SUSTAINABLE MANUFACTURING : OPTIMIZATION OF ELECTRICAL ENERGY CONSUMPTION IN PLASTIC INJECTION MOLDING PROCESS

By

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ABSTRACT

This research discussed the optimization energy consumption in injection molding process to meet energy efficiency in production and get an optimal parameter setting. Injection molding is one of the techniques used in producing plastic product by injecting plastic materials molten by heat into a mold and then cooling and solidifying. It is a very complex process due to various parameters that must be considered. At this time, the industry manufacturer plastic consumes high electrical energy to produce plastic product. This in turn will release carbon dioxide gas which can have adverse effects on the environment. In this research, the all-electric injection molding machine is used because of this machine proven consume less energy compare with hydraulic and hybrid machine. Hence, this gives an advantage to the manufacturer to reduce the energy consumption from the optimization process. To optimal setting up of injection molding process, variables play a very important role in reducing electrical energy consumption to produce product. The variables involved to control settings are holding pressure, injection pressure, injection speed, mold open/close speed and screw rotation speed. Furthermore, this research presents a simple and efficient way to optimize parameter setting in injection molding process by using Taguchi experimental method and signal-to-noise ratio. With using both methods, optimal parameter settings can be achieved. In this research, an orthogonal array (OA) and signal-to-noise (S/N) ratio are employed to conduct optimization of injection molding parameter. As a result, optimization in injection molding can create the better process parameter settings which can not only reduce electrical energy consumption but, be more robust and also enhance the stability of injection process. In addition, this in turn will contribute towards sustainable manufacturing processes and reducing the carbon dioxide emissions.

Keywords: Injection molding machine, optimization, parameter setting, Taguchi Method, sustainable manufacturing

ABSTRAK

Kajian ini membincangkan penggunaan tenaga yang optimum dalam proses pengacuan suntikan untuk memenuhi kecekapan tenaga dalam pengeluaran dan dapat mengoptimumkan penetapan parameter. Pengacuan suntikan adalah salah satu teknik yang digunakan dalam menghasilkan produk plastik dengan menyuntik bahan plastik lebur dengan haba ke dalam acuan dan kemudian menyejuk dan memejal. Ia adalah satu proses yang sangat kompleks kerana pelbagai parameter yang perlu dipertimbangkan. Pada masa ini, pengeluar industri plastik menggunakan tenaga elektrik yang tinggi untuk menghasilkan produk plastik. Ini seterusnya akan membebaskan gas karbon dioksida yang boleh memberi kesan buruk kepada alam sekitar. Dalam kajian ini, semua-elektrik mesin pengacuan suntikan digunakan kerana mesin ini terbukti menggunakan tenaga yang kurang berbanding dengan mesin hidraulik dan hibrid. Oleh itu, ini memberi kelebihan kepada pengeluar untuk mengurangkan penggunaan tenaga melalui proses pengoptimuman. Tetapan optimum daripada pembolehubah proses pengacuan suntikan memainkan peranan yang amat penting dalam mengurangkan penggunaan tenaga elektrik untuk menghasilkan produk. Pembolehubah yang terlibat untuk mengawal tetapan ialah memegang tekanan, tekanan suntikan, kelajuan suntikan, acuan terbuka kelajuan / rapat dan skru kelajuan putaran. Tambahan pula, kajian ini membentangkan satu cara mudah dan berkesan untuk mengoptimumkan tetapan parameter dalam proses pengacuan suntikan dengan menggunakan kaedah eksperimen Taguchi dan dan isyarat-kepada-hingar. Dengan menggunakan kedua-dua kaedah ini, tetapan parameter yang optimum dapat dicapai. Dalam kajian ini, pelbagai ortogon (OA) dan isyarat-kepada-hingar (S / N) digunakan untuk menjalankan pengoptimuman pengacuan suntikan parameter. Hasilnya, pengoptimuman dalam pengacuan suntikan boleh membina proses tetapan parameter yang lebih baik yang bukan sahaja boleh mengurangkan penggunaan tenaga elektrik tetapi, menjadi lebih mantap dan juga meningkatkan kestabilan proses suntikan. Di samping itu, ini seterusnya akan menyumbang kepada proses pembuatan yang mampan dan mengurangkan pengeluaran karbon dioksida.

Kata kunci: Suntikan mesin pengacuan, pengoptimuman, tetapan parameter, Taguchi Kaedah, pembuatan mampan

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LIST OF ABBREVIATIONS

Abbreviations

ANN	Artificial Neural Networks
ABC	Artificial Bee Colony Algorithm
CO2	Carbon Dioxide
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWh	Gigawatt Hour
IMM	Injection Molding Machine
kWh	Kilowatt-hour
MSD	Mean Square Deviation
OA	Orthogonal Array
ROI	Return of Investment
S/N	Signal to Noise Ratio

CHAPTER ONE

INTRODUCTION

1.1 Introduction to the Study

Electricity is the main source for daily life and now it is classified as primary human need. In Malaysia, 90% of electricity generation is divided into two sources in which 60% is from gas and 30% from coal, while the rest of 10% is from hydro and oil (Bakar, 2011). Electricity is used in various sectors including domestic, industrial, enterprise, agriculture and education and so on. In this country, the electricity demand has recorded an increase of 6.1% per year (Consumer Research and Resource Centre, 2012). The electrical energy is generated almost every day to meet the needs of users in daily life. Demand for electricity in Peninsular Malaysia in 2010 continued to increase over 2009 of 7.8% from 94.748 in 2009 to 102.139 GWh (Energy Commission Report Malaysia, 2010). The sources used to generate electricity are based on oil, gas and coal which cannot be renewed due to the shortage of these resources.

Electricity is the most important element in an operating system of a residential or commercial building. Some of the systems within a building include lighting system, air conditioning system, motor equipment systems, communication systems, production systems and etc. The absence of electricity causes the system to stop its work as well as affect the activity of users in various sectors to do their work effectively.

However, at present the concern is the negative impact on the environment and humans when electricity is used inefficiently. In energy management, besides using energy saving mechanical or electrical appliances consumers must be educated to use energy efficiently. In other words, users in various sectors should be given awareness about the importance of energy efficiency as well as to rescue the environment and also to reduce cost.

Therefore, through utilizing energy saving equipment efficiently and at optimal, it is the best way to reduce the emission of carbon dioxide by each user in addition, to providing financial returns from the saving of electrical energy bills. There are two challenges that the world has to face in the field of energy, which are expensive, insufficient energy supply and also the negative impact of human activities on the environment. The economic growth of the country depends on sufficient energy to sustain its economic growth. To maintain a sustainable environment for the continuity to the next generation, the resources of electricity supply must be managed and preserved as best as possible (Pah & Syed, 2013).

In the context of this research, the focus of electrical energy consumption on manufacturing sector is in plastic product industries. The plastic production industry is one of the most dynamic and vibrant growth sectors within the Malaysian manufacturing sector. The Malaysian plastics industry has developed into a highly diversified sector producing an array of products including automotive components, electrical and electronic parts as well as components for the telecommunications industry, construction materials, household goods, acrylic sheets, bags, bathroom accessories, battery casings, bottles, containers, toys, games and packaging materials. With a supply of 2 million metric tonnes per annum of locally produced resins, the production of these value added finished products has further increased over the last years.

In fact, Malaysia is one of the largest plastic producers in Asia, with over 1,550 manufacturers, employing some 99,100 people. The country's plastic products are exported worldwide including the EU, China, Hong Kong, Singapore, Japan and Thailand ("Market Watch 2012", The Malaysian Plastic Industry). Hence it becomes one of the major electrical energy consumers in the Malaysian manufacturing sector. This gives an alarming signal since higher energy consumption will cause higher carbon emissions.

The plastic production industry can be divided into four sub-sectors, namely plastic packaging, E&E and automotive components, consumer and industrial products; and others. With 40% of total industry output, the largest sub-sector for the plastic industry remains plastic packaging involving both flexible and rigid (including bags, films, bottles and containers). The main production processes used in the plastic products industry are injection molding, film extrusion, blow molding and foam molding ("Market Watch 2011", The Malaysian Plastic Industry). Figure1.1 illustrates the percentage of the plastic products industry by manufacturing process.

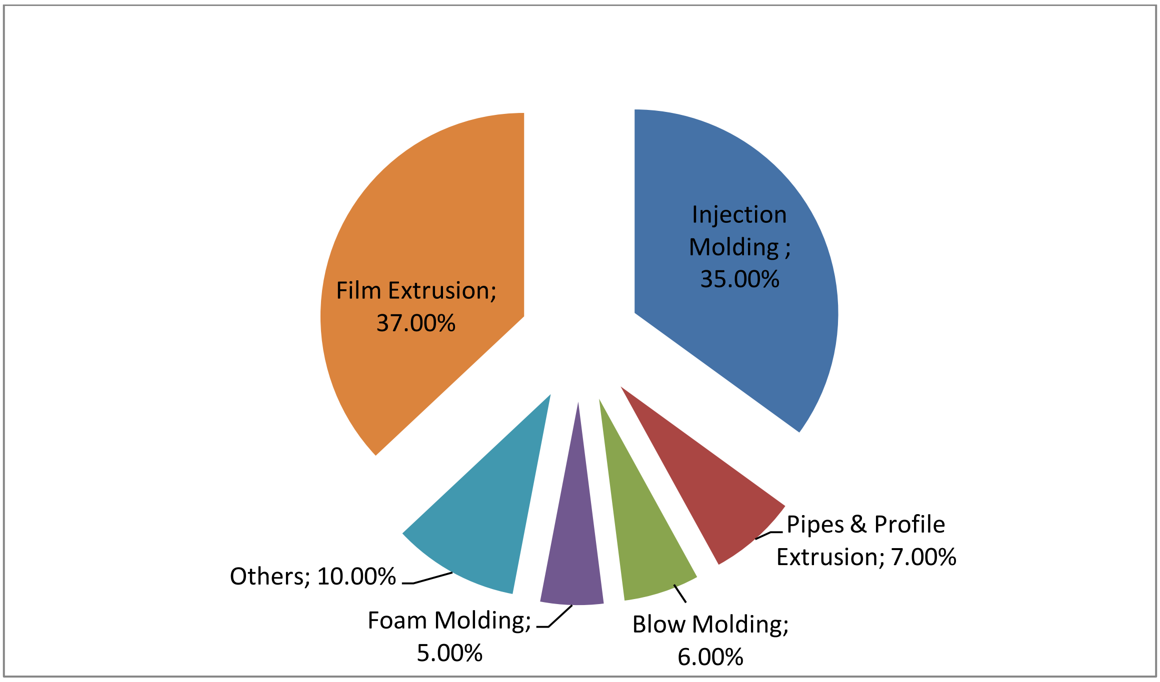


Figure 1.1 *Profile of the Plastic Products Industry by Manufacturing Process, 2009*
Source: "Market Watch 2011", The Malaysian Plastic Industry

1.2 Background of the Problem

Based on the percentage as above, the electricity consumption in Malaysia by sector from 2011 until 2013 indicates that electrical energy consumption in the industry sector is higher than other sectors. In 2011, 2012 and 2013 the electricity consumption in an industry sector indicates the total percentages which are 43.74%, 45.89% and 43.28% respectively is higher compared to various sectors. Therefore, the total consumption of electricity from 2011 till 2013 shows an enhancement in terms of utilization within various sectors. In 2011 the total electricity consumption was 107,330 GWh. However, in 2012 there was an increase to 115, 718 GWh in electricity consumption. The total electricity consumption continued to increase in 2013 to 116, 087.51 GWh. This shows, the total electricity consumption in Malaysia has been increasing from year to year and the industry sector is the highest contributor to the increase in electricity consumption.

Figure 1.2, 1.3 and 1.4 below shows the total percentage of electrical energy consumption by sector in Malaysia and total electricity consumption from year 2011 until 2013.

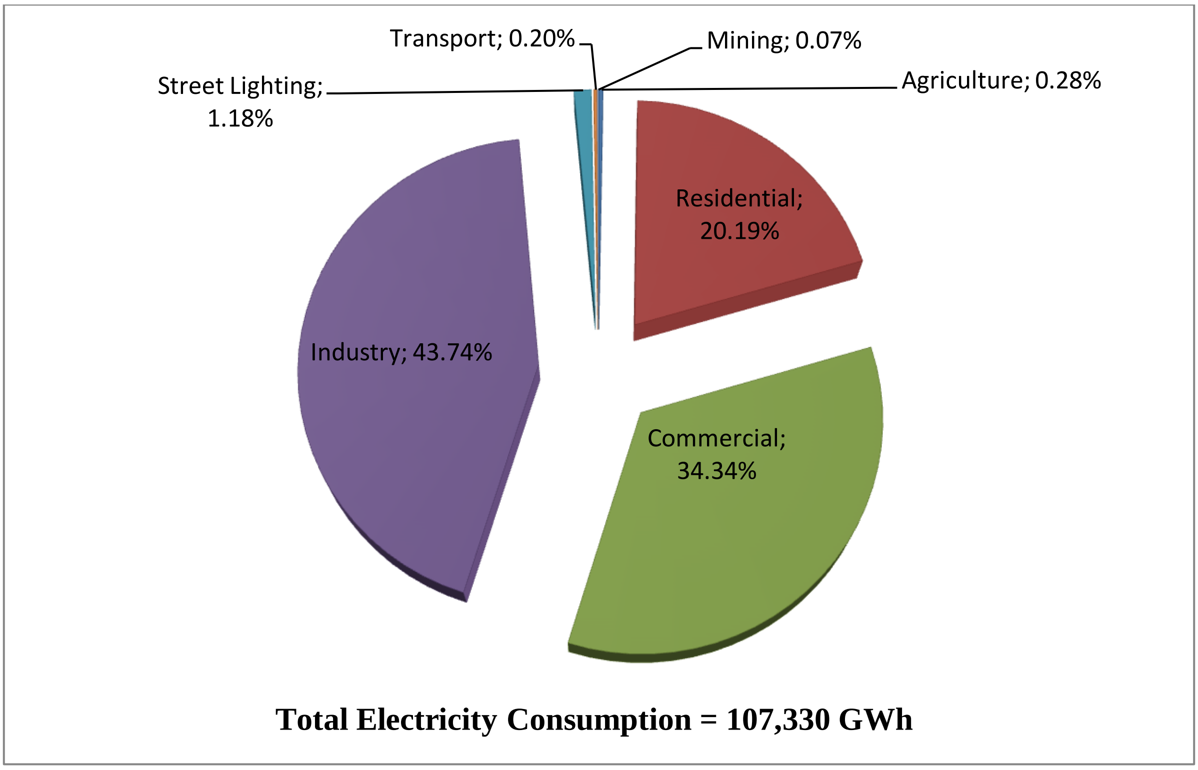
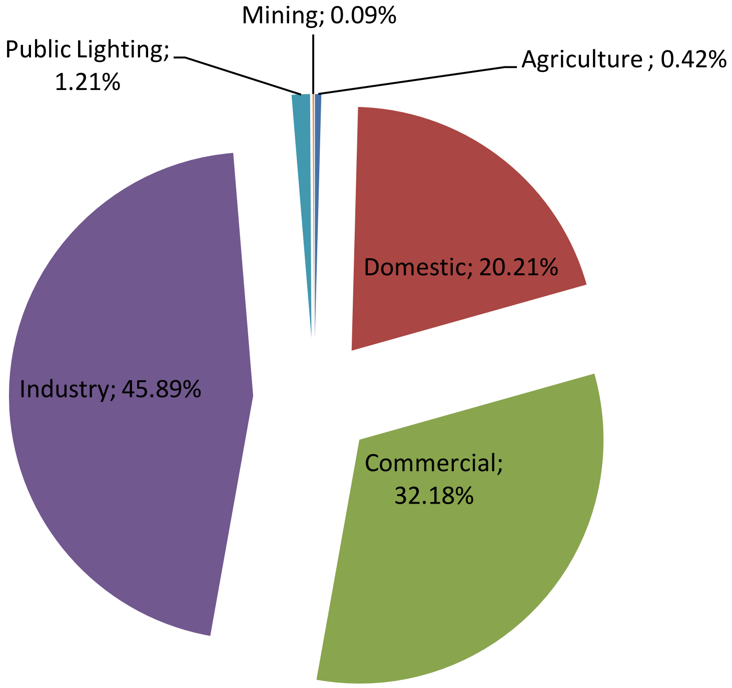
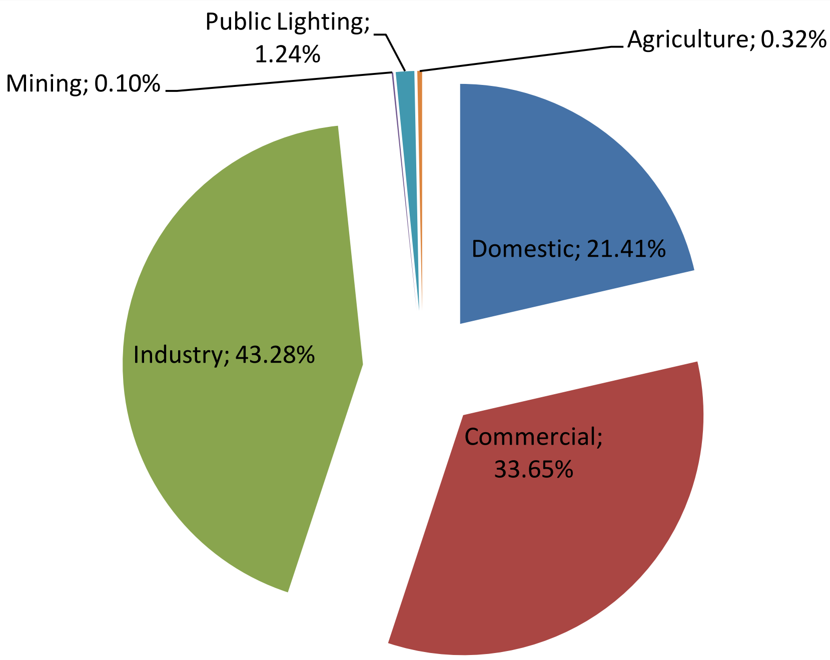


Figure 1.2 *Electricity Consumption in Malaysia by Sector (%), in the Year 2011*
Source: Energy Commission (EC)



Total Electricity Consumption = 115,718 GWh

Figure 1.3 *Electricity Consumption in Malaysia by Sector (%), in the Year 2012*
Sources: Energy Commission (EC)



Total Electricity Consumption = 116,087.51 GWh

Figure 1.4 *Electricity Consumption in Malaysia by Sector (%), in the Year 2013*
Sources: Energy Commission (EC)

Based on reports from Department of Statistics Malaysia, in the year 2011, the plastic products industries have grown by 23.6 % compared to the previous year. The plastic products industries contributed around RM 7 million towards the Malaysian Gross Domestic Product (GDP) (Department of Statistics, 2013). Hence, this industry is one of the highest contributors in the manufacturing sector in Malaysia. Thus, it becomes one of the major electrical energy consumers in the Malaysian manufacturing sector.

Injection molding is one of the best methods in the production of plastic products. Over 30% of plastics are produced by injection molding for manufacturing large quantities of plastic products in variety of shapes and sizes (Mathivanan, Nouby, & Vidhya, 2010). Therefore, injection molding technology is widely applied to various types of industries such as automotive, home and kitchen products, electronic products, construction products, sport and leisure's products and many more. With the high demand in the injection molding processes from industrial sector around the world, it requires higher energy consumption to drive the industry. This activity increases the carbon emissions from the energy production and injection molding production. The carbon emissions from energy production are released into the atmosphere. The waste emission from injection molding production is a disposal of plastic and any type of chemical used in mold fabrication and injection molding processes.

At a marketplace nowadays, a lot of new equipment with energy efficient is introduced by the machine makers to help industry in saving energy. However, the cost may be too high. Some companies are not willing to allocate resources for this purpose because a return of investment (ROI) by replacing new machines with energy saving technology may be difficult. Replacing new machines may not benefit the industries especially when an existing machine is still in good condition and the future business prospect is uncertain.

Therefore, there is a need to research and analyse the practice in plastic injection molding process to improve the energy consumption for existing machines. Manufactures are generally reluctant to invest in new technologies that support sustainable manufacturing process. In addition, this research will focus on existing machines used by the company. New method on how to reduce energy consumption can be optimized to facilitate and promote awareness about the importance of optimizing the use of energy consumption and reducing manufacturing cost.

1.3 Problem Statement

The increasing trend of high consumption of energy will cost irreversible impact on the environment. Therefore, it is important that electrical energy consumption be optimized. In this research, the injection molding industries are considered. Injection molding industries are facing a lot of challenges in reducing cost of production while at the mean time the cost of electrical energy has increased. Hence, optimization technique in injection molding process normally applies to meet the best optimal energy consumption in producing the products with less production time.

The complexity of determining the appropriate parameters provide a major challenge to ensure the optimal electricity distribution in injection molding process. It is closely related to the holding pressure, maximum injection pressure, injection speed mold open or close and screw rotation speed by re-setting parameter to be optimized and to indirectly reduce the energy consumption.

Eventually, the research will lead to an optimized use of electrical energy consumption and help to mitigate the irreversible environmental effect of high electrical energy consumption. One approach is to analyse the plastic injection molding processes and parameter setting and find the most productive and energy-efficient way to do a process.

1.4 Research Objectives

This research approaches the subject of injection molding in analytical parameter to optimize electrical energy consumption. The objectives of the present research are as follows:

a) To investigate the distribution of electrical energy consumption in injection molding process.
b) To produce an electrical energy consumption map of injection molding process using variable parameter setting.
c) To find out the optimum parameter setting of injection molding process to reduce energy consumption.

1.5 Research Questions

This study addresses the overall research question:

a) How the electrical energy is distributed through each of process in injection molding?
b) What is the effect of different parameter setting towards electrical energy consumption?
c) What is the best suitable parameter setting towards optimizing electrical energy consumption in plastic injection molding process?

1.6 Significance of the Study

The purpose of conducting a research on this area is to reduce energy consumption in manufacturing sectors notably in injection molding process. The higher electricity consumption will give negative effects on manufacturers as well as the environment in terms of increasing the cost of production to suppliers and will cause higher carbon emission. Therefore, energy consumption must be managed properly so that manufacturers can continue to contribute to the saving of energy consumption. Noted that, proper energy management practises can help manufacturers to reduce the cost of production, optimize usage, increase profit and strengthen the economy. This is to emphasize the importance of energy management in a whole area in the plant as a path to strategic competitive advantage.

In injection molding process, through determination of electrical energy distribution for each of the steps, the manufacturer can identify which of the steps in injection molding consume the highest amount of electrical energy. This is important, so that the manufacture can figure out steps need to be taken in order to reduce the electrical energy consumption that has been determined earlier in this research.

To reduce energy consumption in the plastic injection molding process through optimization must correct parameter setting must be carried out. By having proper guidelines through the energy map, the machine operator can choose the best parameter settings that can ensure optimal energy consumption and at the same time emphasizing on the quality of products. Reduction in energy consumption will not only reduce the total cost of production but, also indirectly help to reduce the effect of air pollution caused by emission of carbon dioxide during production. Carbon dioxide is released by the process of energy production to produce product. Therefore, it will give irreversible impact to global warming. With the energy map that represents the setting of parameters in plastic injection molding machine a technician can choose the best selection of the best parameter setting for energy consumption.

In addition, this energy map could help the technician to improve the efficiency of the time spent in making parameter setting. With the existence of an optimal parameter setting in injection molding process, it will add new information and also knowledge to produce better plastic product with regard to the energy requirement in terms of the production with suitable mold design or product. After an extensive literature review, the researcher is satisfied that with reliable analysis and valid assessment will give benefit to the manufacturer in energy saving for reduction of overall cost of operation and reduce carbon emission into environment. Hence, optimization of electrical energy consumption can save cost and support sustainable manufacturing. In other words, by implementing energy saving practices a manufacturer can be categorized as effective because the overall cost of production is reduced without compromising on the quality of products. Among the benefits gained by the manufacturer through energy saving is that his or her public image is enhanced and will be seen as a protector of environment when compared with his or her competitors who are not. Additionally, it also can assist in the reduction of Greenhouse Gas (GHG) emissions which affect the environment. By adopting and introducing energy saving measures, industries can contribute to economic growth without damaging the environment and strengthening the political stability of the country (Galarraga, Abadie, & Ansuategi, 2013).

1.7 Scope of Study

The scope of this research is limited to manufacturing sectors in Malaysia that use injection molding machines for producing plastic products. In this research the fully electric injection molding machine model Nissei NEX 500 is used due to the fact that it is cost saving compared to hydraulic and hybrid machines in terms of electrical consumption and maintenance. This could lead plastic products manufacturers towards energy reduction in their entire production activity. However, it is very important for industry to review parameter setting for each process to ensure efficient energy consumption in injection molding machine. This is because; total electrical energy consumption depends on how the parameter setting is made. On the other hand, Taguchi experimental method will be employed to analyse optimization for energy efficient manufacturing system. For more understanding, this researcher has chosen the Northern Manufacturer in injection molding as a sample for research.

1.8 Definition of Key Terms

There are several key terms utilized in this study which are defined as follows:

a) Optimization

The word "optimum" originated from Latin which means 'the ultimate idea'. Therefore, optimization is regarded as to maximizing desired factors and minimizing undesired ones. Optimization is defined as a process of making something as perfect, functional or effective as possible. Generally, optimization can be described as a process in which an object or a system is being changed, so that a property or a function of multiple properties would reach a desired value and performance.

b) Sustainable Manufacturing

Sustainable manufacturing herein is known as transform material through developing technology to be environmental friendly without releasing greenhouse gases, use of non-renewable or toxic material or generation of waste (Allwood, 2005). Besides that, in the context of this research, sustainable manufacturing refers to reduce carbon emission in environment during energy usage and which will automatically reduce cost in manufacturing. Therefore, the industries need to adopt sustainable manufacturing concept in production.

c) Injection Molding

Injection Molding is an important part of manufacturing processes. In the perspective of this research, it is referring to process of forming plastic products by forcing molten plastic material under pressure into a mold. The plastic is being let to be cooled, solidified and removed by opening the two halves of the mold. Injection molding process comprises of 8 main steps where each of these steps consume dissimilar amount of electrical energy. The 8 steps in injection molding consist of mold close, high clamp, injection holding pressure, plasticizing, cooling, mold open and lastly ejection.

d) Injection Molding Machine (IMM)

This research takes the content approach of defining what constitutes injection molding machine. There are three main categories in injection molding machines which are Hydraulic, Hybrid and All-Electric Injection molding machine. In this research, the All-Electric Injection molding machine (IMM) is used. This machine has the characteristics of electrical energy saving. Besides that, it shows tremendous cost saving compared to hydraulic and hybrid machine in term of electrical energy consumption and maintenance.

e) Taguchi Method

Taguchi experimental method is used in this experimental research. This method is developed by Dr. Genichi Taguchi. This method consists of Orthogonal array (OA) and signal to noise ratio (S/N) which will be used as a medium to showcase the result of research and the experiments performed. Experimental design which is suggested by Dr. Genichi Taguchi entangles in the collection of necessary data to determine the factors which affect the quality of products by doing minimum experiment, hence saving time and resources. This method is very appropriate for this experiment to achieve high quality without increasing cost (Nalbant, Gökkaya, & Sur, 2007).

1.9 Organization of Remaining Chapters

This research is divided into five chapters. The first chapter introduces the research comprises background of the study, the problem statement, objective of the study, research question and potential contribution of the study.

The second chapter focuses on review of the existing literature related to the variable considered in this study including the concept of optimization and sustainable manufacturing. Based on literature review, this chapter subsequently discusses the theoretical framework and also hypotheses generated for this study.

The third chapter is research methodology. This chapter consists of research design related to Taguchi Method for optimizing process by having four processes, data collection procedure and data analysis technique.

This is followed by fourth chapter, which comprises analysis and result of research. In this chapter I will explain the calculated power, total power, total energy, S/N ratio and MSD in distribution of energy, an energy map and optimization parameter by utilizing suitable equation. Then, the result of equation will be visualized in suitable chart and table.

Finally, the research ends with fifth chapter, which discusses and concludes the outcome of this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter explains in regard to developing sustainable manufacturing through optimization of injection molding machine with different parameter setting. To achieve that, the focus of this research will discuss injection molding process of forming a plastic product, optimization towards sustainable energy consumption and the theoretical framework which involves two variables that are independent variable and dependent variable. Concluding this chapter, the hypotheses development for this research is then established.

2.2 Plastic Injection Molding Process

Fundamental of plastic injection molding process is transforming the plastic resin into desired shape (product) which is melting the plastic material and injecting into a mold cavity under specific pressure until it is frozen in certain temperature. In the process, firstly, molds need to be installed on the machine and dryer unit is used to dry the material. After that, the material will be transferred into the machine. The machine functions to inject plastic into the mold to produce the desired product. Machine will melt the plastic material, and then it will be injected into mold cavity and holding pressure is applied until it is cold and solid. Once completed, it will be out from the mold. This final product is called ‘plastic product’. Figure 2.1 below explains the complete cycle of injection molding process from the view of the machine operation.

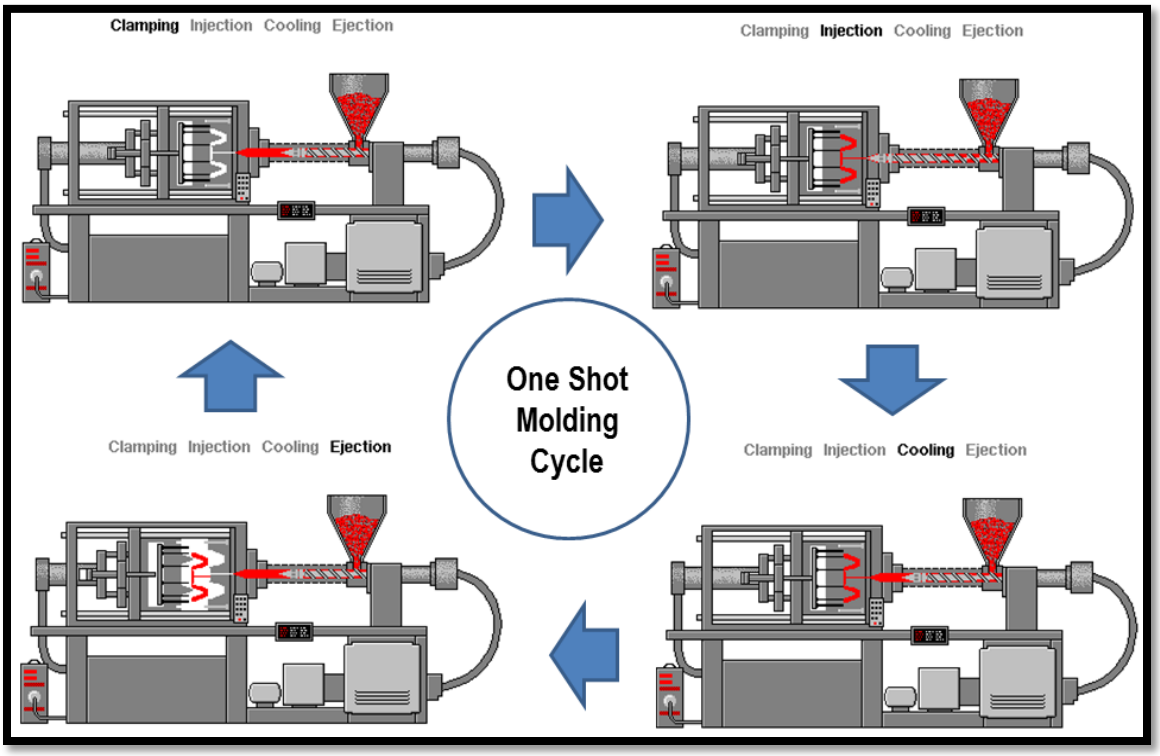


Figure 2.1 *Complete Cycle of Injection Molding Process*

All the processes in injection molding require energy to drive the machine and other equipment. In other word, total electrical energy consumption in injection molding processes are different with each other depending on how the parameter setting is made. There are five basic things that are required to perform in injection molding process which are raw plastic, dryer unit, mold, injection molding machine and mold temperature control machine (Damir, Maja, & Mladen, 2012a).

There are two types of plastic materials, which are the thermoplastic and thermosetting. Both are called "Resin". The difference between thermoplastics and thermosetting is that thermoplastics melt when heated to a certain temperature while thermosetting only becomes soft when heated. In the injection molding process, this resin has to be first dried in a dryer to remove the moisture contained in the resin before injection molding process can be done (Madan, Mani, & Lyons, 2013). Heating and drying the plastic uses high amount of electrical energy.

The machine is designed into three sections including clamping unit, injection unit and control unit. Clamping unit serves to hold and clamp mold, injection unit serves to melt the plastic material and inject into the mold cavity and the control unit functions as a system controller of the equipment, where parameter limits are set and optimization done.

This research experiment is based on Taguchi Method on an all-electric injection molding machine model Nissei NEX500 as in Figure 2.2 which has proven to consume less energy and most efficient in electrical consumption compared to hydraulic and hybrid machine (Kanungo & Swan, 2008; Thiriez & Gutowski, 2006). In addition to that, the Nissei NEX500 operates much faster thus indirectly shortens the injection molding cycle (Damir, Maja, & Mladen, 2012b). Hence, this gives an advantage to the manufacturer to reduce the energy consumption from implementation of optimization process.

Figure 2.2 *Model Nissei NEX 500 All Electric Injection Molding Machine*

2.3 Definition and Conceptualization of Optimization Energy

Recently rising costs of energy and natural resources has heavily burdened a large number of manufacturing companies all over the world. Hence, optimizing energy demand in manufacturing is important for reducing the energy intensity of products and their weaknesses to escalating energy prices (Mativenga & Rajemi, 2011). Thus, from both environmental and economic perspectives, improved energy efficiency in manufacturing is urgently required (Guo, Loenders, Duflou, & Lauwers, 2012). Mechanical machining is one of the most widely used production process and conducted on machine tools powered by electrical energy supply. Regarding machine tools in operation, investigations into energy minimization through selecting optimal process parameters were performed by several researchers. It is clear from literature that reducing energy consumption has been the main focus for the optimization of machining operations through resetting parameter while environmental sustainability has received little attention (Mativenga & Rajemi, 2011).

Plastic injection molding process is actually one of the complex manufacturing processes, and higher electrical energy consumption depends on determination of parameter setting (Chen, Liou, & Chou, 2014). Nevertheless, each of the elements in injection molding processes consume significant amounts of energy, directly or indirectly as shown in Figure 2.3 (Damir *et al.*, 2012a). Hence, one of the aims in this research is optimizing energy consumption in manufacturing processes.

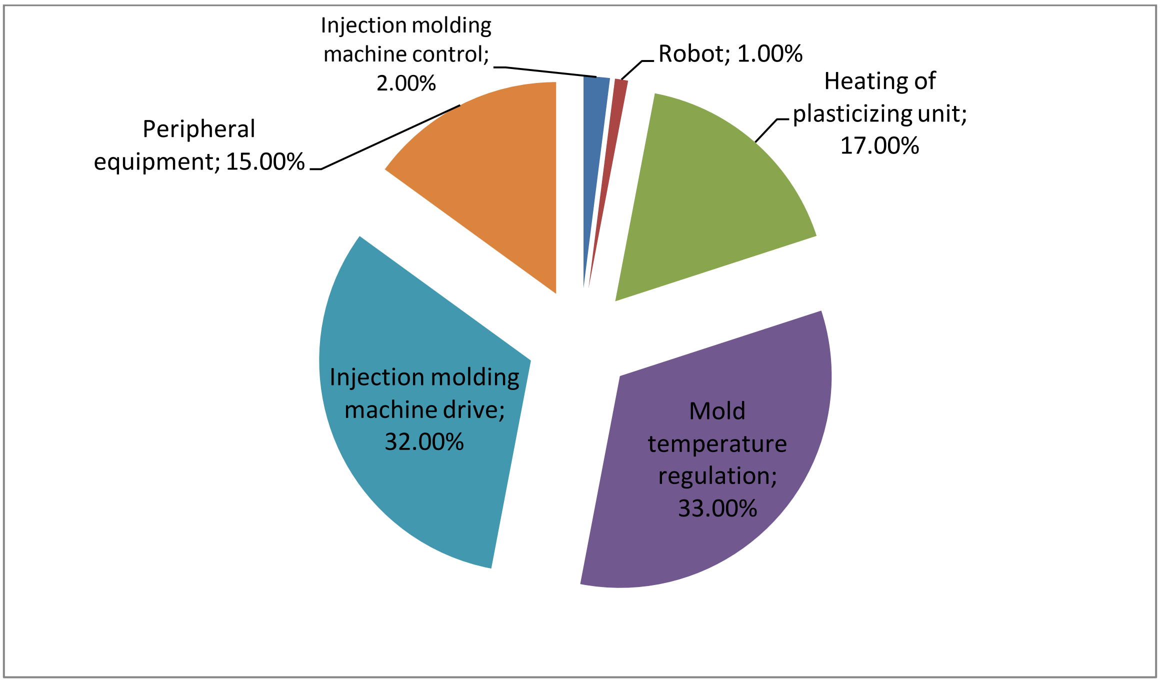


Figure 2.3 *Share of Energy Consumption in Representative Injection Molding Process*
Source: Damir *et al.*, 2012a

The possibilities of energy savings in injection molding process starts in the early phases of molded part design, selection of molded part material, and mold design, in order to obtain a more energy efficient process. Energy efficiency is usually defined as the relationship between the amount of energy consumed and the result of optimization process. Energy efficient injection molding is not only economically profitable, but also environmentally beneficial. According to Kent (2008), the fact that use of 1 kWh of electric energy presents approximately equivalent of 0.43kg of carbon dioxide (CO2).

In a nutshell, optimizing parameter setting is an extremely critical issue requiring prompt and effective solution from the manufacturing industry, notably when searching for the global optimal process parameter setting. Hence, the determination of the optimal process parameter setting is recognized as one of most crucial step in plastic injection molding for reducing electricity during the processing plastic product to accomplish optimization energy (Chen *et al.*, 2014).

2.4 Sustainable Manufacturing

Sustainable manufacturing has gained significant attention from the industries and the academicians. Sustainable manufacturing relates closely to sustainable development. Sustainable development which is the development that meets present needs without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). The report also highlights that sustainable development lies on three main pillars that is the economy, social and environmental factors. Environmental factors can be controlled by reducing the amount of waste, for example, carbon emissions to the environment.

Industrial activity, in particular manufacturing sector, do give a significant impact towards the environment (Duflou *et al.*, 2012). Therefore in order for the industries to be sustainable, they must adopt sustainable manufacturing concept. Sustainable manufacturing by mean of increasing business competitiveness through reduction of manufacturing cost in energy usage can boost the industrial performance. To meet this, organization need to find ways on high level of knowledge and experience to optimize the overall energy needs in manufacturing process and system. The importance in determining the electrical energy distribution in machining must be highlighted (Rajemi, Mativenga, & Aramcharoen, 2010).

Sustainability in manufacturing requires that the energy and carbon footprint of machined products be optimised. Hence, energy reduction in industry has become one of the main goals on each manufacturers for achieving environmentally friendly manufacturing (Guo *et al.*, 2012). Sustainability can be achieved by reducing energy consumption in the industry through knowledge and techniques. Employees should be given adequate training and knowledge to operate the machine effectively. While emphasizing on the quality and quantity of products produced, the correct settings of parameters are also important to ensure efficient energy use. With the availability of technique and equipment to measure the energy used, the data retrieved can help employees to set the machine parameters by comparing and contrasting each parameter setting made. Knowledge about energy used in injection molding can also lead to a better and efficient use of electrical energy. Employees should be informed that each parameter setting will not only have an impact on changes in the quality of the products but also energy consumption.

Eventually, the research will lead to an optimal use of electrical energy consumption and help to mitigate the irreversible environmental effect of high electrical energy consumption. One approach is to analyse the plastic injection molding processes and parameter setting and find the most productive and energy-efficient way to do a process.

2.5 Research Model / Framework

In previous plastic injection molding research, different control process parameters have been used. For example, the researcher used six process parameters (mold temperature, melt temperature, gate dimension, packing pressure, packing time, and injection time) to determine the optimal initial process parameter settings for injection-molded plastic parts with a thin shell feature and under single quality characteristic (warpage) considerations(Huang & Tai, 2001). Meanwhile, according to Wu and Liang (2005), six process parameters (mold temperature, packing pressure, melt temperature, injection velocity, injection acceleration, and packing time) to be used to discuss the effects of process parameters on the weld-line width of injection molded plastic products. Another researcher used four control process parameters (mold temperature, melt temperature, injection pressure, and injection time) to determine the optimal initial process parameter settings for injection-molded plastic parts with a thin shell feature and under multiple quality characteristic considerations (Chiang & Chang, 2006). Therefore, determination of an optimum setting of injection molding process is of great concern for the plastic industry because it critically affects the productivity, quality, and cost of production (Ng, Kamaruddin, Siddiquee, & Khan, 2011).

Based on the preceding research, the theoretical framework model is developed and illustrated in Figure 2.4. The model involves 6 constructions which include holding pressure, maximum injection pressure, injection speed, mold open/close speed and screw rotation speed as well as electrical energy consumption as dependent variable. In this research, 5 control process parameters will be used to optimize electrical energy consumption. Hence, through utilizing the Taguchi method, it can only find the best set of specific process parameter level combinations which are discrete setting values of the process parameters. Therefore, this research can propose an effective process parameter optimization approach to help manufacturers reduce electrical energy consumption and onwards achieve sustainability in manufacturing.

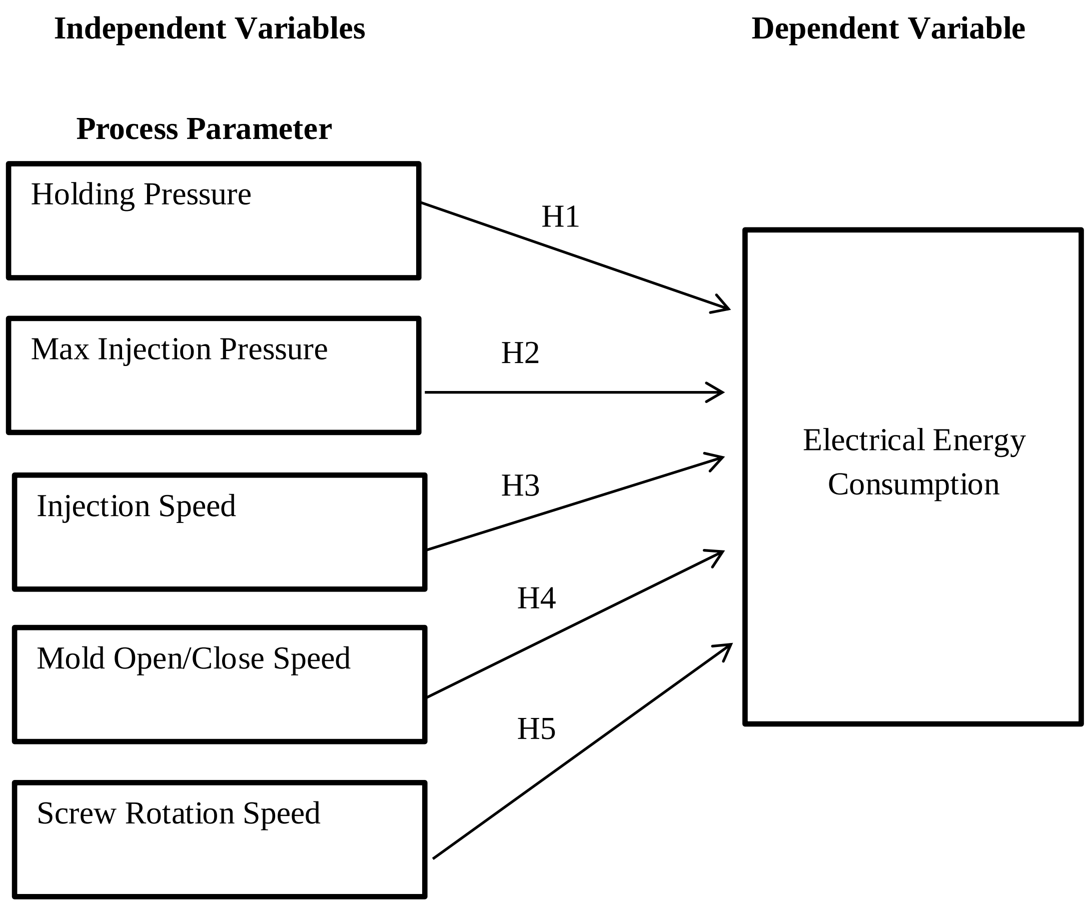


Figure 2.4 *Theoretical Frameworks for Electrical Energy Consumption*

2.6 Definition of Variables

There are definition variables whether independent variable or dependent variable that are utilized in plastic injection molding process. These variables are interrelated with each other in determining optimization.

a) Holding Pressure

Holding pressure is a one of the parameter that is used in the injection molding process. Holding pressure is applied at the very end of the primary injection stroke and is used for the final 5 % filling of the cavity image. It is called holding pressure because it holds pressure against the cooling plastic in the cavity image while that plastic being solidified. This helps to ensure a dense part molded with uniform pressure and controlled shrinkage. Holding pressure is usually in the range of 50% of the primary injection pressure. Holding pressure must be applied against a pad of extra material called a cushion. The unit of holding pressure is Mega Pascal [MPa].

b) Max Injection Pressure

The injection pressure can be defined as the amount of pressure required producing the initial filling of the mold cavity image. The cavity image is the opening in the mold that will be filled with plastic to form the product being molded. Use the phrase initial filling that represents approximately 95% of the total filling of the cavity image. The unit of maximum injection pressure is Mega Pascal [MPa].

c) Injection Speed

The injecting in a plastic injection molding machine which is an injection plunger or a screw moves forward inside a cylinder to inject molten plastic into the mold. The unit of injection speed is [mm/sec].

d) Mold Open/Close Speed

The mold opening and closing speed is the speed at which the mold is opened and the speed at which the mold is closed. The unit is [mm/sec]. Although the time required for opening and closing the mold being small is effective in shortening the cycle time. If the opening and closing speed is too high, the danger becomes high of the molds colliding with each other, and hence it is necessary to put a brake just before the molds meet. Also, if the mold opening speed is too high, the mold releasing state fluctuates which can cause fluctuations in the quality.

e) Screw Rotation (Plasticizing) Speed

The screw rotation speed in plastic injection molding is the speed of rotations of the screw for mixing the pellets. Its unit is revolutions per minute [rpm]. If the screw rotation speed is too high, air gets mixed inside the molten plastic which can make gas generation to occur easily. Also, if the screw rotational speed is too low, sufficient kneading will not be made and the material quality can fluctuate.

f) Electrical Energy Consumption

Electrical energy consumption is the distribution of energy for each of the injection molding processes from loading of resin until products is packed. Hence, it is capable to display the distribution of the energy used by each processes for parameter. By having to reveal the energy distribution can help to select best machine parameters to be optimized in fabricating plastic product. This in turn will help to reduce energy consumption as well as support sustainable manufacturing process. The unit of electrical energy consumption is kilo Watt Hour [kWh].

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter contains the research methodology applied in this study. It provides details of the research design and methods that is used throughout the research for collection of data as well as data analysis. Essential background and fundamental guidelines of injection molding parameter setting are provided. The subsequent sections describe the process and method of this research through data collection procedure and data analysis technique. The chapter concludes by explicating the analysis approach for empirical data.

3.2 Research Design

The design of this research is quantitative study uses Taguchi experimental method on an electric injection molding machine to generate data as well as uses Signal-to-Noise Ratio to generalize result. The experiments involve the understanding of the characteristic of the current machine. By having to record electrical energy consumption, the distributions of energy for each of the injection molding processes are identified and then optimised.

This experiment utilized the Taguchi experimental method. Taguchi method was developed by Dr. Genichi Taguchi from Japan. He developed a method to design an experiment to investigate how different parameters affect the requirements in product development. Dr. Genichi designed experimental methods that can be done in a variety of conditions. The parameter design of the Taguchi method utilizes Orthogonal array (OA) (Karna & Sahai, 2012) and Signal to noise ratio (S/N) (Berube & Wu, 2000) as a medium to showcase the results of research and the experiments performed. The mentioned techniques help in simplifying experimental design, data analysis, and prediction of optimum results. As a result, Taguchi method is considered to be an important approach to minimize performance variation and hence, the interest in the literature of Taguchi method continues to grow (Fei, Mehat, & Kamaruddin, 2013).

According to Rashi, Joshi & Kamble (2012), there are several techniques that have been published to design and determine the optimal process parameter of injection molding such as Artificial Neural Networks (ANN), Case Based Reasoning (CBR), Finite Element Method (FEM), Non Linear Modeling, Response Surface Methodology and Linear Regression Analysis. Nonetheless, in this research Taguchi Method has been employed with great success in experimental designs for problems with multiple parameters due to its practicality in designing high quality systems that provide much-reduced variance for experiments with an optimum setting of process control parameters (Fei *et al.*, 2013). Besides that, it has a good potential for savings in experimental activities. On the other hand, it can only find the best specified process parameter level combination which includes the discrete setting values of process parameters (Chen, Fu, Tai & Deng, 2009). Besides, Taguchi methods using statistical methods can improve the manufacturing of goods (Karna & Sahai, 2012).

The optimal processing parameter in the plastic injection molding industry is directly influenced on product quality, costs and overall productivity. Hence, suitable method to design and customize processes within the certain limits is crucial importance. Many researchers acknowledge that, the method introduced by Taguchi, especially in development design to study the variation was very effective. Manufacturing processes are affected by a lot of factors; hence Taguchi methods of identifying those factors have the greatest effects on product variability. Common achievement is to minimize costs, maximize production, and improve efficiency.

The goal of this research is to develop a sustainable manufacturing system. The aim is to develop an energy map to optimize the electrical consumption of injection molding machine through determining the optimum setting parameter that gives minimum amount of energy usage. Taguchi method has been proven a great success in experimental designs for problems with multiple parameters setting technique (Yadav, Dravid, & Rajput, 2012). His ideas were widely used by successful manufacturers around the world in creating the optimal process and improve production costs. The proposed approach of Taguchi's parameter design method can effectively assist the management to determine final optimal process parameter settings through developing energy map. Therefore, it is hoped that this goal can be achieved successfully (Chen *et al.,* 2009).

The steps applied for Taguchi optimization in this research as follows. (1) Select control factors and control variables, (2) Select Taguchi Orthogonal Array (OA), (3) Analyse the results using Signal-to-noise ratio (S/N), (4) Identify the optimum performance and finally (5) Resetting parameter. Figure 3.1 below indicate the steps applied for Taguchi optimization in this research.

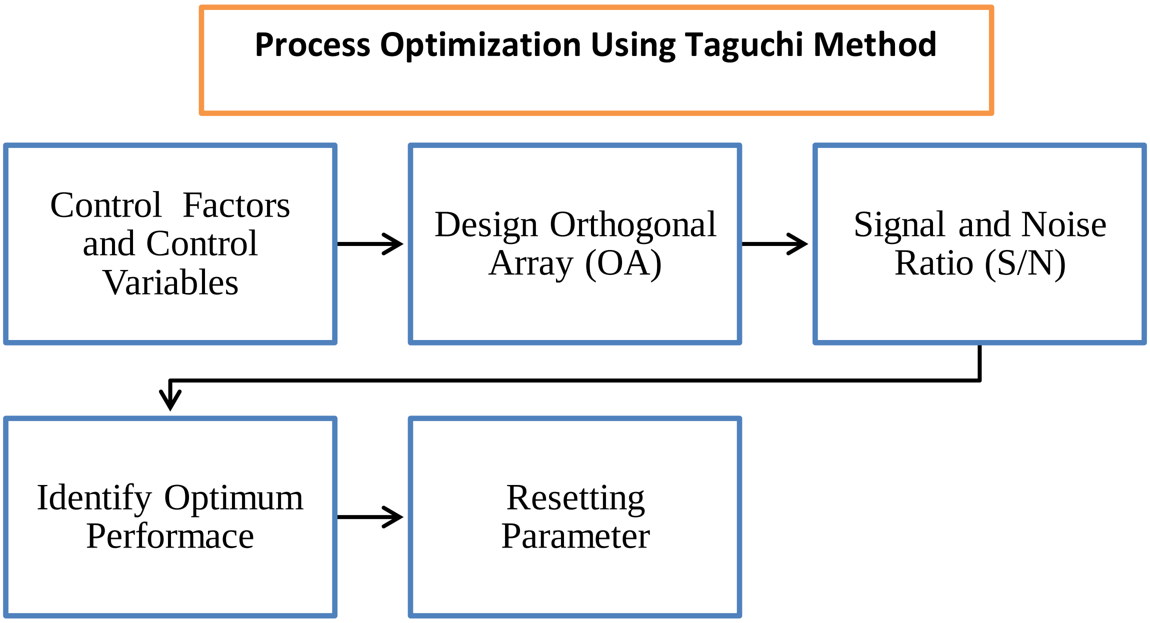


Figure 3.1 *Steps Applied for Taguchi Optimization Process*

According to Kamaruddin, Zahid & Foong (2010), the optimization tool is fundamental and frequently applied for most activities. Trial and error through a case study are one of the most popular, but the experimental design procedures are not easy without suitable methods and tools. A large number of experimental works have to be carried out when the number of process parameters increases (Yadav *et al.*, 2012). Besides that, trial-and-error processes which depend on the engineers' experience and intuition to determine initial process parameter settings. On the other hand, the trial-and-error process is costly and time consuming, thus it is not suitable for complex manufacturing processes. Other than that, when using a trial-and-error process, it is impossible to verify the actual optimal process parameter settings. To solve this problem, the systematic determination of optimal solutions through applied Taguchi's parameter design method to determine the optimal process parameter settings.

More details regarding the steps applied for Taguchi optimization process will be described step by step for more understanding. It is shown as follows.

3.2.1 Identify Control Factors and Control Variables

The goal of this research is to find parameter settings that would consistently obtain optimization as shown in Figure 3.2. Optimizing parameter is routinely performed in the manufacturing industry, particularly in setting optimal process parameters. Final optimal process parameter setting is recognized as one of the most important steps in injection molding process for optimizing distribution electrical energy consumption. There are five process parameters included as the parameter control factors, such as holding pressure, injection pressure, injection speed, mold open and close speed, and screw rotation speed. Meanwhile, six factors which are holding time, curing time, metering position, mold temperature, barrel temperature and mold high clamp are assumed as control variables. At this stage, these control variables will be fixed, so that the control variables value can be kept constant. Hence, the experiment data can exhibit valuable information on the energy trends of electricity in injection molding machine.

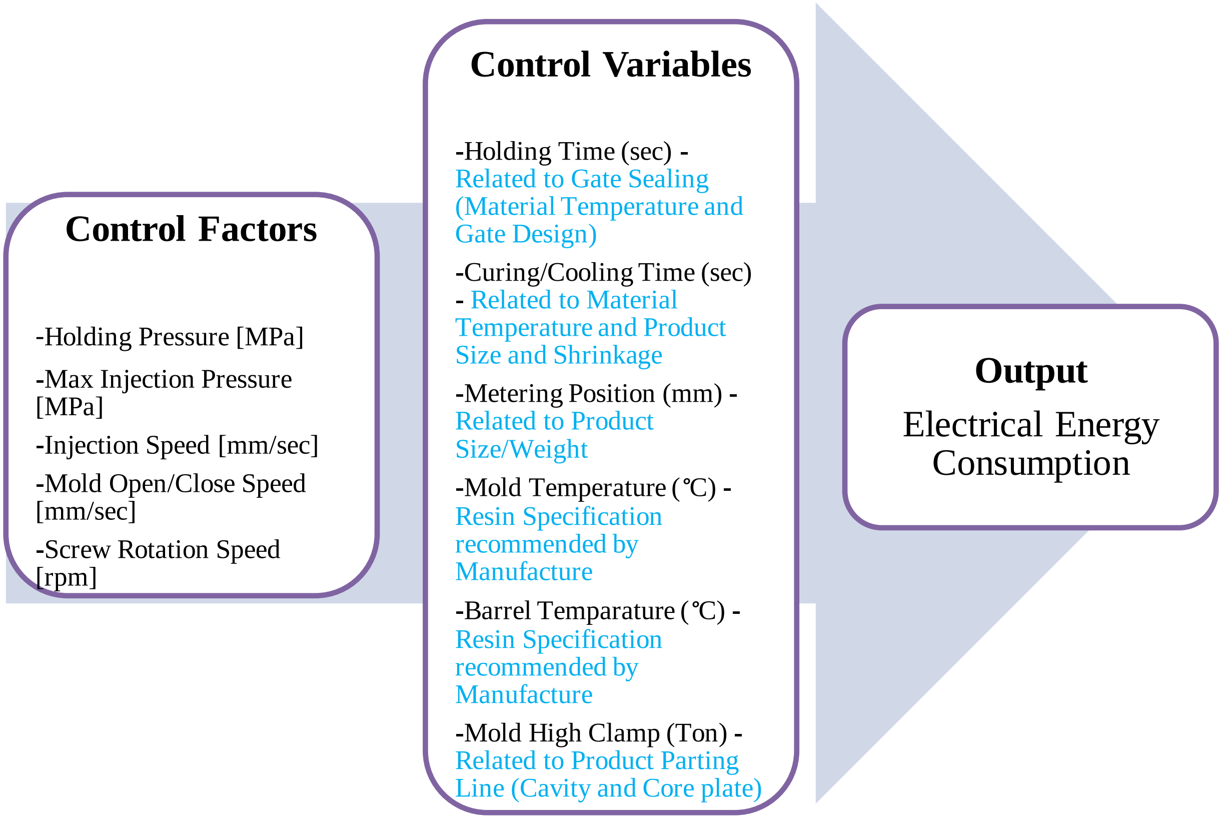


Figure 3.2 *Control Factors and Control Variables in Injection Molding Parameter Setting*

3.2.2 Development Parameter Setting Orthogonal Array (OA)

According to Chen *et al.*, (2009), Taguchi's parameter design method is used to arrange an orthogonal array experiment and to reduce the number of experiments. The effect of many different parameters of experiments can be examined by using the Orthogonal Array (OA) experimental design proposed by Taguchi. When the parameters that affect a process can be controlled have been determined, the extent of these parameters need to be changed must be determined (Ng *et al.*, 2011). For determining levels of a variable must require an in-depth understanding in processing, including the minimum, maximum, and current value of the parameter to test. The values of the parameter to be tested depend on the range and number of parameter required within the range.

To apply orthogonal array, the first step is to firmly set the number of experimental factor and level. Table 3.1 indicate 5 experiment factors which refer to control factors which are determined during first level of process optimization. Each factor has 3 levels which are (1) lower, (2) centre and (3) upper. Value for centre column will be set refers to present parameter setting. Lower and upper values depend on the best value of minimum and maximum boundary of parameter setting. After the experimental factor and level is identified, next step is to choose the right orthogonal array. Table 3.2 shows the standard orthogonal array selector matrix. Name of the appropriate array can be found by looking at the column and row corresponding with the number of parameters and number of levels. Once the name has been determined (L_{18}) the predefined array can be looked up. These arrays are created using an algorithm developed by Taguchi, and allows for each variable and setting to be tested equally as referred to in Table 3.3.

H = Holding Pressure (H1 = level 1, H2 = Level 2 and H3 = Level 3)

P = Maximum Injection Pressure (P1 = level 1, P2 = Level 2 and P3 = Level 3)

I = Injection Speed (I1 = level 1, I2 = Level 2 and I3 = Level 3)

M = Mold Open/Close Speed (M1 = level 1, M2 = Level 2 and M3 = Level 3)

S = Screw Rotation Speed (S1 = level 1, S2 = Level 2 and S3 = Level 3)

Table 3.1 *Process Parameter Factors and Levels*

Process Parameter Setting and Level

No.	**Experiment Factors**	**Experiment Levels**		
		1	**2**	**3**
A	**H**olding Pressure [MPa]	Lower	Centre	Upper
B	Max Injection **P**ressure [MPa]	Lower	Centre	Upper
C	**I**njection Speed [mm/sec]	Lower	Centre	Upper
D	**M**old Open/Close Speed (%)	Lower	Centre	Upper
E	**S**crew Rotation Speed [rpm]	Lower	Centre	Upper

Table 3.2 *Taguchi Orthogonal Array (OA) Matrix Table*

		No of Parameter (P)																													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
No of Levels	2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
	3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
	4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32																					
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

Source: (Karna & Sahai, 2012)

Table 3.3 *Orthogonal Array L_{18} Smaller-the-Better*

Orthogonal Array L_{18} (5^3)

Trial No.	Control Factors A	B	C	D	E
1	H1	P1	I1	M1	S1
2	H1	P1	I3	M2	S3
3	H1	P2	I1	M3	S3
4	H1	P2	I2	M1	S2
5	H1	P3	I2	M2	S1
6	H1	P3	I3	M3	S2
7	H2	P1	I2	M2	S2
8	H2	P1	I3	M3	S1
9	H2	P2	I1	M2	S1
10	H2	P2	I3	M1	S3
11	H2	P3	I1	M1	S2
12	H2	P3	I2	M3	S3
13	H3	P1	I1	M3	S2
14	H3	P1	I2	M1	S3
15	H3	P2	I2	M3	S1
16	H3	P2	I3	M2	S2
17	H3	P3	I1	M2	S3
18	H3	P3	I3	M1	S1

3.2.3 Identify a Signal to Noise Ratio (S/ N)

Since the objective of this research is to optimize parameter setting, Taguchi proposed using Signal to Noise ratios (S/N) to optimize processes. S/N is a one of the methods in Taguchi experimental design. It is utilized to determine the initial process parameter settings that have minimal sensitivity of noise under the consideration of most major quality characteristic (Chen *et al.*, 2009). The concept is explained in the Taguchi Loss Function. The Taguchi approach takes the view that it might be preferable to have a robust process that gives consistently good results. S/N analysis determines the most robust set of operating conditions from variations within the results. The term "SIGNAL" represents the desirable value and the "NOISE" represents the undesirable value. The formula for signal-to-noise is designed so that the experimentalist can always select the larger factor level settings to optimize the quality characteristics of an experiment. Therefore, the method of calculating the signal-to-noise ratio depends on whether the quality characteristic equation which has smaller-the-better; larger-the-better or nominal-the-better formulation is chosen. S/N is an essential tool to define how much a signal as meaningful information has been corrupted by the noise as the unwanted signal. A high S/N guarantees clear acquisitions with low interference and artefacts caused by noise. Indirectly, the best set of parameter setting combination can be determined to develop a robust electrical energy reduction map. It can be derived from the formula below:

$$\text{S/N} = \frac{P_{signal}}{P_{noise}} = \mu \,/\, \sigma$$

Where;

μ = Signal mean or expected value

σ = Standard deviation of the Noise

S/N Quality Characteristics Equations

Nominal-the-Better	S/N = -10 Log_{10} (μ^2 /σ^2)
Larger-the-Better	S/N = -10 Log_{10} (1/n $\sum$ 1/${Y_i}^2$)
Smaller-the-Better	S/N = -10 Log_{10} (1/n $\sum {Y_i}^2$)

Where;

μ = Signal mean or expected value

σ = Standard deviation of the Noise

n = Number of test conducted

Y = Value of Mean Square Deviation (MSD)

The S/N ratio for each level of process parameters is computed based on the S/N analysis. The aim of this research is to produce minimum energy consumption in electricity. Therefore, to obtain optimal electricity, a smaller-the-better performance characteristic for energy consumption should be taken for obtaining optimal energy consumption. This is because; to get the S/N ratio corresponds to the smaller variance of the output characteristics around the desired value. Besides that, the deviations S/N ratio are very small each parameter and negligible (Nalbant *et al.*, 2007).

3.3. Data Collection Procedures

In electrical energy optimization process, the data is collected by utilizing quantitative method through Taguchi experimental that was inspired by Dr. Genichi Taguchi. Therefore, this method is the best to identify problems and make solutions. With that, an adequate knowledge of the process is necessary so that optimization progress can be done successfully. All of these began with review of past research and how the process worked for efficient and systematic decision making approach. To design the optimization process, it requires a deep understanding of the influences that can achieve desirable performance. Thus, it needs an efficient and systematic decision making strategies.

The period for the collections of this data has taken approximately two weeks to finish. The data is collected by doing experiment on the specific model of injection molding machine that is used as a sample. During the experiment, selection of the suitable and reliable tools is important. This is because; it can cause data errors obtained during experiment. The fully electric injection molding machine model Nissei NEX500 is used in this research. When conducting this research from the beginning until the end, it consists of two phases. In first phase, experiment for electrical energy consumption using current setting of injection molding parameters is investigated using Taguchi experimental method. Injection molding parameter consist of 8 main steps in which each of these steps consumed different amount of electrical energy.

Dr. Genichi Taguchi developed a method to design an experiment to investigate how different parameters affect the requirements in product development. Experimental design proposed by Taguchi involves the collection of necessary data with minimum experiment, thus saving time and resources. Analysis of changes in the data collected from the Taguchi experimental can be used to select best parameter setting to optimize the objectives and it requirements.

The experiment has used current logger Kyoritsu KEW 5020 to capture current flow during each steps in injection molding such as in Figure 3.3. The current logger was clamped onto the live wire of plastic injection molding machine. The fluctuation of current is monitored to determine power use for each of the process which includes start-up of machine until fabrication of final product. It takes 40s to complete the whole cycle of an injection molding process. The current flow was tabulated in suitable chart to visualize the data. This data revealed the characteristics of machine and was used to develop an energy map.

Figure 3.3 *Kyoritsu KEW 5020 Current Logger*

The second phase involves developing suitable analysis from collection of data by current logger to determine the distribution of electrical energy consumption for injection molding machine. Appropriate charts were used to depict the data. These charts are suitable to determine the machine components or activities that consume the most electrical energy during the injection molding process and time taken for each operation.

The complete cycle of the injection molding process is called ‘one-shot cycle’. Each shot of injection molding consists of eight main operational steps. It starts from mold closed, high clamp, nozzle injection, holding pressure, plasticizing, cooling, mold open and parts ejection. From the eight main operational steps, it is divided into four phases that consists of metering or plasticizing; material injection and holding pressure; cooling or curing and part removal. Injection molding machine is designed to continuously repeat this process cycle. Intervals cycle time is set at 1s in between two injection shots.

In this research, the total time taken for each shot cycle is 40s and this experiment was repeated 4 times shot cycle to get accurate data by utilizing 3 levels such as lower, centre and upper which are referred to parameter settings. In addition, only five parameter settings can be adjusted according to experimental design. To set 3 levels for each parameter setting must be referred to the standardized Taguchi Experimental method.

All of the current values are essential and must be recorded at all the time during injection molding processes. The data was tabulated inside suitable table to calculate the distribution of electrical energy consumption using appropriate formula. Analysis of this data is presented in Chapter 4.

3.4 Data Analysis Techniques

According to Sekaran, (2000) prior to data analysis, steps, such as coding, data screening and selecting the suitable data analyses strategy should be completed. Raw data should be coded properly and consistently to help statistical analysis. Besides that, data screening is also conducted to make sure detection of any data entry related errors. The method utilized for screening data was by performing descriptive statistics of the variables. From the outcome, the missing data and normality were determined.

All the data collected for this research are interpreted and analysed utilizing Taguchi Method to find the result of analysis. Taguchi Method approach is claimed to be useful in this analysis because it has a good potential for savings in experimental activities.

Orthogonal array (OA) and Signal to noise ratio (S/N) are used as a medium to showcase the results of research and the experiments performed. For this purpose, this analysis covers and narrows down injection molding parameters setting for the most efficient energy of all-electric injection molding machine.

Through re-design the parameter setting will reduce energy consumption without affecting the product quality. Develop an energy map as a guideline for energy saving technique. Furthermore, to develop ideas and tips for energy saving. In addition, the findings from this analysis can be very useful to help industry to participate in energy saving activities.

CHAPTER FOUR

ANALYSIS OF RESULT AND DISCUSSION

4.1 Introduction

This chapter describes the analysis conducted and present the result for this research. It involved three analyses of data had been recorded during each process of electrical energy consumption in the injection molding in which the distribution of electrical energy consumption, generate energy map and determine optimization parameter setting. Data were analysed using equation power, total power, total energy, S/N ratio and MSD respectively. The arrangement of this chapter is as follows. First and foremost, is to identify the distribution of energy for each of the injection molding process. This is followed by to generate an energy map as a guideline to technician in determining amount energy usage in injection molding after that to optimize parameter setting after doing analysis. And, the last part a discussion of the findings from this result.

4.2 Distribution of Energy

In the first part, by having to record electrical energy consumption, the distributions of energy for each of the injection molding processes were recognized. Data collected was visualized in suitable charts. These charts were appropriate to determine the machine components or activities that consume the most electrical energy in the process. The machine parameters were set at injection rate 125 cm^3/sec, injection pressure 225 MPa and injection force 97 kN. Barrel heater setting at nozzle was set at 305°C. Therefore, the power and total electrical energy consumption for the injection molding used were calculated utilizing Equation 1 and 2 respectively.

The power used, Equation 1: [W]

$$P = 415 \times \sqrt{3} \times A \times 0.85$$

Where: A= Current [A]; Power factor = 0.85

The total energy used, Equation 2: [Ws]

$$E_T = P_{MC}t_1 + P_{HC}t_2 + P_I t_3 + P_{HP}t_4 + P_P t_5 + P_C t_6 + P_{MO}t_7 + P_E t_8 + P_{MI}t_9$$

Where: P_{MC} = Mold closing [W]; P_{HC} = Mold high clamp [W]; P_I =Power injection [W]; P_{HP} = Power holding pressure [W]; P_P = Power plasticizing [W]; P_C = Power cooling [W]; P_{MO} = Power mold open [W]; P_E = Power part ejection [W]; P_{MI} = Power mold interval [W]; t = time for each operation [s]

Each shot of injection molding consists of eight main operational steps. It starts from mold closed, high clamp, nozzle injection, holding pressure, plasticizing, cooling, mold open and parts ejection. It was essential to record all the current values for each second using current logger because, to calculate amount of electrical energy used by each of the injection molding operation. Figure 4.1 showed the amount of current and time taken during for each of the steps in injection molding.

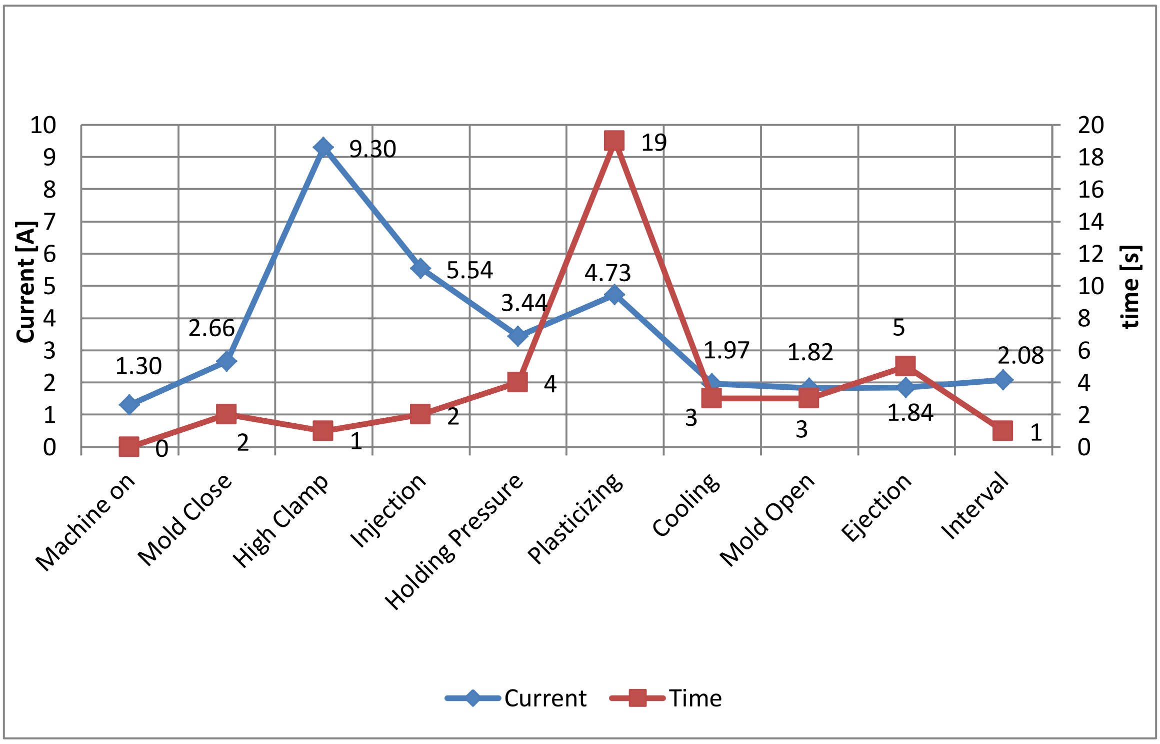


Figure 4.1 *Amount of Current and Time in Injection Molding Processes*

In the Figure 4.1 clearly showed that high clamp uses the highest amount of current compared to other operations. Nevertheless, the high current did not mean that operation consumed highest amount of energy. Electrical energy was the product of power and time. Since the time taken for high clamp was not high, it results in low amount of electrical energy. Plasticizing operation had the longest time taken for single operation. This operation should be optimized so that the time taken was reduced. Lower time taken would result in reduced electrical energy consumption.

Related to the total energy consumption, Figure 4.2 showed distribution of electrical energy consumption in plastic injection molding machine. According to Rajemi *et al.*, (2010) highlight that the initial setup in turning process consumed the highest amount of energy compared to the machining process itself. In this initial process, the electrical power of injection molding machine only consumed 794.3 W by using Equation 1. Since duration for one single shot was 40s, and the machine must be always turn on during the operation, total energy to turn on the machine was 8.83 kWh. This energy consumption was still lower than the plasticizing operation. This fact proves that for injection molding, initial start-up for injection molding did not consume highest amount of electrical energy.

By using Equation 2, plasticizing operation consumed most of energy consumption compared to other operations. Figure 4.2 showed that plasticizing process consumed 65.2% of the energy in injection molding process. The plasticizing rate was 16 kg/h. Plasticizing operation was located inside the injection unit. Thus, heater was needed to melt the plastic granules. NEX500 Injection molding machine have 4 heating zones consist of barrel trout, metering, compression and melting. The temperature for these zones was maintained in between 265°C to 315°C. Hence, heating operation explains why plasticizing operation consumed high electrical energy.

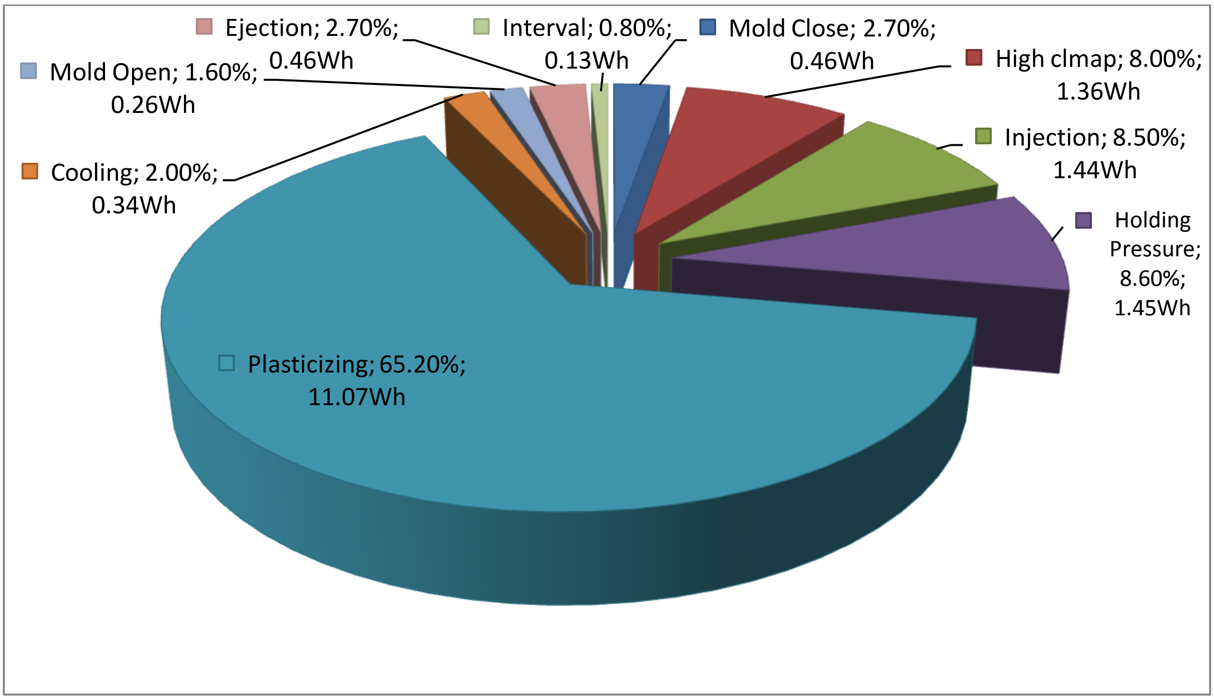


Figure 4.2 *Distribution of Electrical Energy Consumption in Injection Molding*

Referring to Figure 4.2, injection unit holding pressure consumed the second highest amount of electrical energy followed by injection and high clamp. In Figure 4.1, the current for high clamp was the highest, but electrical energy only consumed 8 % (1.36 Wh). This value supports statement that high current did not necessarily have high energy consumption. As being mentioned before, electrical energy consumption depends on time for each operation. Longer operation consumed higher electrical energy. Therefore there was a need to optimize the injection molding operation, so that the time taken for the process could be reduced. Reduction in time for operation would definitely lower the energy consumption. This onwards would help to support sustainable manufacturing process.

The optimization of energy consumption could be achieved by having to determine suitable machine parameters such as injection speed and pressure.

Therefore, an energy map was needed to help technician for understanding effect of relevance to select different injection molding parameter.

4.3 Energy Map

This research could be further extended to optimize the machine parameter for reducing electrical energy consumption in injection molding machine. Hence, with step forward by generating electrical energy map for injection molding using different sets of machine parameters. The map could assist machine operator to select an optimized machine parameter to reduce electrical energy consumption.

In this part, the current data was used to calculate the total power and total electrical energy consumption for the injection molding using Equation 1 & 2 respectively with duration 40s to complete the whole cycle of an injection molding process.

Assuming the power factor equal to 1,

Equation 1: Total power, P_T [kW]

P_T: $415 \times \sqrt{3} \times [\mathrm{A}_1 + \mathrm{A}_2 + \cdots + \mathrm{A}_{40}]$

Where: A = current [A] for each second.

Equation 2: Total energy, E_T [kWs]

$E_T = P_T \times 40$

In developing energy map, parameters were set according to injection speed and holding pressure, in which 150 mm/s and 225 MPa respectively. This set was known as standard parameter that recommended by supplier machine because; only the supplier machine knew the best standard parameter on that machine. Subsequently, the injection speed and holding pressure were varied as shown in Figure 4.3. The current flows were recorded to calculate the electrical energy consumption for the single shot.

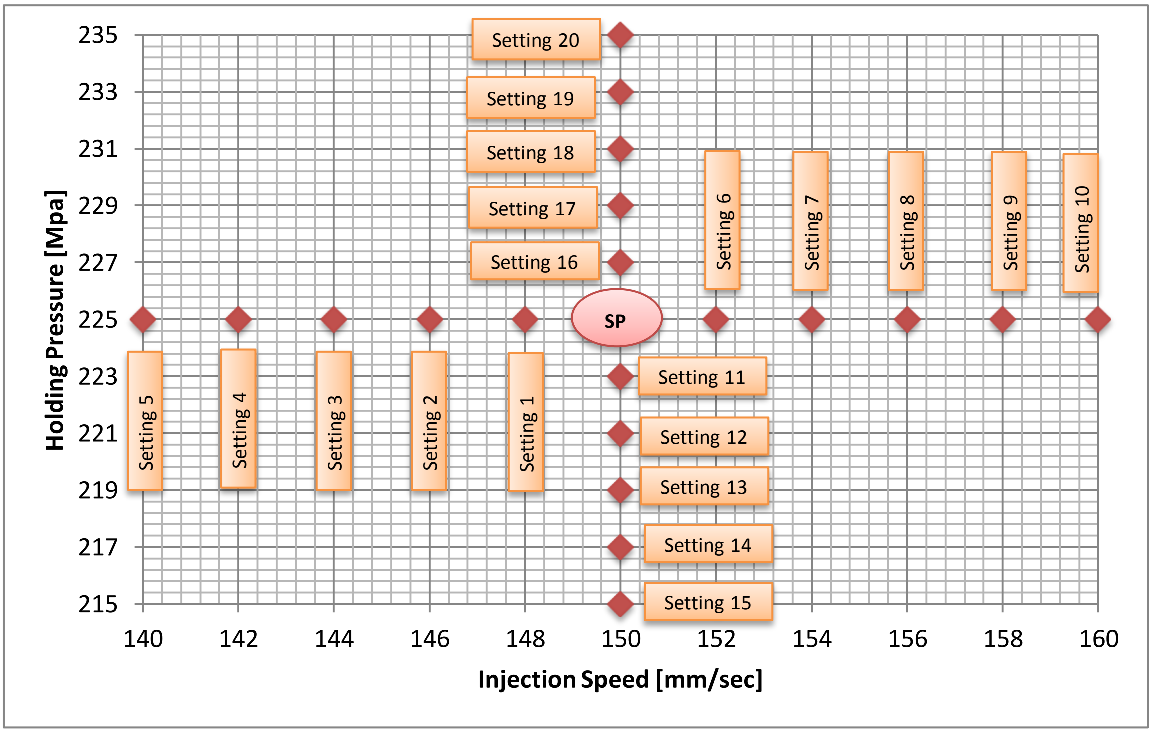


Figure 4.3 *The Injection Speed and Holding Pressure Parameter*

The calculated power was visualized in suitable diagram as showed in Figure 4.4. This data was then used to generate a suitable electrical energy map. The total power and total energy were calculated using equation 1 and 2. The standard parameter 150 mm/s and 225 MPa were used as reference to determine the fluctuation of energy consumption for each of the settings.

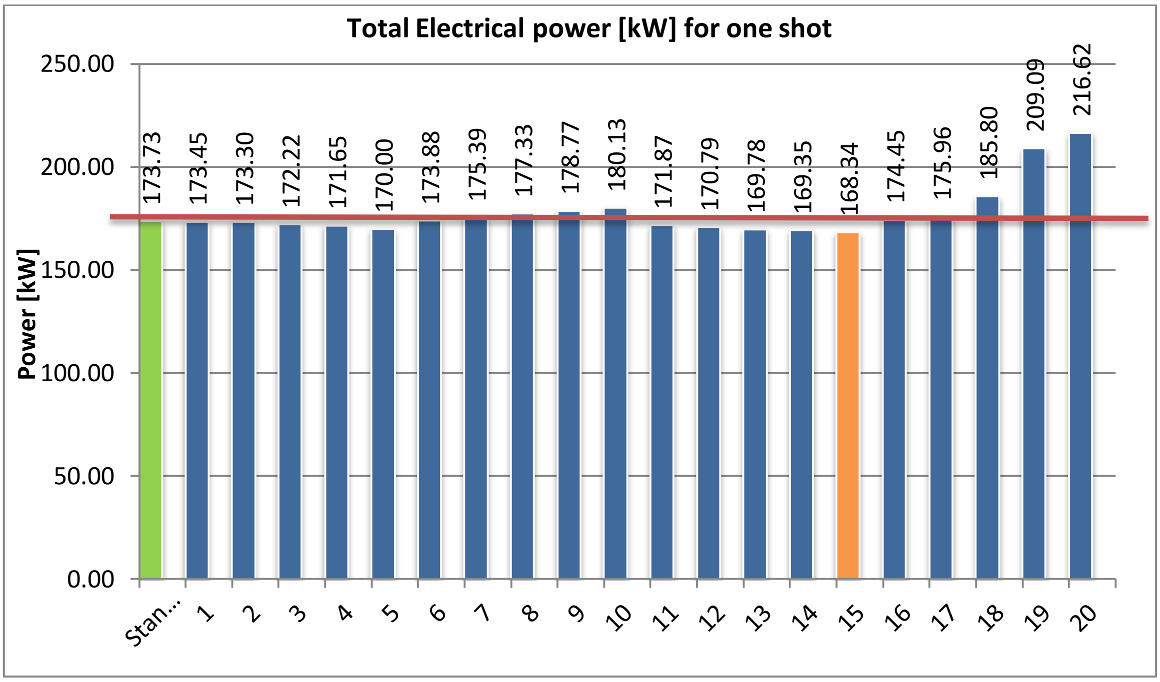


Figure 4.4 *Electrical Powers [kW] for Each Setting*

Varying the injection speed and holding pressure result in a different amount of energy consumption for injection molding process. The total electrical power was calculated using equation 1. The standard parameter with injection speed and holding pressure of 150 mm/s and 225 MPa respectively uses almost 174 kW. Maximum power of 217 kW was from the setting of 150 mm/s and 235 MPa which was setting number 20. The minimum power was 168 kW using setting 15. These were 6 kW and 49 kW lower than the standard and setting 20. The average power for the settings including standard setting was 178 kW.

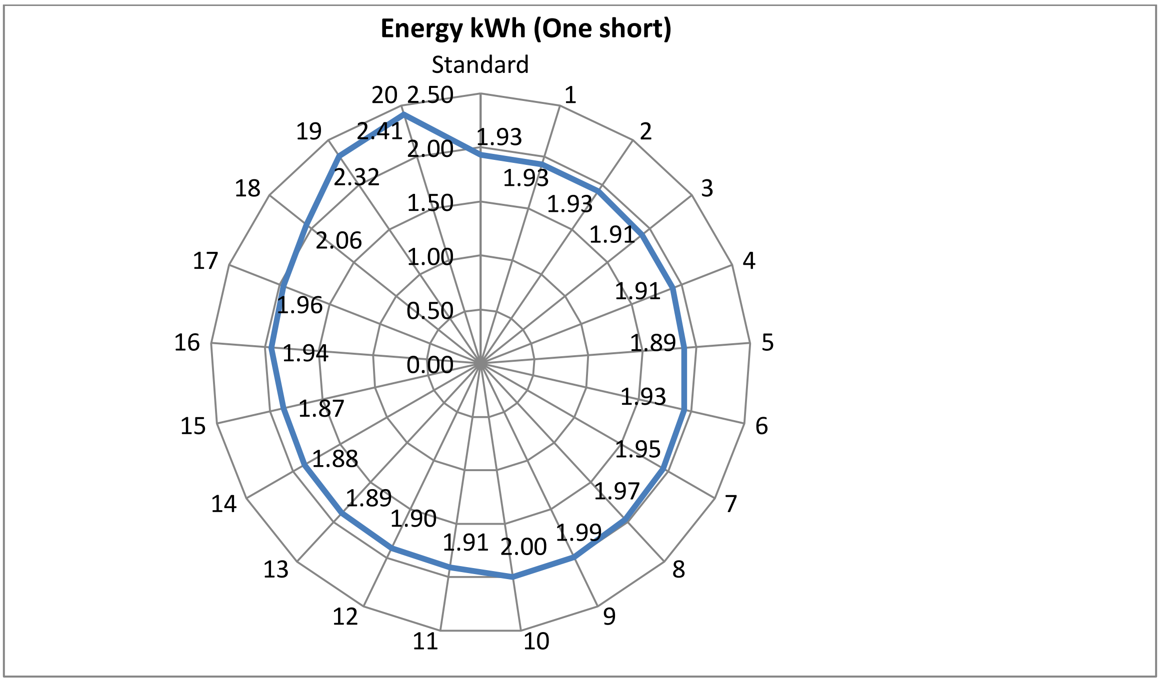


Figure 4.5 *Electrical Energy Map for Each Setting*

Figure 4.5 showed the electrical energy map for each of the settings. The electrical energy was calculated using equation 2. The total time taken for each shot was 40s. Setting 20 uses the highest amount of electrical energy in a single shot that was 2.41 kWh. The standard setting only uses 1.93 kWh. The average amount of electrical energy used for the whole setting was 1.97 kWh. Nonetheless, this was not the lowest amount of energy used in a single shot. Setting number 15 uses the minimum amount of energy usage in a single shot. In this setting the injection speed was 150 mm/s and the holding pressure was 215 MPa. The amount of energy used was 1.87 kWh. This was 0.06 kWh less than the standard setting.

The map proves that each of the settings did give a different amount of energy usage. This map was useful to the technician in determining most suitable machine setting to reduce amount of electrical energy in each process for injection molding operation. Reduction in electrical energy usage would not only reduce the cost of manufacturing plastics product, it also helps to support sustainable manufacturing in injection molding industries.

Reduction of electrical energy might not be so significant for a single shot. Nonetheless, the amount of energy savings would increase as the number of shot increases. Simulating the amount electrical energy reduction through undergo 1000 shots using these particular machine results in reduction of 3.1 % or 51 kWh as showed in Figure 4.6 as follow. The reduction only refers to one machine in one same operation. The reduction would be more significant if there was more than one machine used to produce the plastic product.

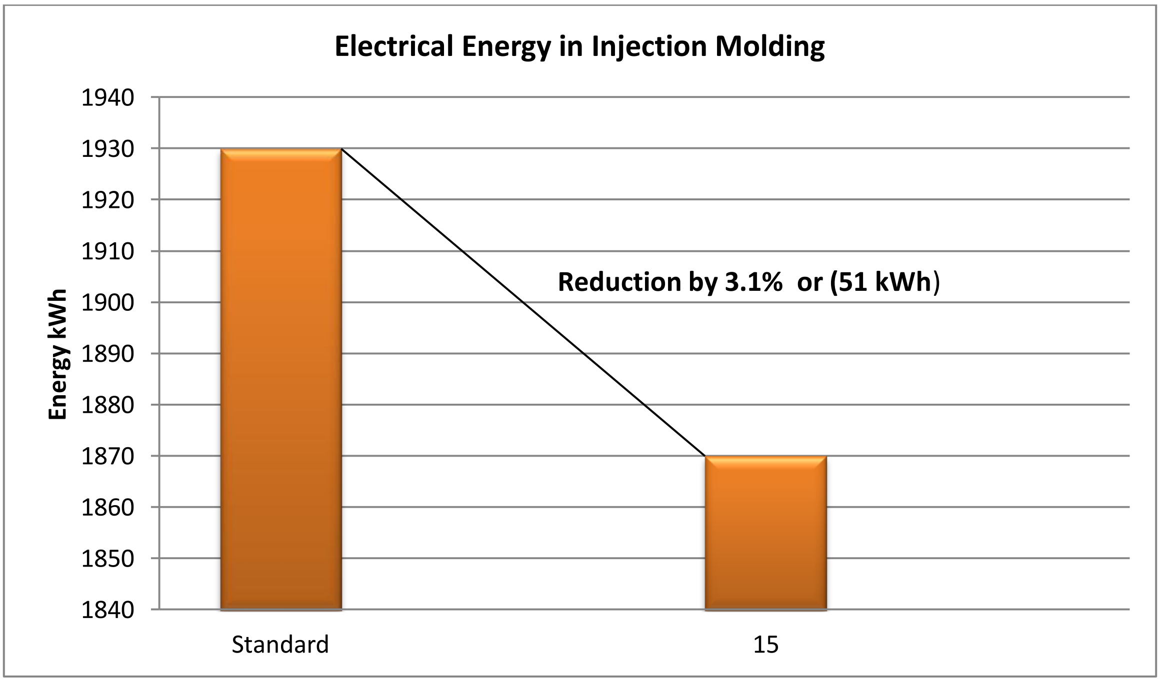


Figure 4.6 *Electrical Energy Usages for 1000 Shots*

In summary, by using electrical energy map, could educate machine operator or technician about the amount of electrical energy used in their daily operation. This map could help them to identify the best machine parameter to reduce the electrical energy consumption. Reduction of cost in manufacturing would give a positive impact to their customers who always seeking for a cheaper and greener product in their daily life.

Furthermore, through reduced in electrical energy would eventually decrease the amount of carbon emission emitted during producing plastic product. Any reduction of carbon emission supports the sustainable development. As being mentioned earlier in previous section, one of the pillars in sustainable manufacturing is the environmental factor. Industries that reduce the amount of carbon emissions would help the environment and hence, supports sustainable manufacturing process. This further helps the sustainable development agenda.

4.4 Optimization Parameter Setting

In this part, optimization parameter setting would be determined after data was collected and analysed through Taguchi method. During optimization process, selection of the injection molding parameters and their levels should be done. The feasible space for molding parameter was defined by varying the holding pressure in the range 100.7 - 111.3 Mpa, the injection pressure in the range 109.30 - 120.80 Mpa, the injection speed in the range 24.2 - 26.8 Mpa, the mold open and close speed in the range 30 – 45%, and the screw rotation in the range 30 – 50 rpm. Most of these ranges were selected based on the data available in the literature, machine technical data, and plastics injection molding handbooks. There were five parameters identified to control the injection process has been selected as shown in Table 4.1.

Table 4.1 *Injection Molding Parameter and Their Levels*

Factor	**Setting Parameter**	**Level 1**	**Level 2**	**Level 3**
A	**Holding Pressure [Mpa]**	100.7	106.0	111.3
B	**Maximum Injection Pressure [Mpa]**	109.3	115.0	120.8
C	**Injection Speed [mm/sec]**	24.2	25.5	26.8
D	**Mold Open and Close Speed (%)**	30%	40%	45%
E	**Screw Rotation (Plasticizing) [rpm]**	30	40	50

After selecting of the injection molding parameter, next step was selection of an appropriate orthogonal array (OA). Therefore, an L_{18} (5^3) orthogonal array with five columns, three levels and eighteen rows was used in this research. The experimental layout for the injection molding parameters using the L_{18} OA was shown in Table 4.2. Each row of this table represents an experiment with different combination of parameters and their levels.

Table 4.2 *Experimental Plan Using L_{18} Orthogonal Array*

Orthogonal Array L_{18} (5^3)

Trial No.	Control Factors A	B	C	D	E
1	H1	P1	I1	M1	S1
2	H1	P1	I3	M2	S3
3	H1	P2	I1	M3	S3
4	H1	P2	I2	M1	S2
5	H1	P3	I2	M2	S1
6	H1	P3	I3	M3	S2
7	H2	P1	I2	M2	S2
8	H2	P1	I3	M3	S1
9	H2	P2	I1	M2	S1
10	H2	P2	I3	M1	S3
11	H2	P3	I1	M1	S2
12	H2	P3	I2	M3	S3
13	H3	P1	I1	M3	S2
14	H3	P1	I2	M1	S3
15	H3	P2	I2	M3	S1
16	H3	P2	I3	M2	S2
17	H3	P3	I1	M2	S3
18	H3	P3	I3	M1	S1

According to Taguchi experimental design, the results for total electrical energy consumption based on distinct combination parameters and levels in OA were presented in Table 4.3. Therefore, S/N (signal-to-noise) ratio was used to measure quality characteristic deviating from the desired value. Data points were analysed using the “smaller-the-better approach” due to this research was focused on minimize energy in injection molding process within optimal process parameters. The S/N ratio was calculated using Equations 1 and MSD using Equation 2. MSD was the mean square deviation, y represents the value of energy and n was the number of tests in one trial.

Equation 1: S/N ratio, $\eta = -10 \log (MSD)$

Equation 2: $MSD = \frac{1}{n}\sum_{i=1}^{n} y_i^2$

Table 4.3 *Experimental Results for Total Energy and S/N Ratio*

Run	**Energy [Kwh]**			**Mean**	**MSD**	**S/N Ratio**
	1	**2**	**3**			
1	0.00615	0.00777	0.00663	0.00685	0.00004738	43.24405
2	0.00638	0.00646	0.00584	0.00623	0.00003885	44.10609
3	0.01150	0.01482	0.00733	0.01122	0.00013520	38.69023
4	0.00510	0.00509	0.00682	0.00567	0.00003281	44.83994
5	0.00290	0.00507	0.00422	0.00406	0.00001731	47.61703
6	0.00768	0.00910	0.00833	0.00837	0.00007039	41.52449
7	0.03011	0.03015	0.03001	0.03009	0.00090541	30.43155
8	0.03050	0.03073	0.03253	0.03125	0.00097759	30.09843
9	0.04232	0.04300	0.04034	0.04189	0.00175577	27.55532
10	0.02947	0.02861	0.02803	0.02870	0.00082423	30.83952
11	0.03605	0.03586	0.03801	0.03664	0.00134343	28.71785
12	0.04105	0.04436	0.04524	0.04355	0.00189986	27.21278
13	0.03118	0.03257	0.03388	0.03254	0.00106028	29.74579
14	0.04558	0.04451	0.04326	0.04445	0.00197670	27.04059
15	0.03142	0.03058	0.03056	0.03085	0.00095209	30.21322
16	0.04025	0.04323	0.04416	0.04255	0.00181300	27.41602
17	0.04064	0.03728	0.03077	0.03623	0.00132940	28.76344
18	0.03268	0.03200	0.03055	0.03174	0.00100843	29.96354

Meanwhile, to calculate mean S/N ratio for example holding pressure at levels 1, 2 and 3 could be calculated by averaging the S/N ratios for the experiments 1–6, 7–12 and 13–18, respectively. The mean S/N ratio for each level of the other parameters could be computed in the similar manner. It was summarized and called the S/N response table for total energy and constructed in Table 4.4.

Table 4.4 *Response Table for Signal to Noise Ratio*

Level	**Mean S/N Ratio**			**Delta**	**Rank**
	1	2	3		
A	43.33697	29.14258	28.85710	14.47987	1
B	34.11108	33.25904	33.96652	0.85204	5
C	32.78611	34.55919	33.99135	1.77308	3
D	34.10758	34.31491	32.91416	1.40075	4
E	34.78193	33.77927	32.77544	2.00649	2

Based on the response table of S/N ratio at Table 4.4, S/N ratio response graphs for energy could be seen in Figure 4.7 as follow. Through this figure, it could be easily to identify the optimal parameters to minimize energy. Selecting the highest value among each point could identify these optimization levels.

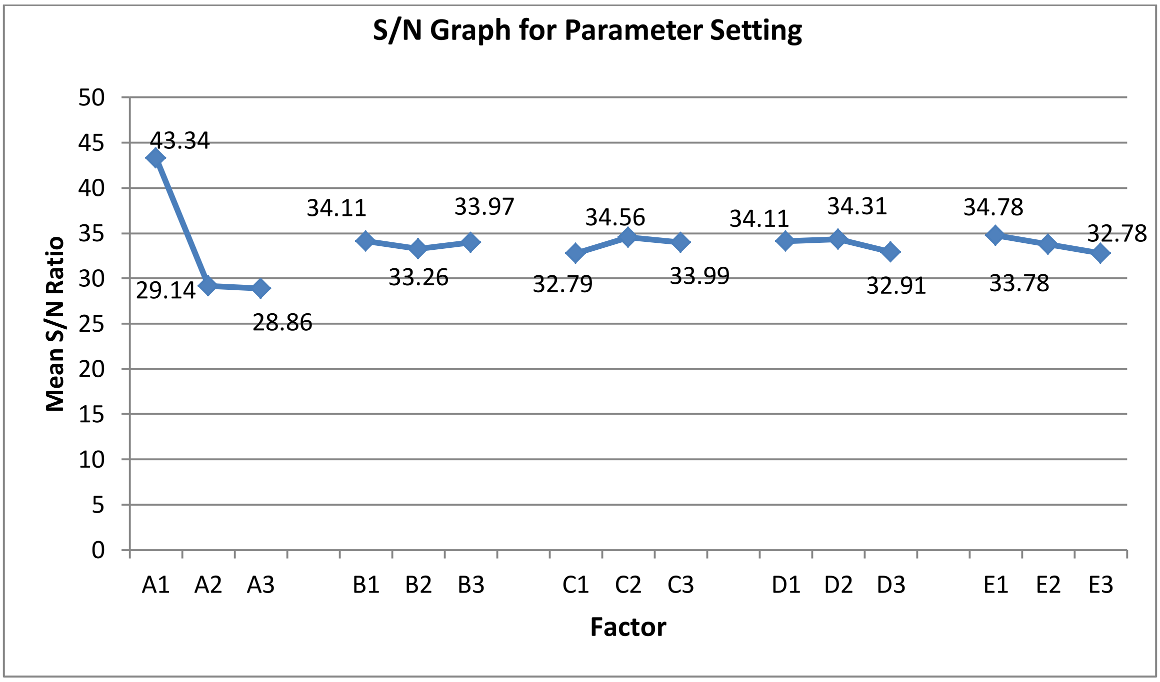


Figure 4.7 *Response Graph of S/N Ratio*

Next, based on Table 4.5 below the optimum setting for this research was presented. The highest data was belonging to holding pressure. It clearly could be concluded that holding pressure was the most significant parameter that affect the value of energy.

Table 4.5 *Optimum Setting Table*

S/N	**A(1)**	**B(1)**	**C(2)**	**D(2)**	**E(1)**
Rank	1	5	3	4	2

Hence as a conclusion, optimum setting result was produced by a combination of A1, B1, C2, D2 and E1 and there were holding pressure 100.7 Mpa, injection pressure 109.3 Mpa, injection speed 25.5 mm/sec, mold open / close speed 40% and screw rotation speed 30 rpm that presented in Table 4.6. With that, to reduce energy consumption in injection molding processes, this recommended parameter setting was significant to implement.

Table 4.6 *Recommended Setting*

Factor	Recommended Setting
Holding Pressure (A)	100.7 Mpa
Maximum Injection Pressure (B)	109.3Mpa
Injection Speed (C)	25.5mm/sec
Mold Open / Close Speed (D)	40 %
Screw Rotation Speed (E)	30 rpm

4.5 Discussion

In this research, the result of distribution electrical energy consumption clearly showed that plasticizing operation consumed most of electrical energy in injection molding processes. Even though, the high clamp uses the highest amount of current compared to other operations but, the high current does not mean that operation consumed highest amount of energy. In this operation, high clamp uses 8A of current compared to other operation which uses below 8A of current. Nonetheless, after calculation using energy equation the actual energy usage for each operation can be identified. Therefore, plasticizing proved that uses the highest amount of energy. This is because, electrical energy is the product of power and time to do operation and they are interrelated with each other. Hence, since shortest time taken for high clamp is used with highest amount of current, it results in low amount of electrical energy. Meanwhile, plasticizing uses low amount of current with longest time taken and it results in high amount of energy usage. Thus, plasticizing operation should be optimized so that the time taken is reduced and onwards will reduce electrical energy consumption.

In developing an energy map, different parameter setting affect towards amount of energy consumption in injection molding. Adequate knowledge of injection molding technology is necessary to perform parameter setting. Generally, there are no right or wrong on how parameter setting is made among expert molding as long as the final product meets the requirements given. From this energy map, it can be utilized as a guideline by the technician in order to determine amount energy usage for each different setting parameter in injection molding. Besides that, they can identify the best machine parameter to reduce the electrical energy consumption through assistance energy map.

To accomplish optimization, the selection suitable parameter setting plays a main role to optimize parameter. Besides that, selection suitable range also needed give attention between each level to grant more effect during conducting operation. By this, it will ensure manufacturers to start production with a better starting setting and furthermore can reduce time consume, carbon emission during production, manufacturing cost and further to achieve sustainability manufacturing.

According to the experiment results, Taguchi approach and signal-to-noise ratio are not only reduced the amount of energy used during operation but also enhances the stability of the entire injection molding process.

Meanwhile, the experimental results support Taguchi experimental method and signal-to-noise ratio are feasible and effective for process parameter optimization in plastic injection molding and can assist the manufacturing industry in achieving competitive advantages on greener product and low cost production.

CHAPTER FIVE

CONCLUSION

5.1 Introduction

This chapter provides summary of the results, and conclusion of the research. The general aim of this research was to have a better understanding the impact of using high electrical energy consumption by the manufacturing industries especially in plastic injection molding companies. The chapter starts with a recapitulation of the research followed by a section on the summary of the results. Next section is included limitation of doing this research and followed by suggestion for future research. Subsequently, the conclusion is then covered in last section, which summarizes the whole chapter.

5.2 Recapitulation of the Study

This research approached the subject of highest electrical energy consumption in plastic injection molding industries through optimize parameter setting for achieving sustainable manufacturing. Taguchi experimental method was used to design an experiment to investigate how different parameters affect the requirements in product development. The data collected to investigate distribution of energy consumption in injection molding processes, develop energy map and onward to optimize parameter setting that selected. Thereafter, an analysis of data was presented each one by one to determine best parameter setting to optimize the objectives and it requirements. To recap, the study research questions were as stated below:

a) How the electrical energy is distributed through each of process in injection molding?
b) What is the effect of different parameter setting towards electrical energy consumption?
c) What is the best of suitable parameter setting towards optimizing electrical energy consumption in plastic injection molding process?

5.3 Summary of Results

Based on this research, the following conclusion can be drawn:

First and foremost, this research found that the current for each process of injection molding machine has different electrical energy consumption. And, also the time taken was different depends on during each operation. In distribution of electrical energy consumption, showed that to calculate power and total energy must use appropriate equation to get the value. In this part, high clamp indicates the highest amount of current usage compared with other processes. Nonetheless, after doing calculation of equation energy it showed that plasticizing process consumed the highest amount of electrical energy consumption compare to other eight processes in injection molding process. Thus, the highest electrical energy usage in the injection molding process was plasticizing based on calculating the equation energy.

Secondly, in developing energy map, this research found that the various parameter setting could influence different amount of electrical energy consumption in injection molding process. This electrical energy was calculated using equation total energy. In this part, there are 20 setting were varied according to injection speed and holding pressure for the single shoot. Standard parameter was used as references to determine ups and downs of energy consumption for each setting. Then, map was developed to prove the different setting parameter give different amount of energy usage. From the map, maximum energy usage was settings 20 which use 2.41 kWh meanwhile minimum energy usage was settings 15 which use 1.87 kWh. And, standard parameter setting only uses 1.93 kWh.

Thirdly, to accomplish optimization there were several steps need to be done to find the significant parameter setting. The first was selection of the injection molding parameters and their levels. There were five parameter would be selected in which holding pressure, injection pressure, injection speed, mold open and close speed and screw rotation based on their range. Afterward, the selection of an appropriate orthogonal array (OA) L_{18} (5^3) was used in this research. After results for total electrical energy consumption based on distinct combination parameters and levels in OA are visualized, S/N (signal-to-noise) ratio was used to measure by using formula. The graph would be plotted based on mean S/N ratio each parameter. With that, the highest energy would be determined and holding pressure uses a lot of energy during operation. Hence, optimum setting result was produced by a combination of A1, B1, C2, D2 and E1.

5.4 Limitation of Study

This research has a several limitation. The first limitation is secondary data that used for analysing. In this research, secondary data was used from experiment which conducted by technician. The result of the experiment implemented, data have been collected and utilized to do analysis for this research. Besides that, the researcher is not exposed with injection molding machines as well as in processing carried out to produce plastic products during performing this research.

The second limitation in this research is time constraint. The duration to do this research is beginning in February and has to complete for submission in May. The researcher needs to learn a new things and this will take a lot of time to review previous research and other related things such as formula to do calculations.

5.5 Suggestions for Future Research

This research can be further extended by using type of materials such as Polycarbonate / Acrylonitrile Butadiene Styrene (PC/ABS) thermoplastic as well as machines like hydraulic and hybrid that used in injection molding. With this, the result of electrical energy consumption in injection molding process indeed different. Hence, the methods to optimize parameter also totally distinct.

Other than that, some other methods such as artificial bee colony (ABC) algorithm and artificial neural networks (ANN) also can be used to optimize the process parameters in injection molding. Hence, these methods can be compared through performance among Taguchi Method so that can choose which one is the best.

5.6 Conclusion

This research reveals the significant impact of the electrical energy consumption in injection molding processes towards sustainability manufacturing. Hence, by using Taguchi Method and Signal-To-Noise Ratio we can find the optimum level parameter of process in injection molding machine. So, it can be stated that Taguchi method and signal-to-noise ratio are powerful tool for reducing electrical energy consumption in the plastic injection molding. Through optimum process parameter we can achieve lower electrical energy in production process.

Reduction of electrical energy usage during producing plastic product automatically will reduce demand in generating electricity. Through reduction of energy consumption it will definitely reduce the carbon emission when production occurs. Hence, this supports the environmental pillars in sustainable development. For the industries, reduction of electrical energy consumption will lead to reduction of production cost. This reduction in cost can benefit the industries and also their customers. This supports economical pillars in sustainable development. The last pillar in sustainable development is the social factors. The reduction of electrical energy will reduce the irreversible impact towards the environment. This will sustain our world for future generation.

As a conclusion, this research can help to support sustainable development in manufacturing especially in plastic industries. The understanding of energy consumption characteristic of the molding machine can assist industries to optimized machine parameters and reduce electrical energy consumption.

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