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ENERGY CONSUMPTION IN MANUFACTURING SYSTEMS

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Abstract: Green manufacturing represents a paradigm shift towards sustainable production processes that minimize environmental impact by reducing energy consumption and conserving natural resources. This paper explores green manufacturing strategies, focusing on the adoption of energy-efficient technologies, the use of recycled materials, and the redesign of manufacturing processes to minimize waste and emissions. The research highlights the importance of energy reduction at multiple system levels—process, equipment, facility, and supply chain—demonstrating how dynamic scheduling and modern technologies can lead to significant energy savings. The study emphasizes the growing need for industries to adopt green manufacturing practices as a response to global warming and environmental degradation, while also recognizing the financial benefits of reduced energy consumption. The integration of environmentally friendly designs, sustainable materials, and optimized energy usage throughout the manufacturing process is presented as crucial to achieving both economic and environmental sustainability in the manufacturing sector.
Keywords: Energy Consumption; Green Manufacturing; Sustainable Production; Global Warming; Environmental Degradation

1 INTRODUCTION

Green manufacturing refers to the sustainable production of goods using processes that are environmentally friendly and energy-efficient, ensuring minimal waste of natural resources [1]. Irani and Gupta [2] describe green manufacturing as a paradigm that employs systems and techniques that are both eco-friendly and cost-effective. The increasing awareness of environmental risks, particularly those associated with global warming, has driven the adoption of green manufacturing practices. These practices emphasize reducing energy consumption, recycling materials, and minimizing unwanted outputs [3].

The main emphasis in green manufacturing is the adoption of manufacturing processes that lower the consumption of energy. To achieve the concept of green manufacturing, the manufacturers normally result to use of recycled materials, change in the design of factory, designing processes and use of equipment that do minimise the consumption of energy [4]. The green manufacturing is a multi-dimensional concept that is not limited to the use of environmental designs products only but also encompasses the use of raw materials that are environmentally friendly, application of distribution systems that are environmentally friendly and the reuse of the products after they have served their course. This paper main focus is on the reduction in energy consumption in the different system levels of manufacturing using scheduling system.

Manufacturing processes normally consume a lot of energy, the energy intensiveness of the manufacturing processes in either industry has been found to be high [5]. In the advent of the sustainable manufacturing processes, there is need for adoption of energy saving manufacturing processes. According to Jawahir[1] recycling of products reduces the energy consumption as the energy that could have been used to prepare new raw materials is significantly reduced. Manufacturers all over the world normally produce heat and operate machineries using different types of energy. The commonly used sources of energy include electricity, natural gas and other forms of fossil fuel. In the usage of these sources of energy, Green manufacturing endeavours to create product systems that consume less material and reduce unwanted outputs in order to reduce the high energy usage [7].

In the developed countries the industrial emissions resulting from fossil fuels use have been blamed to be responsible for the greatest contributing of greenhouse effect. For instance, in the USA the industrial energy use contribute to 30% of the greenhouse gas emission in the country and which has been a major contributor to the climatic change [8]. An example of the gas emitted by the energy intense industries includes the carbon dioxide which has the highest prevalence among the greenhouse gases. The increasing concentrations of C02 in the atmosphere causes a great threat to environment, there is thus the need for industries to adopt sustainable manufacturing processes that reduce emission of the carbon fuels.

In 2030, the energy demand is predicted to have risen by 45%, this energy will be greatly required to power machines, electricity is one of the energy sources that the demand is predicted to keep on increasing. The sources of the electricity are mainly carbon based sources.

2 MOTIVATION TO REDUCING ENERGY CONSUMPTION

The rising awareness on the effects of global warming has resulted to environmentalists pushing for the measures that ensure environmental sustainability. There is pressure from governments and United Nations to ensure that manufacturers adopt processes that are environmentally friendly. The environmental conservation has thus become the responsibility of each and every person, this underscores the need for green manufacturing [9]. The mandate stems from

the need to use energy that is cost effective, in the 21st century competition has become very stiff and manufactures have to device production processes that are cost effective and can compete favourably in the global market. Therefore, the integration of the technological processes that are energy efficient with the economical mindset of cost cutting makes green manufacturing a reality [10]. The production of same commodity using lesser energy is a way of making extra cash.

Global warming has also been a world challenge; the world is experiencing unpredictable weather patterns and climate changes that have been attributed to the greenhouse effect. The main cause has been pollution and emission of gases mainly from the manufacturing plants and other human activities. Failure to embrace measures to reduce the global warming by being sensitive to the natural environment, the natural resources will end up being wasted and in near future the generation will suffer due to the lack of resources or face harsh conditions such as increased UV radiations due to depletion of ozone layer [11]. The manufacturing industries are thus tasked with being at fore front of adopting environmental sustainable processes [12].

3 ENERGY CONSUMPTION IN MANUFACTURING

The concept of green manufacturing is a relatively new concept that has been used as an option. However, the advent of realisation of the eminent danger of global warming and the financial benefits resulting from green manufacturing has made it a mandate and manufacturers are obligated to use manufacturing processes that are not energy intensive [13]. In the manufacturing process, energy is key to running of the plants and consumption of energy is evident in different levels of the manufacturing process. Evans [14] found that the manufacturing activities are major users of energy in the world accounting for over one-third of the world's usage of energy. It is factual that the world population is on the increase and there is significant rise in living standards which translates to increased demand of manufactured goods. The challenge facing the manufacturing sectors is the energy consumption. As the populations grow, more manufactured products are required and subsequently a lot of energy is used to manufacture the products. Therefore, manufacturing systems and processes that are energy efficient should be incorporated in the production process [15].

There are many researches that have been carried to provide knowledge on the ways energy consumption can be reduced at various levels of manufacturing system. This literature review focuses on the energy consumption reduction in the levels of manufacturing; the main focus will be on the system level and use of dynamic scheduling. Despite of the system level being key in the manufacturing system, there is little research that has been carried on this level of manufacturing. Bearing in mind that the system level cross-cuts the whole manufacturing process, efficiency in the level can lead to significant reduction in the consumption of energy.

3.1 The Process Level

Process level refers to the activities that are undertaken in manufacturing, they include refining, cutting, grinding and milling [16]**.** Energy has been found to be largest operating expense after the raw materials in the process level; there is thus the need to reduce energy consumption at the process level in order to ensure cost effectiveness of the processes. According to [17] modern technologies that reduce the use usage of energy at the process level are key to overall result of realising that manufacturing is energy efficient. Once a plant has been built, the management normally makes decision that relate to the consumption of energy and the related variable cost of production. In order to ensure that there is energy reduction in the process level of manufacturing, modern technologies can be adopted to ensure that systems are operating at levels that ensure maximisation of production and reduce the energy consumed [18]. For instance, the use of computer aided systems to control the processes of manufacturing.

In the comparison of power consumption between manual control of machines and computerised systems, it was found that the computer control systems have reduced the energy consumption with a 1-3% energy saving in the computerised system. The computer control systems that were applied were the multi variable predictive model and the real time technologies for optimisation. These technologies hold the production processes at multiple constraints which enabled carrying out trade-off in the operation process resulting to maximisation of production and subsequent saving of energy.

3.2 The Equipment Level

The equipment level in manufacturing involves the care and maintenance of the equipment that are used in the manufacturing. For efficient energy consumption machines and equipment should be in good condition to avoid energy wastage through leakages and slow output [19]**.** Once a plant has been built, it goes to the processes of operation depending on the decisions that are made and engineers instructions. Just like any other machine, the machines undergo wear and tear and there is thus the necessity of retrofitting the equipment to ensure that the machine remains efficient. It has however been found that the retrofitting is normally limited after the plant is already in operation. The resulting factor is that the systems and equipment end up being not economical in terms of the energy usage. It has been found that the selection and development of better technology leads to better energy utilisation in the process retrofitting.

This method of upgrading of new technologies is commonly referred to as *smart revamp* and has been acclaimed for being cost effective and significantly reduces energy consumption. A leading Asian company dealing with chemical manufacturing was engaged in a retrofit process in one of its aromatic plants. In the retrofit, energy consumption was one of the key factors warranting the move; hence a study was conducted on the energy improvement of the whole aromatic plant. The results of the study showed a 20% percent overall reduction of the energy required in the whole

plant. This study did not focus on the separate unit but on the whole aromatic plant. The study points to positive benefits of the retrofit technologies in ensuring that energy consumption is reduced.

3.3 The System Level

The system level entails design that ensure that energy consumption is reduced through continuous integration of processes through scheduling which ensures energy is not lost in between the processes [20]. Energy efficient designs play a great role in the manufacturing processes and ensuring that cost effectiveness is realised. Green and flexible manufacturing that is geared at reducing energy usage is achieved through the system level which employs the use of hybrid dynamic systems [21]. The hybrid dynamic systems normally have two distinct characteristics in which there is continuous and discrete behaviour in the manufacturing. The discrete behaviour is classic and there is application of constancy in the energy consumption while the dynamic scheduling is continuous and is based on ensuring that energy consumption is minimised through time in which the lowest time possible is used for a production.

There are two main scheduling processes used in the system level which include the classic and the dynamic scheduling [22] stated that good quality solution to the scheduling problems is a crucial factor if effective utilisation of flexible manufacturing systems is to be achieved and reduce the consumption of energy.

In the classic, the manufacturing parts are normally delivered to machines in batches; these batches are normally in the right sizes. The batches normally create intersection points in which energy may be consumed without production. This to some extent increases energy consumption. On the otherhand the use of the dynamic scheduling ensures that the efficiency in energy is achieved as the intersection constraints are avoided. In the dynamic scheduling the parts in the manufacturing are normally delivered to the buffers that are being used in the machine at a continuous flow, which allows equal distribution of time [23]. The stretch of execution time of a manufacturing process leads to more consumption of energy in the process of manufacturing, therefore having discontinuous batches in the classic level has substantial energy loses that can be saved if a continuous flow was implemented. In the dynamic scheduling the manufacturer considers the energy losses that could be saved from the classic scheduling. In some manufacturing systems, the maximisation of the performance is key and this has been found to have an effect in the minimisation of the energy that is consumed through lean manufacturing [24]. In a research to explore energy based constrained scheduling of tasks that were real time. The findings of the studies have shown significant saving of energy in execution of tasks.

Scheduling is crucial when set of resources are required to be shared in order to manufacture items at the same time. The main goal behind scheduling is to ensure that machines operate in a manner that is efficient and that time factor is utilised efficiently in the manufacturing. The processing in the dynamic scheduling is the determining factor, here the machines rely on automated systems that are controlled by computers, therefore continuity is achieved as there is to interference and disturbance of the system, the results for the dynamic scheduling is that there is fixed off line that guarantees system efficiency.

4 FACILITY LEVEL AND SUPPLY CHAIN

The facility level involves the energy consumption that relates to the whole plant points of energy consumption. The reduction of energy consumption at facility level can be effected from the design stage of the factory [25]**.** The initial design that is used for a plant determines the energy that will be required in the operation. Facility energy efficiency is greatly influenced by the engineers when doing the initial designs of the facility. The manufacturing facilities normally have common features in which the utility systems consume the fossil fuel which in turn produces power and steam to run the facility's process of manufacturing [26]. Suitable design and ensuring that there is proper integration of the processes and systems of utility are key to ensuring energy efficiency. According to [25] it is possible for engineers to create facilities that combine optimised design process and energy consumption efficiency. This is true if the initial designs of the facility are made with foresight of the issues relating to reduction of energy consumption.

An example of energy reduction at facility level is the undertaking by Aspen Tech and BP that have designed a next generation olefin a plant separation system. The new design of olefin has been found to reduce the consumption of energy by 15% compared to other facilities of similar function. For the reduction in energy consumption at the energy level, engineers need to use integrated engineering process that is based on the smart technologies that are currently in place.

Researches carried have shown that in the manufacturing process, the acquiring of raw materials is very crucial to ensuring efficiency and reducing the levels of energy consumption [27]. The supply chain involves the manufactures acquiring the right materials to be used for production from the suppliers. To reduce energy consumption manufacturers can use recycled materials and employ the green chain supply strategy in which the suppliers are to abide by environmental requirements of the manufacturer. Even though this does not impact directly on the manufacturing process, the green supply impacts positively on environment and ensures sustainability by encouraging practices that are environmentally friendly. In addition, the supply chain is supposed to ensure that the raw materials being delivered to the plant do not require a lot of energy in the process of manufacturing [28].

5 CONCLUSION

Manufacturing processes are energy intensive and account for over one third of the total energy consumption. As the world population continues to grow, so is the need for energy. This energy used is normally fossil and the more the energy used the more the emission of greenhouse gases to the atmosphere. The challenge that has resulted from emissions of the gases has been the climatic changes normally marked by the global warming. With the changes in climate there are many challenges that are offing and one of them is that in future there may be no enough energy to sustain the growing demand.

The industries thus have to tackle the challenge by devising energy efficient processes in their manufacturing activities. To achieve this adoption of green manufacturing that focuses on reducing the energy consumption is a mandate for every manufacturer. The green manufacturing should be integrated in all levels in the system of manufacturing, starting from the starting from the process, system level equipment level, system level to the facility level and the supply chain. Saving energy is thus a key strategy that is needed by manufacturers to ensure that environmental sustainability is achieved and there is marked reduction on usage of the fossil fuels.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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