected using Legrand model digital type three phase energy meters installed at the point of power input to the accumulator. The power consumption data readings from the machine were recorded for a period of 120 days before and after. This was used as a benchmark in comparing the differences after implementation of changes in the system.

3.3 Identification of Energy Losses

Through calculations the energy losses were identified at the accumulator. The surface temperature on the equipment was measured and recorded at specific time intervals using hand held infrared thermometer gun Fluke 62 MAX+ model with an accuracy of + or – 1.5°C. Production volume and power consumption was also monitored and recorded in this period.

3.4. Analysis of Different Insulation Materials

Different insulation materials that could be used in the accumulator were analysed based on previous data of heating capabilities. The ease of handling formed the critical factor in determining the insulation material for this study. Fibreglass, cellular glass, calcium silicate and ceramic fibre were analysed in terms of cost viability and heat loss reduction based on optimal thickness of insulation calculated for the different materials and a comparison done.

3.5. Estimation of Energy Savings

The power consumption on the machine was analysed together with production data based on amount by weight produced. The production data was compared and analysed. The data was automatically retrieved from the machine report records at the start of every shift in the morning. The energy savings were also estimated using energy equation based on a fixed volume production sample of 3500 Litre tank to actually estimate the cost of energy saving as a result of insulation.

3.6 Cost Benefit Analysis

This section looked at various aspects of economics of fibre glass lagging which included; capital expenditure, operational expenditure, cost benefit analysis and energy expenditure equilibrium of substitution and finally the technical analysis of the project. These were based on comparing the changes as a result of insulation.

3.6.1 Capital Expenditure

Capital expenditure for the insulation system was calculated based on the installation of the fibre glass on the accumulator. This included: fibre glass; aluminium plate cover; design, bolts and nuts costs, mechanical installation, and labour.

3.6.2 Operational Expenditure

Operational expenditure considered included both the attendance and the maintenance costs of the lagged accumulator. The following were considered for the operational expenditure: attendance costs and maintenance costs. Where a lagged system is considered primarily on financial grounds. A simple payback term and Return on Investment (ROI) were calculated to determine if the project was acceptable.

$$\text{Simple payback period} = \frac{\text{capital invested}}{\text{annual savings}} \tag{6}$$

$$\text{ROI} = \frac{\text{Gain from investment} - \text{cost of investment}}{\text{cost of investment}} \tag{7}$$

3.6.3 Financial Viability

Cost benefit analysis was done to give management a picture of the costs, benefits and risks. Cost benefit was to determine the benefits and savings that were expected from the system and compare them with the expected costs. The cost benefit analysis was carried out based on a projection over a period of five years. The key parameters were plant cost, installation cost, and maintenance cost, fuel handling cost and the cumulative of all these costs for the entire individual year. This in summary gave the cost of the insulation project.

The benefits of the insulation project were also done to give clear indication of the gains incurred. This was done by analysis of electricity cost reduction and projected cumulative benefits for five years.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the of the research study, analysis of the data and discussion. The analysis was performed to determine if there is any correlation on heat loss between the insulated and the non-insulated accumulator. The results were analysed based on the parameters whose data was collected.

4.2 Determination of the Energy Consumption at the Accumulator

Data was collected for the accumulator without insulation for a period of 120 days. Table 4.1 shows the daily power consumption and production.

Table 4.1 Accumulator Power Consumption and Production with No Insulation

Day	Power consumption (kWh)	Production (kg)	Day	Power consumption (kWh)	Production (kg)	Day	Power consumption (kWh)	Production (kg)
1	6641	3534	36	8121	3897	72	6509	3012
2	5213	2353	37	6149	4768	73	6029	2398
3	2514	4543	38	5816	4237	79	7736	1333
4	2512	3466	39	3442.5	3278	80	7209	2560
5	2515	4774	40	3442.5	2678	81	5280	2576
6	2516	2673	41	6912	4576	82	7025	2037
7	4998	3827	42	7675	3654	83	7025	2432
8	4988	3420	43	7825	4365	84	7025	2553
9	5709	3875	44	7803	4265	85	7025	1287
10	3027	2980	45	7189	3987	86	3913	2543
11	3026	4650	46	5482	2765	87	6684	3804
12	3022	4271	47	5482	2865	88	2680	2578
13	8461	3875	48	8240	4389	89	8336	2385
14	5728	2987	49	8812	3245	90	5802	1083
15	5305	2765	50	7846	3722	91	6263	2360
16	2414	2873	51	7852	3787	100	6827	2535
17	5253	2567	52	4823	1200	101	3870	3424
18	2789	3372	53	2676	3200	102	6450	3533
19	4735	3278	54	2674	2312	103	2832	3231
20	4735	2743	55	2663	3121	105	3468	2572
21	4235	2836	56	4140	2313	106	916	2573
22	6000	3657	57	5595	1097	107	744.5	1573
23	3314	3172	58	6493	1095	108	744.5	863
24	3314	2368	59	5070	1096	109	1699	862
25	3314	3987	60	4243	1534	110	4881	857
26	7779	2465	61	4244	2734	111	4428	3453
31	8525	2874	62	4329	2938	112	6637	3465
32	6684	3256	68	6813.5	3979	118	7483	2643
33	6684	3109	69	6813.5	2736	119	4357	3532
34	8254	2898	70	6509	2019	120	3542	3254
35	7468	3298	71	5201	2987			

The energy consumption per unit kilogram of HDPE produced (i.e. energy intensity) was calculated as shown below.

$$Energy\ intensity = \frac{Power\ (kWh)}{Production\ (kg))} \quad (8)$$

Taking a sample calculation for day 1, then, the energy intensity is given by;

$$Energy\ intensity = \frac{6641\ (kWh)}{3534\ (kg)} = 1.879\ kWh/kg$$

Figure 4.1 shows a plot of production versus energy intensity for the period of study (3 months).

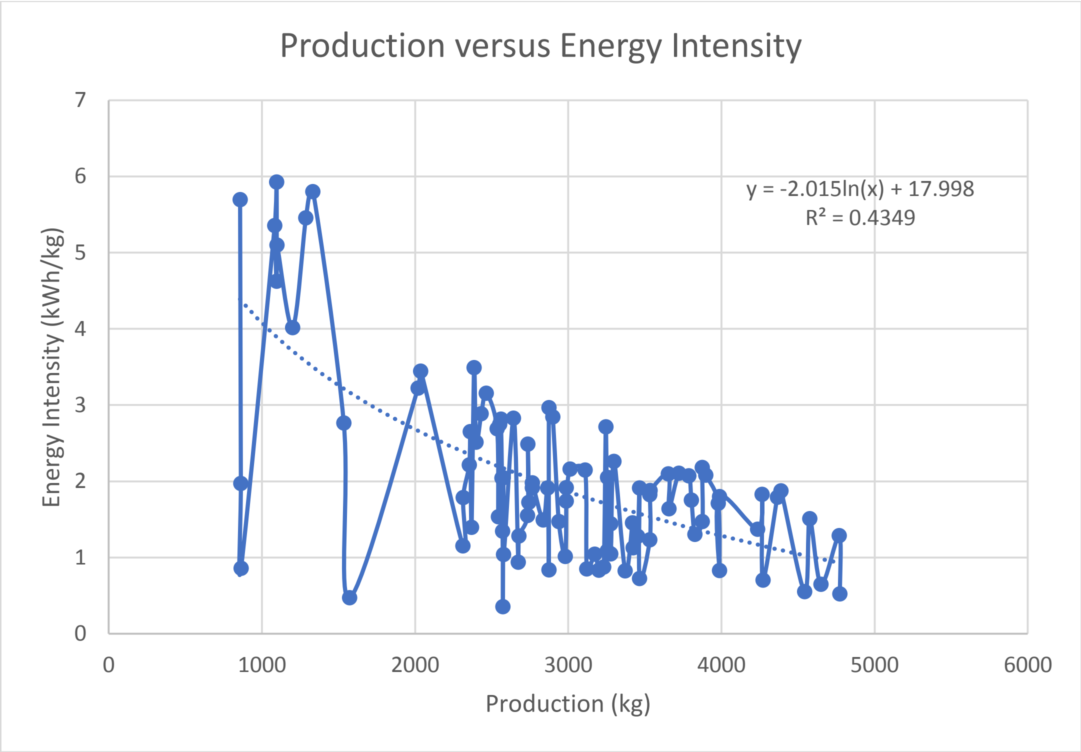

Figure 4.1 Variation of Energy Intensity with Production for Non-insulated Accumulator

From Fig. 4.1 it can be observed that the energy intensity decreases with higher production levels. Hence, it can be inferred that for better utilization of energy, the plant should be operated at maximum or near maximum production capacity. It be noted that there are points of high energy use which necessarily never went into production due to machine breakdowns and during changes in tooling. This is shown by the low coefficient of correlation (R^2).

4.3 Identification and Estimation of Energy Losses on Non-insulated Accumulator

Data on surface temperature was collected for the period of study and returned an average of 65^oC as per the Table 4.2 for the entire study period.

Table 4.2 Accumulator Surface Temperature with No Insulation

Day	Surface Temperature (◦C)	Day	Surface Temperature (◦C)	Day	Surface Temperature (◦C)	Day	Surface Temperature (◦C)
1	58	26	63	55	67	90	67
2	64	31	65	56	63	91	63
3	66	32	64	57	64	100	65
4	65	33	66	58	65	101	66
5	64	34	67	59	66	102	66
6	63	35	65	60	64	103	67
7	64	36	66	61	63	105	64
8	64	37	66	62	64	106	66
9	65	38	64	68	66	107	65
10	66	39	63	69	65	108	67
11	67	40	67	70	64	109	66
12	64	41	66	71	65	110	66
13	65	42	65	72	64	111	67
14	62	43	64	73	66	112	68
15	64	44	65	79	66	118	65
16	65	45	67	80	67	119	64
17	64	46	68	81	68	120	66
18	64	47	65	82	64		
19	63	48	66	83	65		
20	67	49	66	84	66		
21	65	50	64	85	65		
22	66	51	65	86	66		
23	66	52	64	87	68		
24	67	53	66	88	66		
25	64	54	65	89	66		

With the above data the calculation of energy losses through convective heat transfer and radiative heat transfer was calculated as follows.

4.3.1 Calculation of Energy Losses

The rate of heat loss to the air based on the accumulator surface temperature was determined. The room air temperature was measured to be 40◦C. The accumulator was assumed to lose heat on the curved surface only. Taking an external diameter of 1.3m and a height of 3m, the heat loss by forced convection was computed as follows:

The heat loss through forced convective heat transfer is given by the Newton's law of cooling. This was due to the induced draught fan at the roof of the factory building hence air moving at a velocity of 0.5 m/s.

$$Q_c = hA(T_s - T_a) \tag{9}$$

Where

Q_c = Heat loss by forced convection

h = Outside convective heat transfer coefficient (was taken as $20\ \mathrm{W/m^2}$ K for air moving at 0.5 m/s in the room *(*Roychowdhury, et al ,2002)

A = Accumulator surface area under consideration

$T_s = 65^oC$

$T_\alpha = 40^oC$

Curved Surface Area, A= πDL (10)

Where D =1.3m

L = 3m

Therefore A= $\pi \times 1.3 \times 3 = 12.25\ \mathrm{m^2}$

Calculating $Q_c = 20\ \mathrm{W/m^2\,K} \times 12.25\ \mathrm{m^2}(65 - 40)°C$

= 20 ×12.9 × 25

= 6125 W (or 6.125 kW)

The heat lost from the surface by free convection from a cylinder;

$$Q_F = hA(T_s - T_\infty)$$

The heat transfer coefficient is obtained from the relation of the Nusselt number,

i.e. $Nu_L = \frac{hL}{k}$

For free convection, the Grashoff's number is of paramount importance. It is defined as;

$$Gr = \frac{L^3 \beta g \Delta \mathrm{T}}{v^2} \tag{11}$$

Taking properties at the mean film temperature, T_f, defined as, $T_f = \frac{T_S+T_\infty}{2}$, we have

$$T_f = \frac{65+40}{2} = 52.5°C \qquad \text{(or 325.5 K)}$$

Taking the properties of air at 325K, Prandtl Number Pr = 0.701, kinematic viscosity,
$\nu = 1.807 \times 10^{-5}\ m^2/s,\ g = 9.81 m/s^2$

The thermal coefficient of expansion, β is calculated as;

$$\beta = \frac{1}{T_f} = \frac{1}{325} = 0.00307$$

Therefore,

$$Gr = \frac{3^3 \times 325.5^{-1} \times 9.81 \times (65-40)}{(1.807 \times 10^{-5})^2} = 6.23 \times 10^{10}$$

For free convection on vertical plates and cylinders, the Nusselt number is given as;

Laminar Flow: $Nu_L = 0.59(Gr.\mathrm{Pr})^{1/4}$ for $10^4 < Gr.Pr < 10^9$

Turbulent Flow : $Nu_L = 0.10(Gr.\mathrm{Pr})^{\frac{1}{3}}$ for $10^9 < Gr.Pr < 10^{12}$

Therefore, Gr×Pr = $(6.23 \times 10^{10}) \times 0.701$

$= 4.367 \times 10^{10}$

Thus, this is a turbulent layer boundary. For flow over vertical plates and cylinders,

$$Nu_L = 0.10(Gr.\mathrm{Pr})^{\frac{1}{3}} \ for\ 10^9 < Gr.Pr < 10^{12}$$

Therefore, $Nu_L = \frac{hL}{k} = 0.10(4.367 \times 10^{10})^{1/3}$

$= 325.15$

Therefore, $h = (325.15 \times 2.816 \times 10^{-2})/3$

$= 3.31 \mathrm{W}/m^2\ \mathrm{K}$

Heat loss therefore by free convection

$$Q_{Free\ Convection} = hA\,(\Delta T)$$
$$= 3.31 \times 12.25 \times (65-40)$$
$$= 1012.3\ \mathrm{W} \approx 1.0\mathrm{kW}$$

The total loss by convection $= Q_{Forced\ convection} + Q_{Free\ convection} = 6.125kW + 1.0kW$

= **7.125 kW**

The heat lost through radiation from the surface was approximated using the Stefan-Boltzmann equation shown below.

$$Q_{rad} = A\sigma\varepsilon(T_s^4 - T_\infty^4) \qquad (12)$$

Where A = Surface Area =12.25 m^2 as above

σ = The Stefan-Boltzmann Constant = 5.6703 $\times 10^{-8}$ (W/m^2K^4)

ε = Emissivity for Aluminium foil cover ≅ 0.04 (Gubareff, et al, 1960)

T_s = *338K*

T_∞ = *313K*

Therefore,

$Q_{rad} = 12.25 \times 5.6703 \times 10^{-8} \times 0.04 \times 25^4$

= 0.0108 W

The radiative heat transfer is quite negligible therefore will not be used.

Thus, the total heat transfer from the surface of the cylinder is given by

$Q_{\text{Convecttion}}$ = 7.125 kW which comes to Kes 2,530.80 for a plant running 24hours per day at a cost per unit in Kwh of Ksh.14.80.

Assuming that the accumulator operates at the rated power of 200 kW, this energy loss from the surface is about 4%. Based on the losses, it is therefore prudent to minimize the energy losses. An effective way to minimize the surface losses is by thermal insulation of the accumulator. Analysis of available insulation materials is presented in Section 4.4.

4.4 Analysis of Different Insulation Materials

The most common available insulating materials were fibre glass, cellular glass, calcium silicate, and ceramic fibre.

4.4.1 Fibre Glass

The thickness of the fibre glass come in standard manufactured sizes as per the industry standard and was used in the calculations of heat loss. The thermal conductivity of the fibre glass was taken 0.045 W/mK based on the working temperatures (TIASA,2013).

By varying the thickness of the insulation, the cost saving with minimum insulation thickness is calculated based on the average surface temperature of the accumulator. The heat lost through conduction was calculated using the standard equation shown below for a cylinder.

$$Q = \frac{T_W - T_{air}}{R_{insul} + R_{conv}} = \frac{T_w - T_{air}}{\frac{In(r_2 / r_1)}{2\pi Lk} + \frac{1}{h(2\pi r_2 L)}} \tag{13}$$

Where,

k = insulation thermal conductivity of fibre glass = 0.045 W/m. K

h = Outside convective heat transfer coefficient (was taken as $20\ \mathrm{W/m^2}$ K for air moving at 0.5 m/s in the room (Roychowdhury, et al ,2002)

r_1 = radius of accumulator surface =0.65m

r_2 = outer radius of insulation 0.665m (based on the minimal standard thickness of fiberglass material of 15mm)

T_w = Wall temperature at accumulator surface = 65℃

T_{air} = Room temperature = 38℃

Computing for $Q = \frac{65-38}{\frac{In(0.665/0.65)}{2\pi\times3\times0.045} + \frac{1}{20(2\pi\times0.665\times3)}}$

$= 873.75\ \mathrm{W}/m^2$

Table 4.3 shows the heat loss and cost for insulation of the accumulator with different fibre glass thicknesses considering additional layers on the standard thickness available. The annual cost of heat loss was computed based on a prevailing rate cost of Kes 14.80 per Kwh.

Table 4.3 Cost and Heat Loss Reduction with Fiberglass Insulation

Thickness in mm	Total area (m^2)	Total Cost (KES)	Heat Loss W/m^2	Annual Heat Loss Cost $(KES)/m^2$	Total heat loss cost (KES)
15mm	12.54	6270	873.75	113,279.94	1,420,530.45
30mm	12.82	9617	472.66	61,279.42	785,602.16
45mm	13.11	14416	326.18	42,288.58	554,403.28
60mm	13.39	22422	250.28	33,485.49	448,370.71
75mm	13.67	27343	203.83	26,426.15	361,245.47
90mm	13.95	34886	172.48	22,361.69	311,945.58

Figure 4.2 shows a plot of cost of heat loss per year against cost of insulation. From the figure, the cost of annual heat loss reduces with additional insulation. However, at 60mm we realize the increase in thickness has minimum effect on heat loss reduction while the insulation cost keeps increasing. A plot of the total cost of insulation reaches a critical value where even with increase in insulation there is no further decrease in heat loss as shown below.

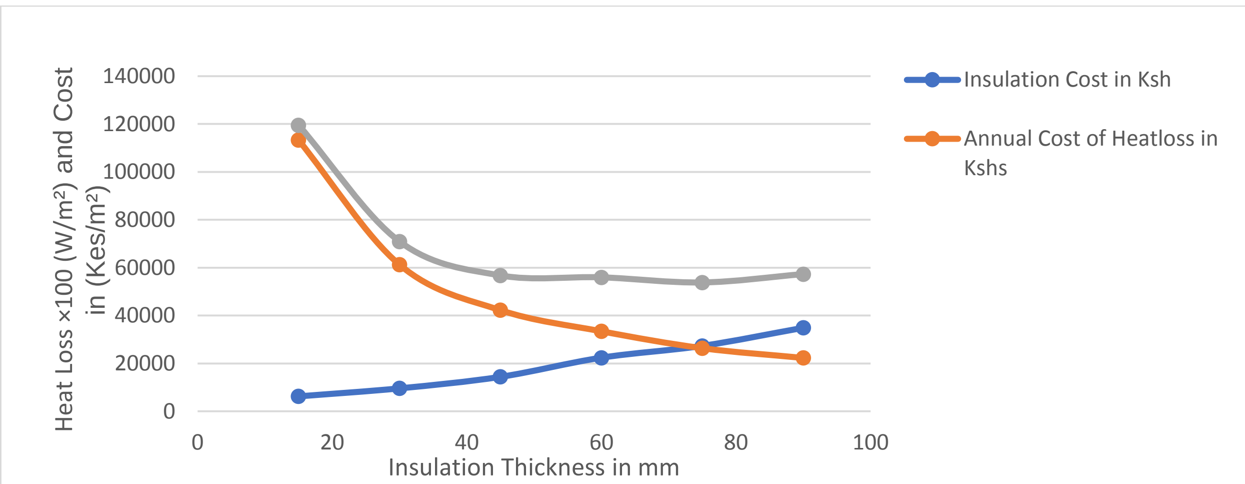

Figure 4.2 Determination of Fibre Glass Optimum Thickness of Insulation

4.4.2 Cellular Glass

An analysis of variation of thickness of the insulation for cellular glass was calculated at an average accumulator surface temperature of 65°C with the parameters on convective heat transfer coefficient remaining constant. As indicated in Table 4.4, the current cost of cellular glass per metre is dependent on standard thickness with the length of the accumulator being 3 metres.

Table 4.4 Cost and Heat Loss Reduction with Cellular Glass Insulation

Thickness in mm	Total area (m^2)	Total Cost (KES)	Heat Loss W/m^2	Annual Heat Loss Cost $(KES)/m^2$	Total heat loss cost (KES)
40 mm	13.01	19,517.00	628.20	81,444.87	1,059,597.76
80mm	13.77	41,297.00	338.79	43,923.45	604,825.91
120 mm	14.52	62,436.00	235.88	30,581.37	444,041.49
160 mm	15.27	87,063.00	183.07	23,734.66	362,428.26

From Figure 4.3, the calculation of heat loss reduction was based on a thermal conductivity of 0.081 W/mK as per (TIASA,2013) and the optimum thickness obtained was at 80mm whereby the costs increase with additional insulation layer. An optimum thickness layer is achieved where any further increase does not have any advantages and results only into increased cost.

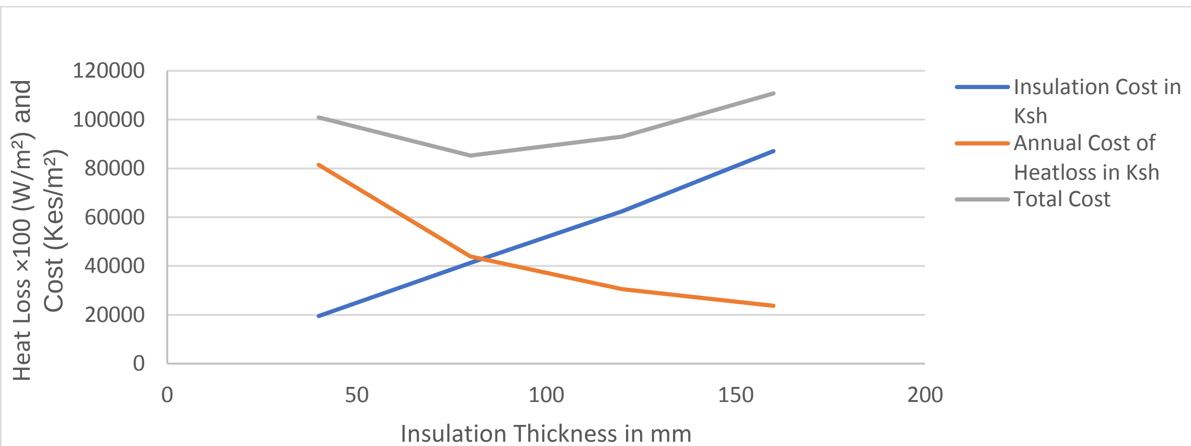

Figure 4.3 Determination of Optimum Thickness of Cellular Glass Insulation

4.4.3 Calcium Silicate

By varying the thickness of the insulation and cost of material the minimum insulation thickness is calculated at an average surface temperature of 65 °C which is an average of the accumulator. The thermal conductivity is 0.063 W/mK as per (TIASA,2013). The heat losses were calculated as shown in Table 4.5.

Table 4.5 Cost and heat loss reduction with calcium silicate insulation

Thickness in mm	Total area (m^2)	Total Cost (KES)	Heat Loss W/m^2	Annual Heat Loss Cost (KES)/m^2	Total heat loss cost (KES)
25 mm	12.73	26,730.00	755.70	97,974.99	1,247,221.62
50 mm	13.20	47,520.00	407.68	52,854.90	697,684.68
75 mm	13.67	66,990.00	282.24	36,591.85	500,210.59
100 mm	14.14	89,100.00	217.56	28,206.22	398,835.95

The thickness of the calcium silicate come in standard manufactured sizes as per the industry standard and was used in the above calculations based on the heat loss equation. From Figure 4.4, the optimum thickness was obtained to be 50mm as per the nearest standard insulation thickness. Any further increase in thickness has no positive effect.

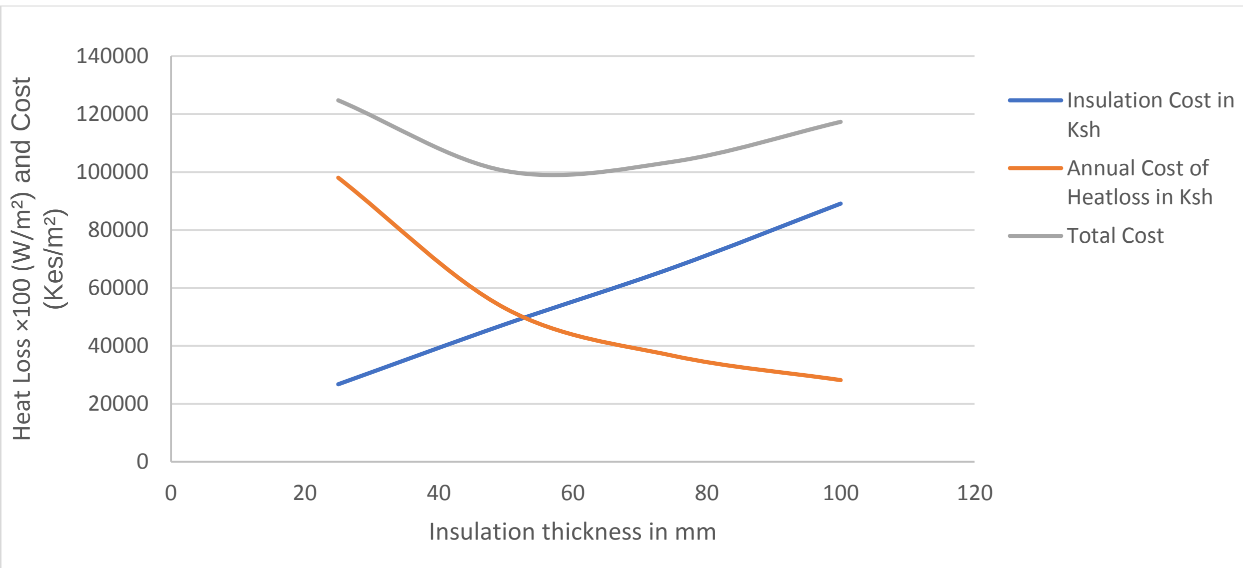

Figure 4.4 Determination of optimum thickness of calcium silicate insulation

4.4.4 Ceramic Fibre

With minimum insulation thickness of ceramic fibre being 6mm, calculations for the various additional layers were computed as per the heat loss equation. The results are shown in Table 4.6.

Table 4.6 Cost and Heat Loss Reduction with Ceramic Fibre Insulation

Thickness in mm	Total area (m^2)	Total Cost (KES)	Heat Loss W/m^2	Annual Heat Loss Cost (KES)/m^2	Total heat loss cost (KES)
6 mm	12.37	6,433	2217.82	287,535.93	3,556,819.45
12 mm	12.48	12,983	1337.17	173,361.42	2,163,550.52
18 mm	12.60	19,651	959.57	128,295.77	1,616,526.70
24 mm	12.71	26,436	749.73	97,200.99	1,235,424.58
30 mm	12.82	33,339	616.18	79,886.50	1,024,144.93
36 mm	12.94	40,360	523.71	67,897.96	878,599.60
42 mm	13.05	47,499	455.88	59,103.93	771,306.29
48 mm	13.16	54,755	404.01	52,379.09	689,308.82
54 mm	13.28	62,129	363.05	47,068.71	625,072.47
60 mm	13.39	69,621	329.89	42,769.57	572,684.54
66 mm	13.50	77,230	302.49	39,217.22	529,432.47
72 mm	13.61	84,957	279.47	36,232.72	493,127.32
78 mm	13.73	92,801	259.86	33,690.33	462,568.23
84 mm	13.84	100,764	242.95	31,497.98	435,932.04
90 mm	13.95	108,843	228.22	29,588.27	412,756.37

A thermal conductivity of 0.063 W/mK as per (TIASA,2013) was adopted. The thickness of the ceramic fibre come in standard manufactured sizes as per the industry standard. From Figure 4.5 below, the optimum thickness was obtained to be 42mm as per the nearest standard insulation thickness.

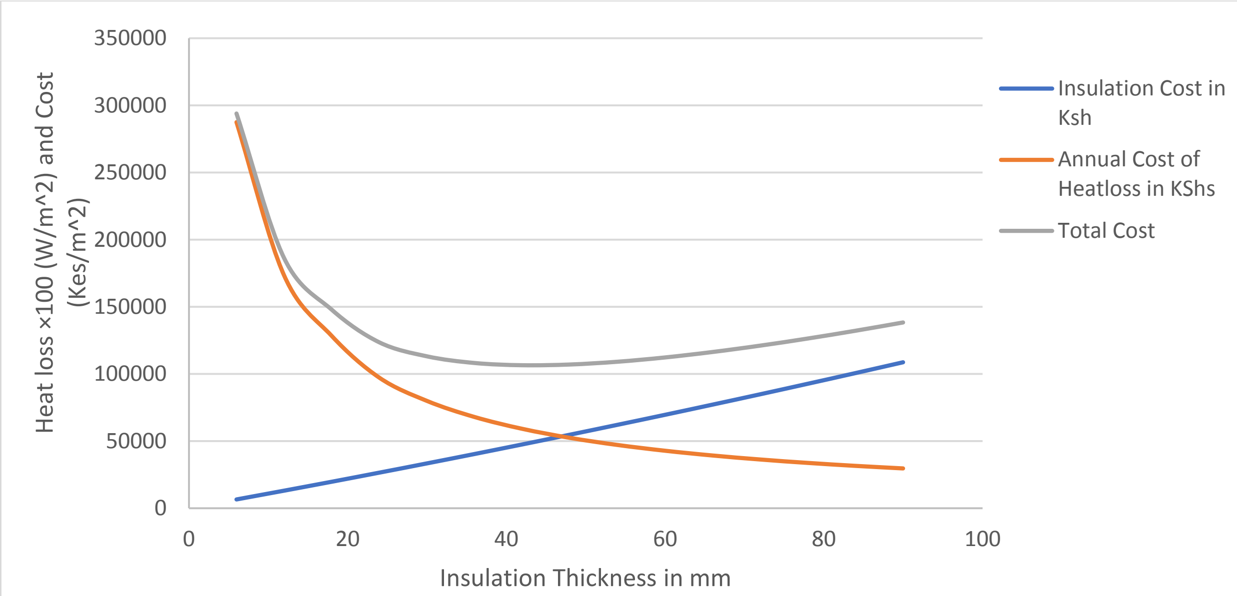

Figure 4.5 Determination of Optimum Thickness of Ceramic Fibre Insulation

4.4.5 Insulation Materials Analysis Summary

The determination of the optimum thickness of insulation for the above materials was summarized as illustrated in Table 4.7 below. It was observed that the cost of insulation increases roughly linearly with thickness while the cost of heat loss decreases exponentially in all insulation materials analysed. Comparing the heat losses within the same range of thickness versus the cost of the insulation material, it was found that fibre glass was the most cost effective option. The accumulator was insulated with 60mm of fibre glass then the energy consumption, production and surface temperature data were collected for 3 months.

Table 4.7 Insulation Material Analysis

Material	Heat Loss W/m^2	Cost (KES)	Thickness in mm	Annual Heat Loss Cost (KES)/m^2	Total heat loss cost (KES)
Fiberglass	250.28	21,422.00	60	33,485.49	448,370.71
Cellular glass	235.88	62,436.00	120	30,581.37	444,041.49
Calcium silicate	282.24	58,787.00	75	36,591.85	500,210.59
Ceramic fibre	259.86	92,801.00	78	33,690.33	462,568.23

4.5 Determination of the Energy Consumption at the Insulated Accumulator

Data was collected for the accumulator with fiberglass insulation for a period of 120 days. Table 4.8 shows the daily power consumption and production.

Table 4.8 Accumulator Power Consumption and Production with Insulation

Day	Power consumption (kWh)	Production (kg)	Day	Power consumption (kWh)	Production (kg)	Day	Power consumption (kWh)	Production (kg)
1	2318	1333	36	1505	5082	72	1254	2820
2	2502	2560	37	1393	5460	73	2130	4200
3	2215	2576	38	1063	3657	79	2128	2940
4	2216	2037	39	2311	2673	80	1903	3276
5	2207	2432	40	2494	3827	81	2697	2422
6	2223	2553	41	2116	3420	82	1488	4452
7	2220	1287	42	3725	3875	83	1488	5586
8	1531	2543	43	4033	2980	84	1488	5124
9	2037	2874	44	3848	4650	85	3498	5670
10	2728	2456	45	1987	4271	86	1748	3429
11	2728	2987	46	1986	3875	87	1213	3240
12	1546	1985	47	2489	2987	88	1213	4110
13	2578	4080	48	2969	4389	89	2516	3420
14	1131	3480	49	2326	3105	90	1250	2820
15	912	2646	50	1110	3214	91	2125	4200
16	1385	4368	51	1108	858	100	2124	2940
17	1647	3186	52	1109	2432	101	2964	3276
18	1373	1863	53	2104	2422	102	3355	4452
19	1373	1200	54	2103	2632	103	2564	5586
20	1400	2736	55	3712	3654	105	2360	5124
21	1090	2873	56	4020	2136	106	1796	5670
22	853	2341	57	3835	3765	107	1795	3429
23	1911	2761	58	1974	3534	108	2704	3240
24	1911	2984	59	1973	2795	109	2892	4110
25	1911	2134	60	2476	3864	110	2572	3340
26	2384	3276	61	2956	4872	111	2118	3467
31	1616	3724	62	2248	3596	112	1254	2820
32	2453	2987	68	2244	3780	118	2130	4200
33	2461	2456	69	2568	3948	119	2128	2940
34	2240	2517	70	1361	5166	120	1903	3276
35	1519	2653	71	1361	4452			

The energy consumption per unit kilogram of HDPE produced (i.e. energy intensity) was calculated as shown below.

$$Energy\ intensity = \frac{Power\ (kWh)}{production\ (kg)}$$

Taking a sample working for day 32, then, the energy intensity is given by;

$$Energy\ intensity = \frac{2987 (kWh)}{2453\ (kg)} = 1.218\text{kWh}/kg$$

Figure 4.6 shows a plot of production versus energy intensity for the period of study (3 months).

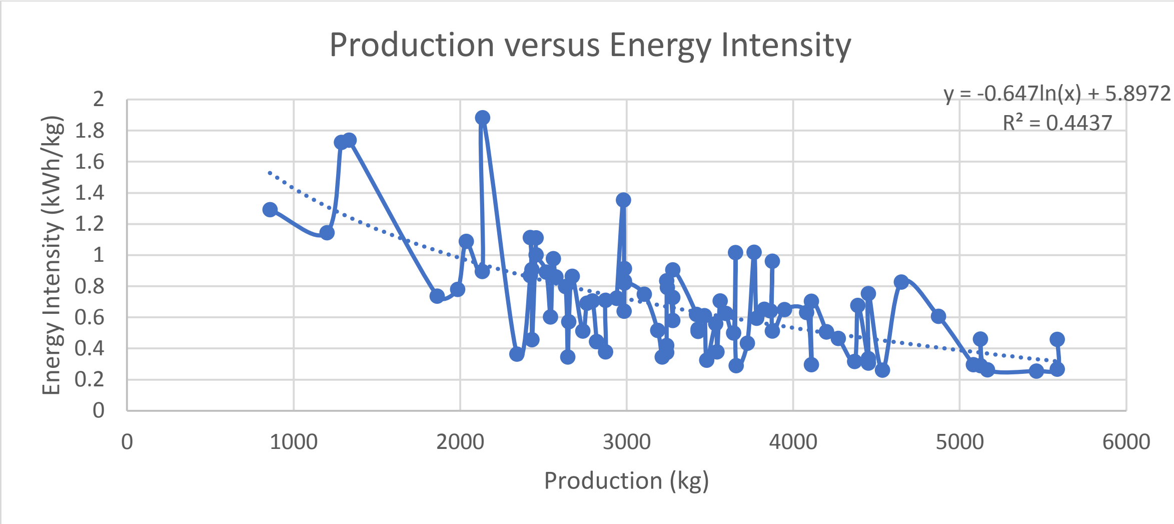

Figure 4.6 Variation of Energy Intensity with Production for insulated Accumulator

From Fig. 4.6 it can be observed that the energy intensity decreases with higher production levels hence it is highly efficient to run the production in full capacity for lowering of the energy use per unit of product produced just as the case for accumulator with no insulation. However, it can be noted that there are points of high energy use resulting to the coefficient of correlation (R^2) not being perfect. This is due human and breakdown factors in the equipment operation resulting to energy used that does not necessarily go into production but with insulation there is a decrease in overall energy intensity. Using the correlation equation, a comparison is done as per Table 4.9 based on a power intensity and production at 1000, 3000 and 5000.It can be concluded that with insulation there is a reduction in energy intensity.

Table 4.9 Power intensity comparison

Production	Power intensity with insulation kWh/kg	Power intensity without insulation kWh/kg
1000	1.2	4.0
3000	0.7	2.0
5000	0.4	0.8

4.6 Estimation of Energy Losses on Insulated Accumulator

Data on surface temperature was collected for the period of study and returned an average of 52 ^{o}C as per the Table 4.9 below for the entire study period.

Table 4.10 Accumulator Surface Temperature with No Insulation

Day	Surface Temperature (◦C)	Day	Surface Temperature (◦C)	Day	Surface Temperature (◦C)	Day	Surface Temperature (◦C)
1	54	26	54	55	48	90	54
2	55	31	51	56	51	91	53
3	54	32	52	57	52	100	53
4	53	33	53	58	50	101	53
5	53	34	54	59	52	102	50
6	54	35	53	60	51	103	54
7	55	36	48	61	49	105	55
8	53	37	51	62	51	106	51
9	55	38	48	68	52	107	52
10	50	39	55	69	52	108	53
11	51	40	52	70	54	109	54
12	53	41	53	71	53	110	53
13	52	42	51	72	50	111	54
14	54	43	51	73	51	112	54
15	54	44	51	79	49	118	54
16	54	45	52	80	51	119	53
17	55	46	50	81	51	120	55
18	51	47	51	82	53		
19	54	48	48	83	49		
20	53	49	50	84	51		
21	49	50	51	85	51		
22	48	51	49	86	53		
23	51	52	54	87	52		
24	52	53	52	88	53		
25	50	54	54	89	53		

With the above data the calculation of energy losses through convective heat transfer and radiative heat transfer was calculated as follows.

4.6.1 Calculation of Energy Losses

The rate of heat loss to the air based on the accumulator surface temperature was determined. The room air temperature was determined to be 38◦C. The accumulator is assumed to lose heat on the curved surface only. Taking an external diameter of 1.41m and a height of 3m, the heat loss by forced convection was computed as follows:

The heat loss through forced convective heat transfer is given by the Newton's law of cooling.

$$Q_c = hA(T_s - T_a)$$

Where

Q_c = *Heat loss by forced convection*

h = Outside convective heat transfer coefficient (was taken as $20\ \mathrm{W/m^2\ K}$ for air moving at 0.5 m/s in the room (Roychowdhury, et al ,2002)

A = Accumulator surface area under consideration

$T_s = 52^oC$

$T_\alpha = 38^oC$

Curved Surface Area, $A = \pi DL$

Where $D = 1.42m$ in consideration of the additional insulation of 60mm

$L = 3m$

Therefore $A = \pi \times 1.42 \times 3 = 13.4\ \mathrm{m^2}$

Calculating $Q_c = 20\ \mathrm{W/m^2\ K} * 13.4\ \mathrm{m^2}(52 - 38)°C$

= 20 × 13.4 × 14

= 3752 W (or 3.752 kW)

The heat lost from the surface by free convection from insulated cylinder;

$$Q_{Free\ Convection} = hA(T_s - T_\infty)$$

The heat transfer coefficient is obtained from the relation of the Nusselt number,

i.e. $Nu_L = \frac{hL}{k}$

For free convection, the Grashoff's number is of paramount importance. It is defined as;

$$Gr = \frac{L^3 \beta g \Delta \mathrm{T}}{v^2}$$

Taking properties at the mean film temperature, T_f, defined as, $T_f = \frac{T_S + T_\infty}{2}$, we have

$T_f = \frac{52+38}{2} = 45°C$ (or 318.15 K)

Taking the properties of air at 318.15K and 1atm pressure, Prandtl Number Pr = 0.7241, kinematic viscosity $\nu = 1.750 \times 10^{-5}\, m^2/_S$, $g = 9.81\, m/s^2$

The thermal coefficient of expansion, β is calculated as;

$$\beta = \frac{1}{T_f} = \frac{1}{318.15} = 0.00314$$

Therefore,

$$Gr = \frac{3^3 \times 318.15^{-1} \times 9.81 \times (52-38)}{(1.750 \times 10^{-5})^2} = 3.80 \times 10^{10}$$

For free convection on vertical plates and cylinders, the Nusselt number is given as;

Laminar Flow: $Nu_L = 0.59(Gr.\mathrm{Pr})^{1/4}$ for $10^4 < Gr.Pr < 10^9$

Turbulent Flow : $Nu_L = 0.10(Gr.\mathrm{Pr})^{\frac{1}{3}}$ for $10^9 < Gr.Pr < 10^{12}$

Therefore Gr×Pr = (3.80 ×10^{10}) × 0.7241

= 2.752 ×10^{10}

Thus, this is a turbulent layer boundary. For flow over vertical plates and cylinders,

$Nu_L = 0.10(Gr.\mathrm{Pr})^{\frac{1}{3}}$ for $10^9 < Gr.Pr < 10^{12}$

Therefore, $Nu_L = \frac{hL}{k} = 0.10(2.752 \times 10^{10})^{1/3}$

= 301.91

Therefore, h = (301.91× 2.699 × 10^{-2})/3

= 2.72 W/m^2 K

Heat loss therefore by free convection

$Q_{Free\ Convection}$ = hA (ΔT)

= 2.72×13.4× (52-38)

= 412.72 W

≈ 0.4 kW

The total loss by convection $= Q_{Forced\ convection} + Q_{Free\ convection} = 3.752kW + 0.4\ kW$

= **4.152 kW**

The heat lost through radiation from the surface was approximated as shown below.

$$Q_{rad} = A\sigma\varepsilon(T_s^4 - T_\infty^4)$$

Where A = Surface Area =13.4 m^2 as above

σ = The Stefan-Boltzmann Constant = 5.6703 $\times 10^{-8}$ (W/m^2K^4)

ε = Emissivity for Aluminium foil cover ≅ 0.04 (Gubareff, et al, 1960)

T_s = *325.15K*

T_∞ = *311.15K*

Therefore,

$$Q_{rad} = 13.4 \times 5.6703 \times 10^{-8} \times 0.04 \times (325.15^4 - 311.15^4)$$

= 54.84 W ≅ 0.054 kW

The radiative heat transfer is quite negligible therefore will not be used.

Finally, the total heat transfer from the surface of the cylinder is then equal to the heat transfer by convection and radiation.

i.e.

$$\mathrm{Q_{Total}} = \mathrm{Q_{Conve}} + \mathrm{Q_{rad}}$$

$$= 4.152\ \mathrm{kW}$$

The total cost of heat loss comes to Kes 1,474.79 for a 24 hour period at a cost of Ksh.14.80 per kWh.

Assuming that the accumulator operates at the rated power of 200 kW, this energy loss from the surface is about 2%. Based on the losses, there is a reduction on energy loss by almost 50% up from the initial 4% and a cash saving of Kes 1,056.00 per day.

4.7 Economic analysis

4.7.1 Cost Benefit Analysis

The cost breakdown for the installation of a 60mm fibre glass insulation is shown in Table 4.11 below.

Table 4.11 Installation Cost Breakdown

Cost Breakdown	Amount (KES)
Fibre glass material cost	22,422.00
Mechanical/Electrical Installation	20,000.00
Aluminium Cover foil	80,000.00
Infrared thermometer gun Fluke 62 MAX+	60,000.00
TOTAL	**182,422.00**

The maintenance cost was assumed to be at 5% in the first and second year, doubling in the third year, fourth and fifth year of the initial maintenance cost. The discounting rate was at 10%. Considering the results for the insulated accumulator the average energy saving is 3.073 Kw per hour based on the loss reduction. For a plant running 24hours per day this translates to 73.752 kWh and at a cost per unit in kWh of Ksh.14.80 and assuming the plant runs for 63% of the 365 days of the year. This is in consideration of the equipment breakdowns and employee inefficiencies based on previous years records the computation is done as per below Table 4.12.

Table 4.12 Cost Benefit Analysis

YEAR	1	2	3	4	5
Installation costs	182,422.00	0.00	0.00	0.00	0.00
Maintenance cost	9,121.10	9,121.10	18,242.20	18,242.20	18,242.20
Total cost per year	191,543.10	9,121.10	18,242.20	18,242.20	18,242.20
Benefits					
Electricity Cost Reduction	253,874.46	253,874.46	253,874.46	253,874.46	253,874.46
Net Cash flow	62,331.36	244,753.36	272,116.66	272,116.66	272,116.66
Discount rate	10%				
Discount factors	1.00	0.91	0.83	0.7	0.68
Discounted cash flows					
Total cost per year	191,543.10	8,300.11	15,141.03	13,681.65	12,404.70
Benefits per year	253,874.46	231,025.76	210,715.80	190,405.85	172,634.63
Net cash flow	62,331.36	222,725.56	225,856.83	204,087.50	185,039.32
Cumulative	62,331.36	285,056.92	510,913.75	15,001.25	900,040.57
NPV	KES;				
IRR	110 %				

This analysis was done to establish the total costs incurred in the projects and the benefits to be gained from the implementation of the project to establish if the insulation was worthwhile. Net present value and internal rate of return were calculated in order to take into account the time value of money. This was done using the excel program. NPV is normally calculated as:

$$NPV = I_1 + \frac{I_2}{1+r} + \frac{I_3}{(1+r)^2} + \cdots + \frac{I_n}{(1+r)^n} \quad (14)$$

Where I's= cash flow for each year

The subscript = year number

r = the discount rate.

The internal rate of return is the interest rate that makes the Net Present Value zero.

$$0 = P_0 + P_1/(1+IRR) + P_2/(1+IRR)^2 + P_3/(1+IRR)^3 + \ldots + P_n/(1+IRR)^n \quad (15)$$

Where;

P_0, P_1, P_2, P_3…. P_n is the cash flows in periods 1, 2, 3. . . n, respectively; and IRR is the project's internal rate of return.

But from the excel function NPV was calculated as;

$$NPV = NPV(rate, value1, value2, \dots) \qquad (16)$$

And

$$IRR = IRR\ (Net\ cash\ flow\ at\ year\ 1{:}\ Net\ cash\ flow\ at\ year\ 5, 0.1) \qquad (17)$$

The cash flows were discounted at 10 percent in order to cater for the risks associated with the project. From the analysis a positive net present value of KES 900,040.57 was realised which was an indicator that the substitution was worthwhile. The internal rate of return was a rate quantity which was an indicator of the efficiency, quality and yield of an investment was calculated to be 110 %.

$$\text{Simple payback period} = \frac{\text{capital invested}}{\text{annual savings}} \qquad (18)$$

$$= \frac{182{,}422.00}{253{,}874.46} = 0.718 \text{ years}$$

$$= 8 \text{ months}$$

$$\text{ROI} = \frac{\text{Gain from investment}}{\text{Cost of investment}} \qquad (19)$$

$$= \frac{253{,}874.46}{182{,}422.00} = 139.16\ \%$$

From the operational expenditure analysis simple payback period was 8 months and return on investment was 139.16 %. The short payback period and high return on investment indicate that this project is of high yielding benefit to the investor. From the four capital budgeting techniques i.e. NPV, IRR, Simple payback period and ROI the investment was profitable and valuable to undertake.

4.8 Technical Analysis of the Project

The insulation project was soundly designed and engineered. It was observed that the additional lagging did not have any effect the quality of the products manufactured. The professionals, technicians and workers on the ground were also able to handle the system without any further training.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The research project was to analyse the energy cost savings by insulating an accumulator on one line of a blow moulding process line. The study was carried out at Kentainers Limited Embakasi, Nairobi County. This chapter presents the summary of the findings on the basis of the objectives and draws appropriate conclusions.

5.2 Summary of Findings

The major findings of this study are summarized according to the research objectives. The first objective was determination of the current energy consumption which was achieved through collection of data for the 120 days. The energy intensity was of significance importance and was compared with production volume and it was observed that with a lower production the energy intensity was high and vice versa. The second objective was to determine energy losses in the existing accumulator without insulation. The losses considered were through radiative and convective heat transfer. The total loss by free and forced convection was determined to be 7.125kW while the heat lost through radiation from the surface was negligible and was not used in final computations. The calculations were based at average external surface temperature readings taken during the period and recorded at 65°C.

The third objective was to evaluate the appropriateness of different insulation materials. The consideration for the selection of the most appropriate hot insulation material was done after analysing available options. Fibre glass, cellular glass, calcium silicate and ceramic fibre were analysed for the purposes of this research. Comparisons were made based on the standard available thickness of each material. It was established that to reduce the surface heat loss to the range within 230 – 280 $W.m^2$, using the standard available thicknesses, fibre glass was the most economical option, at an insulation thickness of 60mm.

The fourth objective was to estimate energy savings as a result of the insulation. Based on the data collected, it was established that there was a reduction in overall energy intensity after insulation. The coefficient of correlation (R^2) for both insulated and non-insulated accumulator were low, hence the plots were not smooth because of external factors like machine operation ability and stoppages as a result of breakdowns on some days. However, there was an overall reduction in convective and radiative heat losses returning 4.452 kW representing a heat loss gain of 40.83% hence the insulation was a success.

The fifth objective of the research was to carry out economic analysis of the new system in order to decide on the viability of the insulation project. From the cost benefit analysis, a positive net present value of KES 900,040.57 was realised which was an indication that the initiative was worthwhile. The internal rate of return was a rate quantity which was an indicator of the efficiency, quality and yield of an investment was calculated to be 110 %. Again, the simple payback period was 8 months and return on investment was 139.16%. Using these four techniques of capital budgeting i.e. NPV, IRR, Simple payback period and ROI the investment was worthwhile to undertake.

5.3 Conclusions

From the study findings, three key conclusions can be made regarding the insulation of the accumulator. First insulation leads to a reduction of the cost of energy used and therefore savings. Secondly, using the four techniques of capital budgeting, that is, NPV, IRR, Simple payback period and ROI the investment was worthwhile to undertake. Lastly the insulation project was soundly designed and it was observed that it did not have any effect the quality of the plastic tanks produced. It can be deduced that running the blow moulding process without stoppages and shutdowns leads to energy savings because of lower energy intensity with increased production. The professionals, technicians and workers on the ground were also able to handle the system without any further training.

5.4 Recommendations

The research presents some interesting areas for future research. There is need to investigate further and determine the efficiency of the insulation to determine the maximum efficiency and the implication of the various points in the study. Future research can expand on improving the ceramic heaters and incorporate methods of longer heat retaining materials in their construction. The mass and energy balance were not done in this research because of lack of capacity but it can be done in future research to get the actual measure amount of energy that goes into the material.

REFERENCES

Allied Way India (2016)- Blow Moulding Machine Manual Model No. HYBM-1999.

Charles A. Harper (2005). *Handbook of Plastics Technologies: The Complete Guide to Properties and Performance*.

Elsheikhi, S.A and Benyounis K.Y. (2016) Review of Recent Developments in Injection Molding Process for Polymeric Materials, Elsevier BV 2016.

Fosco A. (2013). Close the Loop to Save Water & Energy article *An integrated closed-loop process cooling system helps processors achieve sustainability goals.*

Gillingham K, Newell R, Palmer K. (2009). *Energy efficiency policies: a retrospective examination*. Annu. Rev. Environ. Resour. 31:161–92.

Gubareff G, Janssen J, Torborg R. (1960). *Thermal Radiation Properties Survey, A Review of literature.* Honeywell Research Centre, Minneapolis- Honeywell Regulator Company.

https://heatandsensortech.com/products/ceramic-heaters, (accessed on 12.04.17)

Kent Robin (2005). *Energy Management in Plastic Manufacturing Process Paper*.

Kent Robin, (2005). *Energy efficiency in plastics processing – Practical worksheets for industry – Energy worksheets 1-12*, Tangram Technology Ltd, 2005 (www.tangram.co.uk)

Kentainers Limited (2016). Blow Moulding machine manual manufactured by Allied Way India model HYBM-1999.

Kenya Association of Manufacturers Annual Report, (2016). Members Index report available at *www. http://manufacturersandexportersdirectory.co.ke/.*

Khandelwal. M (2010). *Basics about insulations.* Nirma industries, Gujarat, India.

Kishor M. Mahajan , Dr. Atul A. Patil., Prof. V.H. Patil (2016). *A Review on Band Heaters for Heating Performance Enhancement*. Publication Vol. 4, No. 2, May 2016 ISSN (Print) 2277—7261.

Leaversuch, R.D (2003) Article: 8/1/2003 Barrel Heating Gets Faster, More Efficient

Lee, N. C., (1998). *Blow Molding Design Guide Chapter 1*. Hanser Publishers, Munich Mooney, P., Plastic Custom Research Service. Advance, NC.

Mc Crum et al (2005). Principles of Polymer Engineering, 1995, available online: http://www.chem.vt.edu/chemdept/marand/Lecture25.pdf.swell polymer processing (accessed 21.09.16).

Mutua John, Kimuyu Peter (2015). *Household Energy Conservation in Kenya ,* Estimating the drivers and possible savings.Enviroment for Development paper EfD DP 15-04.

Oswald, Tim A. (2005). *Polymer Processing Fundamentals.* Hanser Publisher, Munich, 1998.

P. Westman, Matthew & Fifield, Leonard & Simmons, Kevin & Laddha, Sachin & A. Kafentzis, Tyler. (2010). *Natural Fiber Composites*. A Review. 10.2172/989448.

Plastics Europe, (2010). Association of Plastic Manufacturers Publication available at *https://www.plasticseurope.org/application/files/6915/1689/9288/2010plasticsthefacts_PubOct2010.pdf*

Polymer Processing, Department of Chemical Engineering, and Princeton University, available online: http://www.princeton.edu/~che346/labs/extruder.pdfswellpolymerprocessing February 13, 2005 (accessed 22.08.16).

Recipe, (2006). *Low Energy Plastic Processing*. Project financed by the European Commission, www.eurecipe.com.

Richard T. Bynum, Jr., (2001). *Insulation Handbook* (New York: McGrawHill, 2001) p. 195. Elastomeric coating is required to stop the foam from degrading. Degradation compromises the thermal performance.

Rob V.H, & Verheijen M, (2009). Laborelec , GDF Suez.

Robin K., Tangram Ltd (2005). *"Energy efficiency in plastics processing – Practical worksheets for industry – Energy worksheets 1-12,"* Kent, Dr. Robin, Tangram Technology Ltd, 2005 (www.tangram.co.uk)

Rosato, D. (Ed) (2003), *Blow Molding Handbook*, 2nd ed., Hanser Publishers, Munich.

Roychowdhury D. G, Sarit, K., Das, T., Sundararajan, (2002). Numerical Simulation of Natural Convection Heat transfer and fluid flow around a heated cylinder inside an enclosure. Heat and Mass Transfer 38, pp. 565-576.

Sahu D.K (2015). *A Review on Thermal Insulation and Its Optimum Thickness to Reduce Heat Loss*. International Journal for Innovative Research in Science & Technology| Volume 2 | Issue 06 | November 2015 ISSN (online): 2349-6010.

Sanghani, Chirag & Jayani, Dharmesh. (2016). *Comparative Performance Analysis of Insulating Materials for Heater in Plastic Injection Molding Machine.* International Journal on Advances in Engineering Technology and Science. 2. 2455-3131.

Thermal Insulation Association of South Africa TIASA (2013). Thermal Insulation Handbook August 2013, Page 14.

Volovirta I, Vinha J, Deshmukh, Gajanan & Birwal, Preeti & Datir, Rupesh & Patel, Saurabh. (2004). *Thermal Insulation Materials: A Tool for Energy Conservation. Journal of Food Processing & Technology*.

Yilmazer, Ulku & Cansever, Murat. (2002). *Effects of processing conditions on the fiber length distribution and mechanical properties of glass fiber reinforced nylon-6. Polymer Composites*. 23. 61 - 71. 10.1002/pc.10412.

Zion Research Report, (2016). Plastic Packaging (Rigid Plastic Packaging and Flexible Plastic Packaging) Market for Food & Beverages, Industrial, Household Products, Personal Care, Medical and Other Applications - Global Industry Perspective, Comprehensive Analysis, Size, Share, Growth, Segment, Trends and Forecast, 2014 – 2020" report at http://www.marketresearchstore.com/report/plastic-packaging-market-z47941

APPENDICES

Appendix A. Extruder

The extruder section is composed of a hollow barrel which has heaters and a mechanical screw that rotates at a controlled speed via a variable frequency motor. The screw length according to design should be 5 to 8 times its diameter. The higher the melting point the longer the compression zone in addition to material viscosity. Extruders provide extensive mixing and agitation that causes de-aggregation of the suspended particles in the molten polymer resulting in a uniform dispersion (Kent, R., 2005). The design of the screw which also acts like a pump is critical in this process and a lot of research has been done to improve the efficiency and at the same time save on cost.

The extruder in this study was 3 metres long and composed of 8 ceramic band heaters each rated at 4 kW. The speed at the mechanical screw varied from 0 to 1480 rpm to allow different resins to mix, and was operated by a variable speed motor rated at 55 kW. The operating speeds are also dependent on the type and size of the plastic container being produced. The summary of the process is shown in Figure A-1. Thermoplastic granules are fed into the hopper then melted in the extruder at a temperature of between 180°C to a maximum of 195°C by the ceramic heaters as it is conveyed through the extruder. The surface temperature of the extruder was found to be between 56 °C and 60 °C and this presents an opportunity of energy saving through additional insulation on the ceramic heaters. The total power consumption of this unit was 103kW. The process temperature was controlled through thermostats.

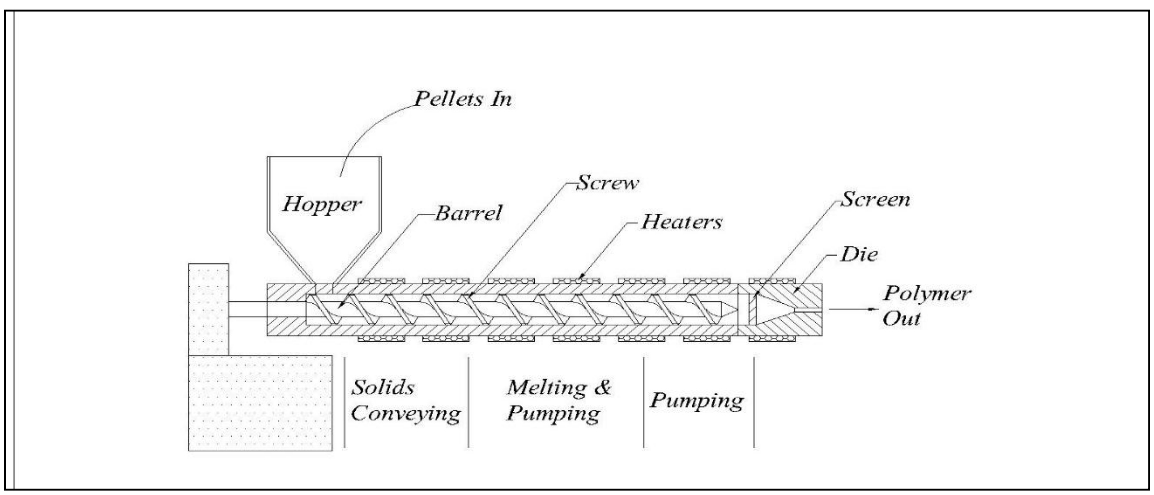

Figure A-1 Extrusion Blow Moulding Process

The electric consumption profile based on the on and off start up times at the time of operation during the blow moulding process was 15 to 20 minutes. This represents an area of energy savings with additional insulation since also the surface temperature was quite high.

Appendix B. Blow Mould

The blow mould consists of two halves, each containing cavities which define the exterior shape of the moulding when the mould is closed. There are no cores to define the inner shape as it is blown by air. Single cavity moulds are used when working with a single parison. When several parisons are in use, a number of single cavity moulds may be mounted on the machine plate, or the need may be met by a multiple cavity mould. Mould details will vary considerably according to the geometry of the product and the blow moulding process in use.

The design of the mould is critical to the success of blow moulding and extrusion blow moulds can either be machined or cast as both processes produce similar nature. The ability of the cavity to conduct heat from the part is critical for competitive processing. Extrusion blow moulds can be made from cast alumina, machined solid alumina, or other good heat conducting alloys, such as copper bronzes. The blow mould chamber area also consists of pinch-off area and blowing device. The pinch-off-zone performs two functions. It must weld the parison to make a closed vessel that will contain blowing air, and leaves pinched-off waste materials in a condition to be removed easily from the blown article.

The blowing device is a blow pin that introduces blowing air into the parison through what will become a neck or opening in the finished blow moulding. The blow pin body has the secondary function of calibrating the bore of the bottle neck. After the mould opens, the blow pin is stripped off by retracting through a stripper plate. (Allied Way India, 2016). Figure B-1 below gives a summary of this process.

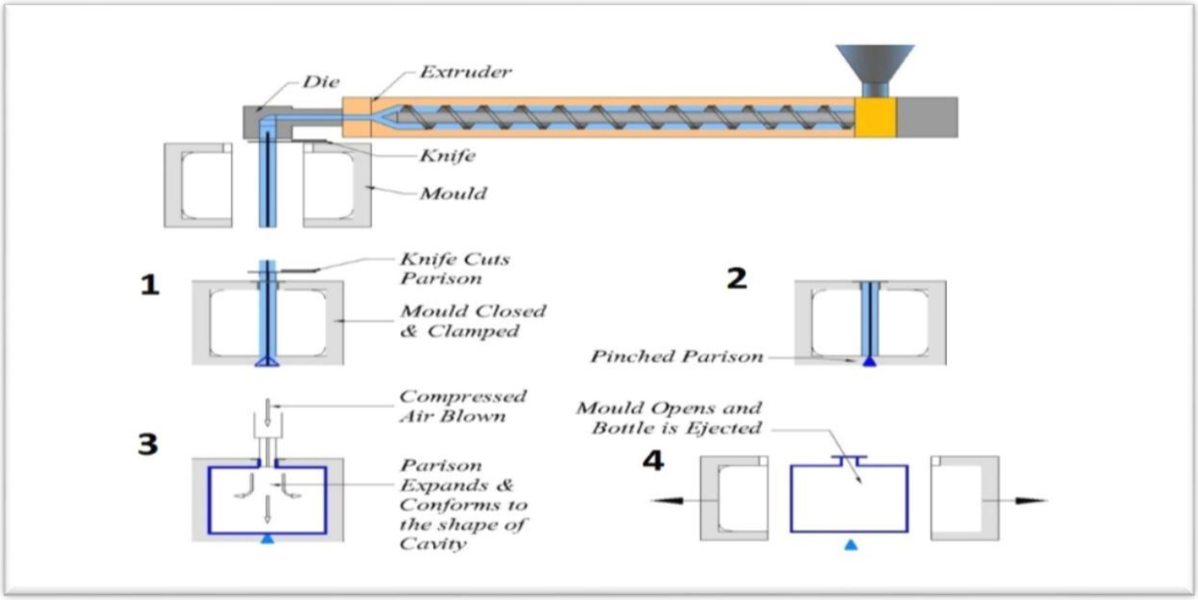

Figure B-1 Blow moulding process