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A Conceptual Paper on Application of Energy Efficiency Measures for Reducing Carbon Footprint in Zinc Phosphate Coating Process of Automotive Industries

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Abstract. Automotive manufacturing consumes a huge amount of energy to operate its production lines. Several processes involve including zinc phosphate coating process, which is a process that commonly used in automotive industries to improve the corrosion resistance of the metal. The process required plenty of hot water supplied by the boiler. Liquefied petroleum gas (LPG) is used to boil the water to produce thermal energy for the process. Although the LPG is crucial in the production of thermal energy but its release by-products such as carbon dioxide and other carbon compounds emitted during the coating process due to the burning of the fossil fuel. The by-products contribute to global warming issues and produce waste to the environment. This research is present to design the energy efficiency best practices on the reduction of carbon footprint in automotive industries. A status quo to be referred to as baseline is determined, i.e. energy consumption and wastage by assessing the thermal requirement of the said manufacturing process. The data obtained is analysed to identify the best measures of energy efficiency. The thermal assessment method is used for data analysis to determine the potential saving of fossil fuels. Besides, pinch analysis assist in the determination of the process optimisation and system optimisation which lead to the reduction of operational cost and wastes as well as efficiently applying the heat during the coating process. Hence, the decreases in energy consumption reduce dependency on fossil fuels and wastes. Eventually, the application of best practices of energy-efficient measures diminishes the carbon footprint for the coating process in automotive industries.

1. Introduction

In this 21st century, the growth of the automotive industry is considered as 'industry of industries' which potentially drive the industrialisation ahead due to its linkage and spilt-over effects on other manufacturing industries. The automotive industry is an organisation involved in design, manufacturing, development, marketing and selling of motor vehicles. The automotive manufacturing process involved chassis production unit, coating process, surface finish centre, pre-assembly and the final assembly line. Coating process plays a significant role in the manufacturing process such as zinc phosphate coating, as it is widely used for corrosion resistance, the primer for painting and decoration. In the coating process, steam boiler is commonly used to supply hot water which requires a large amount of fossil fuel to heat the water before transferring to the other stages. Therefore, boiler consumes high energy, commonly fossil fuels such as liquefied petroleum gas (LPG) to provide thermal energy. However, burning fossils fuels caused a tremendous amount of carbon dioxide

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emissions [1] as well as other by-products to the environment. By improving energy efficiency, which is the critical components of sustainability may reduce the energy consumption of the manufacturing process [2]. Therefore, the determination of the best measure of energy efficiency that aims to reduce the burning of fossil fuels should be the primary concern.

In this research, the energy consumption of the zinc phosphate coating process is studied based on the manufacturing process flow of the automotive industry, i.e. motorcycle manufacturer located at Penang, Malaysia. The research focuses on the reduction of fuel usage and optimising energy consumption in zinc phosphate coating process by applying energy efficiency measures. The ultimate objective is to reduce the carbon footprint. The parameters under study are temperature, pressure and flow rate to set the current status, i.e. baseline of the process. By evaluating the process flow, stream list and Sankey diagram are established. Then, pinch analysis assists in the determination of the process and system optimisation. The best practices energy efficiency measures are recommended to the stages that have the potential for energy saving. The conceptual of energy recovery is verified by three analysis methods which are economics, energy and environmental analysis.

1.1. Problem statement

The automotive industry nowadays is highly desired by many countries due to its contribution toward economic growth, job creation, and technology development [3]. However, a new challenge is faced by the industries in this current environmental era, i.e. global warming and climate change. In Malaysia, the primary cause of greenhouse gas (GHG) emissions in manufacturing firms can be traced to three sources which are electricity consumption, the direct combustion of fuels in the manufacturing process and the fuel consumed in logistical activities [4]. Hence, the automotive industry faces immense pressures in the environmental arena [5]. In the automotive industry, zinc phosphate coating process is one of the processes that commonly used for corrosion protection, the primer for painting and decoration due to low processing cost [6]. The process required thermal energy which provided by heating the water or air in a boiler through the burning of fossil fuels, i.e. LPG [7] to the required temperature for each stage in the process. Even though LPG provides high thermal energy, but it’s polluting the environment as well [8]. Hence, the zinc phosphate coating process indirectly causes environmental issues significantly compared to other stages of vehicle manufacturing [9].

2. Literature Review

Climate changes are driven by human activities such as the burning of fossil fuels in the industry sector, in particular, the production of greenhouse gas emissions that directly impact on environment. In Malaysia, industrial sectors in one of the contributors of carbon dioxide emission. According to statistics from Asian Pacific Energy Center (APEC), the outlook period for carbon dioxide emission from energy consumers in Malaysia is projected to grow about 4.2% annually reaching 414 million tons of carbon dioxide in 2030 [4]. Hence, the industrial sector, like the automotive industry, should aware of the need to address environmental issues in their products and processes.

The automotive industry is defined as the manufacture of motor vehicles, including most components, such as engines and bodies but excluding tires, fuels and batteries [10]. In this era, automotive industries are facing many challenges due to the recent significant increase in overall vehicle production with a rise in energy cost and environmental responsibilities [11]. The manufacturing process of the automotive industry is complex and intense, and it consumes a large number of raw materials as well as utilities, i.e. water and electricity [11]. Besides, the automotive industries responsible for more than one-third of worldwide primary energy use because they rely heavily on energy in its processes [12]. Therefore, an evolution of the manufacturing process in the automotive industry is required to move towards low-carbon emissions and increased sustainability of the process [11] which due to many thermal processes in the automotive industry such as zinc phosphate coating which required burning of fossil fuels to produce thermal energy.

2.1. Zinc Phosphate Coating Process
Zinc phosphate coating is one of the critical processes in the automotive industry. It is generally used for the purposes of corrosion protection, the primer for painting, metal forming lubricants, wear reduction, electrical insulation and even decoration. In this process, many parameters influence the thickness, morphology, protective properties and chemical composition of the coating [13]. For instance, if the temperature of the solution is low, the heat is insufficient for phosphating reaction and reduces the coverage rate of the surface [14]. Therefore, a massive amount of thermal energy is required by the process which conventionally supplies by the steam boiler.

2.2. Thermal Energy and its effect on Environment
In a thermal process that comprises of the heat exchanger to provide required temperature for the manufacturing process, the first law of thermodynamic is typically used to measure the efficiency of energy utilisation by a boiler in actual operation [15]. Moreover, heat power is calculated using the first law of thermodynamic for control volume as well as obtains the energy consumption for the manufacturing process. The basic parameters, i.e. pressure, temperature, and volume, are identified as an input to assist in the determination of optimisation measures by the process. Besides, the Hagen-Poiseuille equation is used to ascertain the flow rate of fluid in the piping system.

Energy consumption is defined as the amount of energy consumed in a process or system. In the automotive industry, around 70% of thermal energy of all automotive industry's total energy consumption is required due to the manufacturing process required thermal energy in the form of steam, hot air or water [16]. Therefore, the reduction of energy consumption is very vital because it can minimise the environmental issues caused by the manufacturing process [12] in which as the energy consumption decreases, less carbon dioxide emissions due to lesser burning of fossil fuels to generate the required heat in the manufacturing process. Ultimately, environmental issues such as global warming effect and greenhouse gases emissions will be lessened.

A recent report, Carbon Risks and Opportunities in the S&P 500, commissioned by the Investor Responsibility Research Center Institute for Corporate Responsibility (IRRCi), found that more than 80% of companies of automotive faced carbon risks resulting from emissions in their supply chain [17]. The burning of fuels released carbon dioxide, which then, absorbed partly by the world's oceans resulting in acidification of those oceans, which leads to ecological and biological changes. Continuously increasing concentration of atmospheric leads to global warming and climate change [1]. Hence, assessing carbon dioxide emissions in the automotive industry using carbon footprint measurement is recommended. Assessing the carbon footprint in the manufacturing process perhaps provides a better understanding, quantify and rigorously analyse the impact of carbon emissions in the manufacturing process [18].

2.3. Efficient Management of Energy
Energy management is the strategy or method of meeting energy demand when and where it is needed. Energy management contributes to the monitoring and controlling of energy and has become a concerning issue recently [19]. Nowadays, the role of energy management is crucial in minimising energy costs and wastes without affecting production and quality as well as to reduce the environmental effects. In the automotive industry, energy management is a central strategy to leverage the present excess heat for the realisation of an efficient manufacturing process [11]. Hence, the waste can be minimised, and the energy consumption can be reduced once the energy is optimised by effective and efficient energy management in the process and production lines. Energy management is positively related to energy efficiency [20]. Therefore, energy efficiency is vital in the manufacturing process of the automotive industry and considered as one of the critical components of sustainability [2]. The reduction in energy consumption by improving the energy efficiency of a system can be achieved by using energy efficiency evaluation which is an effective management strategy [21]. The energy efficiency becomes a driver for the manufacturing industry as it is one of the most significant consumers and carbon emitters in the world [22]. The possible strategies are explored for energy

consumption reduction in the processes, a systematic overview of energy consumption classification and prediction methods for different levels of energy consumption have conducted to investigate methods could be used for energy efficiency evaluation in the processes [21]. The methods such as thermal insulation and heat recovery are commonly applied as a solution for the EE measures.

Thermal insulation is defined as the decrease of heat transfer from the surface of the materials [22]. By improving the insulation of the steam piping and steam boilers, potential savings of 6% to 26% can be achieved [23]. Heat recovery is known as the high temperature is used for one purpose or the waste heat from one process step applied to another process step [24]. The heat recovery in industrial processes has been one of the significant areas of research to reduce fuel consumption, lower harmful emissions and improve production efficiency [25]. The waste heat can be recovered through various waste heat technologies to provide valuable energy sources and significantly reduce energy consumption. There are several types of heat recovery technologies, such as heat exchanger and heat pumps. A heat exchanger is an equipment used for the transfer of heat between two or more fluids at different temperatures [26]. In the manufacturing process, the heat exchanger is installed to preheat the feedwater, so that it can reduce the steam boiler fuel requirements. Two types of heat exchangers can be used to recover heat from boiler exhaust which is gas-gas heat exchanger and gas-liquid heat exchanger [23]. Heat pumps are commonly used to change the energy from a low-temperature level to high-temperature level. It has been used to good effect for waste heat recovery, which creates a temperature lift in the heat source. An excess of 40ºC of temperature lifts can be achieved by using the heat pump. Commonly, two types of heat pump mostly use in the industry, which is an open-cycle heat pump and closed-cycle vapour compression heat pump can be considered for this purpose. However, a thorough study is recommended before opting for the heat pump since the overall efficiency of energy recovery is decreased due to the energy consumption of the heat pump [27].

System optimisation is defined as a methodology, act or process of obtaining entirely perfect, effective and best result to a system [28]. A methodology such as energy efficiency can optimise the system to reduce energy consumption and energy waste. Process optimisation is a popular tool by operating complex processes technically to achieve the best improvement and asset utilisation [29]. Process optimisation can find the optimal parameters for multiple machines and adjust them simultaneously to minimise energy consumption. In the manufacturing process, energy efficiency can be through integrating process optimisation with energy efficiency scheduling [30]. Therefore, the manufacturing process in the automotive industry can be optimised by applying the best practices of energy efficiency.

3. Methodology

The baseline, i.e. current state of the energy usage for the process is determined by analysing the utility bills and existing energy consumption of the target process. Then, the flow sheet is drawn based on the process flow of the zinc phosphate coating section in an automotive factory, complete with essential information collected upon a site visit. The flow sheet of zinc phosphate coating process is in the form of a block diagram. A block diagram is the simplest form of presentation of the overall process. It provides an overview of the process involved. Each block can represent a single piece of equipment or a complete stage in a process. The numbers in the flow sheet indicate the stream number for each flow in the stream list.

The data of zinc phosphate coating process, which is flow rate, humidity, temperature and pressure are recorded for a specified period. Data logger and measuring instruments such as environmental meter, flow meter, thermometer gun and a digital pressure gauge are used to obtain the required data of the process. The flow rate, which measured in kg/s, of fluid in the zinc phosphate coating process, is collected by using a digital ultrasonic flow meter. The temperature of the fluid in the zinc phosphate coating process is collected by using a thermometer gun. The unit of the temperature is Celsius, ºC.

Stream no	1	2	3	4	5	6	7	8	9	10
	Predegreasing 1					Predegreasing 2				Water Rinse 1
	Frame body in	Hot water supply from Hex 1	Hot water return to Hex 1	Make-Up Water Supply	Frame body in	Hot water supply from Hex 2	Hot water return to Hex 2	Make-Up Water Supply	Frame body in	Make-Up Water Supply
Water, kg/h										
Air, kg/h										
LPG, kg/h										
Stack kg/h										
Temp, °C										
S/L/G										
cp, kJ/kg°C										
Enthalpy, kW										

Figure 1. A stream list of a process.

A stream list as shown in Figure 1 is evaluated which consists of temperature (ºC), mass flow (kg/s), heat capacity (kJ/kg°C), enthalpy (kW), energy (kW) and operating hour (h) for each stage in the zinc phosphate coating process. The stream list is generated in a table form. The recorded data such as temperature, mass flow, humidity, pressure and operating hour categorised as raw data is input to the stream list, then, enthalpy and energy consumption is calculated by using the equations.
The formula of the energy consumption is

- Energy [kWh] = Q (kW) * Operating hour (h).

The equation of enthalpy is

- Enthalpy, Q [kW] = $m * q$ [kW] where m = mass flow, q = specific heat capacity, c * temperature change, ΔT.

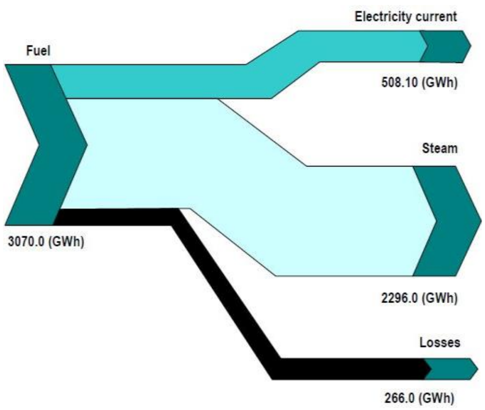

Figure 2. A typical Sankey diagram.

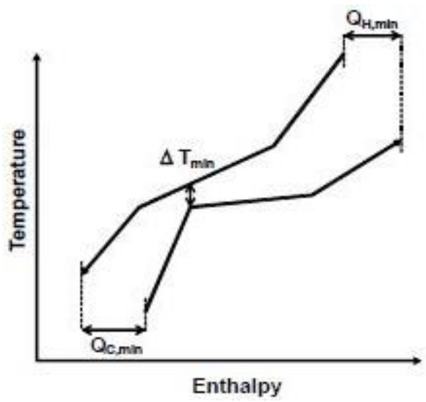

Figure 3. Pinch analysis uses the hot and cold composite curve to determine the energy targets.

The result of the stream list will be the input for Sankey diagram, which is a flow diagram in which the width of the arrows proportional to the flow quantity. The Sankey diagram represents the flows such as energy consumption in a process system or between processes. The Sankey diagram is an essential aid in identifying inefficiencies and potential for savings when dealing with resources [31]. The energy calculated in the stream list is used to generate the Sankey diagram of zinc phosphate coating process. The Sankey diagram is generated by using SankeyMATIC software. Therefore, the different use of energy and energy sources can be identified.

Pinch analysis is a method for reducing the energy consumption in a process by calculating thermodynamically feasible energy targets and achieving them by optimising heat recovery systems, applying energy efficiency and process operating conditions. Besides, pinch analysis which developed by Bodo Linnhoff in 1977 is required to identify energy target and determines the minimum driving force across any of the heat exchanger's inlet/outlet streams [32]. Pinch analysis can identify the potential to apply heat recovery to the process. The result of pinch analysis will be used to determine the specification of heat exchanger fit for heat recovery purposes.

3.1. Verification of Baseline and Proposed EE Measures

Three analyses which are economics, energy and environmental analysis is carried out to compare with the baseline and verify the finding which is recommended practical measures of energy efficiency that feasible to be integrated into the zinc phosphate coating process. Firstly, an economic analysis is carried out to test the method of energy efficiency suggested. The analysis is all about analysing the economic aspects of the recommended measures. It is used to verify that the method is operating effectively and profitable. The total investment of heat recovery in zinc phosphate coating process, annual maintenance cost and other costs are calculated. Then, the pay-back period is calculated to verify that profit is making. Besides, it is also compared to the previous electricity bill with the current electricity bill after the applications of energy efficiency. The energy analysis is used to analyse the process which the energy consumption after the energy efficiency is applied. The energy consumption of zinc phosphate is calculated after the technique or method of energy efficiency is applied. The thermal energy generated is also calculated after the heat recovery technique applied. An environmental analysis is carried out to the method of energy efficiency suggested. It used to analyse the process, whether it bring impacts to the environment. The carbon footprint is calculated after the technique or method of energy efficiency is applied.

4. Conclusion and Recommendation

In the automotive industry, zinc phosphate coating process plays an essential role in the manufacturing processes; however, it caused GHG, i.e. carbon dioxide emissions to the environment. Conventionally, the majority of manufacturers burnt of a large amount of fossil fuel to heat the fluid, i.e. gas or water in the steam boiler to provide thermal energy for the process. Therefore, finding the best measures of effective and efficient energy efficiency to minimise the fuel consumption in the automotive industry and those measures are feasible to be applied is the primary concern. By using the thermal assessment to analyse the data from the existing state, the status quo can be determined. The status quo is evaluated, which include of stream list of the process, Sankey diagram and pinch analysis. The result iswill be used as the input to determine the practical method feasible for the process, i.e. zinc phosphate coating. The application of energy efficiency is significant to the automotive industry in reducing energy consumption and energy waste as well as optimising the process and system.

Hence, the emission of carbon dioxide can be reduced because of the reduction of burning fossil fuels. The economic, energy and environmental analysis are carried out for this research to counter check the measures. Theses analyses are vital because it helps to determine how feasible the measures in term of economy, energy and environmental performance. Hence, the application of the proposed energy efficiency measures s not only reduce the operation cost and time, but increasing productivity as well as promotes a pleasant environment due to the carbon footprint is reduced.

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