Development of EPS Foam Recycling Machine

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Abstract

The research paper is aimed to develop EPS foam recycling machine which made in cooperation with the KPM Center Molding Company Limited. The EPS foam recycling machine can solve the problem about the limited of area to store EPS foam scraps from the production process and high cost of transportation the EPS foam scraps. The researcher studied the data from the experiments and the related theories to design and construct the EPS foam recycling machine.

The material of the machine consisting of many main parts such as size of machine 2,019 mm x 2,720 mm x 2,900 mm, machine structure, machine base, hitting and stirring set, foam material conveying set, foam containing set, extrusion set, danger preventing set, power transmitting set, power source set, temperature controlling set and the work control set etc.

From the tests and the real use of this ESP foam recycling machine, the results show that ESP recycling machine could be really used satisfactorily as the set conditions. The rough-stirring set, and the fine-stirring set could break foam pieces with the maximum size 700 mm x 1,000 mm x 150 mm. The ESP recycling machine could filter the foam size passing the stirring process with the average size about 35 mm x 35 mm x 35 mm and could melt EPS foam approximate 1 kg. per minute.

Keywords: Expanded polystyrene (EPS), Foam Recycling Machine

Introduction

The KPM Center Molding Company Limited is the company that produces foam pattern for the car industry in Thailand. The foam pattern composed of stamping molds, injection mold, magnesium alloy wheels, etc. The company is encountered the problem from increase of scrap foam that can not be reused. The company has changed the production of foam pattern production in the past that mainly used in the construction by human. In the present, the production of foam pattern changed to be used as a machine controlled by CNC to help in production allowing the production of foam pattern more efficient and faster.

In the present, the production process of company has increase capacity causes a large amount of foam scraps that cannot be reused and not enough storage space in the warehouse. The foam scraps in the warehouse will be sold for recycling into plastic beads. In each sale, there are a lot of the foam scraps and spend a lot of time to move the foam scraps. Therefore, the company wanted to reduce the volume of the foam scraps by expelling the air out of the foam scraps. The foam consists of 98% air and 2% polystyrene. If leaving only the polystyrene, it reduced the volume of the foam. The warehouse will have more storage space and the convenient for transportation.

The melting with heat methodology is used to reduce the volume of the foam. The air will be remove by heat. As a result, the rest of the foam will be polystyrene. The foams have been heated by melting, can increase the value twice as compared to the foam scraps that has not yet melted by heat. The foam scraps have been heated by melting will become the main raw material for the production of plastic beads. The foam will be called as PS Recycle (Samper, Garcia-Sanoguera, Parres, & López, 2010; Maharana, Negi, & Mohanty, 2007)

There are a lot of research about EPS recycling such as Brooke and Andrea (2018) present expanded polystyrene life cycle analysis literature review: an analysis for different disposal scenarios. Expanded polystyrene is a common packaging material in the modern world. It is valued for attributes such as low cost and weight. Expanded polystyrene is a petroleum product, without a clear post-use recycling pathway. Life cycle assessment is utilized in this review to explore the environmental impact of the different life stages of expanded polystyrene and their corresponding environmental impacts to inform the debate as to the best end-of-life management for expanded polystyrene. Recycling expanded polystyrene is not currently a common practice, as some of the characteristics that make it desirable for shipping make it challenging to recycle. However, if expanded polystyrene is recycled, it reduces the demand and associated environmental impacts of virgin expanded polystyrene. Dirk, Comm, and Rochelle (2015) propose examining the potential for expanded polystyrene Diversion in Nova Scotia. Expanded polystyrene (EPS) is the most commonly used form of foamed polystyrene and is manufactured from beads made of styrene monomer into a polymeric material that can be shaped and used in many ways. The purpose of this report is to determine effective management methods for EPS waste, both at Dalhousie University and throughout the province of Nova Scotia. Hidalgo-Crespoac et al. (2020) explain about introduction of the circular economy to expanded polystyrene household waste: A case study from an Ecuadorian plastic manufacturer. Transition towards a more sustainable society is a complex task. The depletion of natural resources and waste generation cannot be sustained indefinitely, i.e. as waste increases, local landfills keep growing and land availability reduces. The introduction of circular economy in effective household solid waste management practices should be considered especially for third world countries, such as Ecuador. In this context, plastic recycling is an important step, particularly the case of expanded polystyrene containers that currently are single-use only and later end up in local landfills. This paper presents a methodology for recycling Expanded Polystyrene by means of a case study from an Ecuadorian Plastic Manufacturer. First, the manufacture of resin from post-consume EPS containers was demonstrated possible by the manufacturer. Second, results show that using 30% of post-consume resin in the mix produce satisfactory laboratory results and operational recycled containers.

The KPM Center Molding Company Limited has the problem about the great volume of scrap foam, the limited of area to store and the high cost of transportation. The company want to buy the EPS foam recycling machine in the market but the foam recycling machine in the market is expensive, also difficult and complex to operate. The company contact with the researcher to consult about the problem that occurs. The researcher decides to design and created the EPS foam recycling machine for KPM Center Molding Company Limited in order to decrease the volume of foam scraps, increase the area to store foam scraps, decrease the cost of transportation and increase the value of the foam scraps. The remainder of this paper is organized as follows: Section II describes research methodology, Section III illustrated the results and discussion. Section IV presents the conclusion.

Methods and Materials

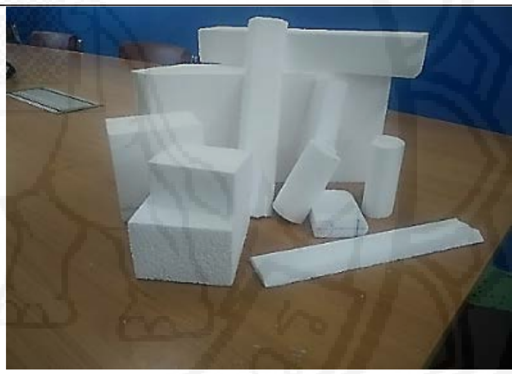
The research methodology is explaining about expanded polystyrene (EPS), the design of EPS foam recycling machine, theory of computation and EPS foam recycling machine process.

2.1 Expanded Polystyrene (EPS)

Expanded polystyrene (EPS) (Samper et al., 2010) is commonly used in the package and packaging sector, mainly because of its excellent impact strength, acoustic isolation, lightness, and easy processing. This material has a great variety of applications in the food industry, in electrical appliances, in hardware, etc. EPS is also widely used as heat insulation material in the building industry. Products made from EPS are characterized by a short useful service life, in contrast to products made from polystyrene which have a longer service life. The material used in the package and packaging industry is converted within a short time into high-volume residue. With the aim of alleviating the problem generated by the accumulation of waste, great efforts are being made to recover residue and thereby avoid incineration and landfilling, as these processes have a high environmental impact. The machine is the better way to EPS recycling.

The EPS foam scraps from the production process of the KPM Center Molding Company Limited can be divided into four types as shown in Figure 1.

Type 1 : Large Size of EPS Foam Scraps



Type 2 : Medium Size of EPS Foam Scraps

Type 3 : Small Size of EPS Foam Scraps

Type 4 : Resolution Size of EPS Foam Scraps

Figure 1 Type of EPS Foam Scraps from the Production Process

2.2 The Design of EPS Foam Recycling Machine

The EPS recycling machine design (Odior, Oyawale, & Odusote, 2012; Polichshuk, Khamzin, Mussin, & Ali, 2018) consist of eleven main parts such as machine structure, machine base, hitting and stirring set, foam material conveying set, foam containing set, extrusion set, danger preventing set, power transmitting set, power source set, temperature controlling set and the work control set.

2.2.1 Machine Structure

The material of the machine structure is selected from strong strength, can be supported the hold of the parts and stable equipment. The steel tube is used to be machine structure. The shape of steel tube is more balanced and beautiful. The steel tube is better bending moment and twisting moment.

Figure 2 Machine Structure

2.2.2 Machine Base

The machine base is made from steel plate because of easy shearing and metal forming immediately and cheaply.

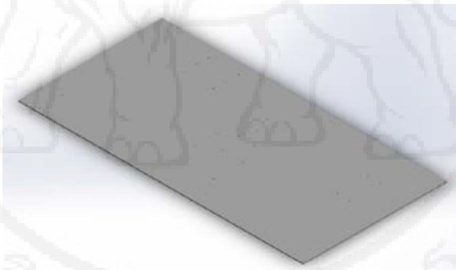


Figure 3 Machine Base

2.2.3 Hitting and Stirring Set

The hitting and stirring set has function to make the large size of foam scraps distribute to be small size of foam cubes. A coarse spinning set is necessary for beat the large size of foam scraps to be smaller. For more efficiency, there is a filter set is used to filter the size of foam cubes before the foam cubes will fall into the pond. The component of hitting and stirring set consists of spinning set machine structure, coarse spinning set, fine spinning set and filter set. The material of hitting and stirring set made from steel plate because of strong strength, easy shearing and metal forming and metal welding immediately.

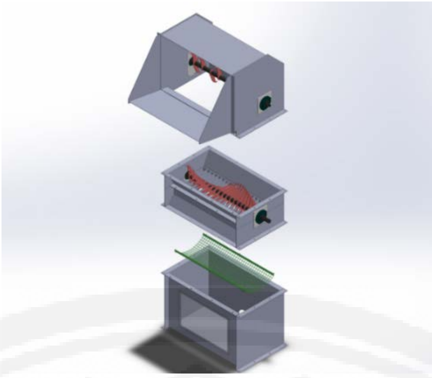


Figure 4 Hitting and Stirring Set

2.2.4 Foam Material Conveying Set

The foam material conveying set has function to conveying foam scraps from pond into storage set. The conveying set have consistent conveying efficiency and pressure capability. The component of foam material conveying set is composed of centrifugal fan and pipeline material. The centrifugal fan selected to use for conveying foam scraps. Due to the foam has a light weight so does not need a lot of conveying pressure.

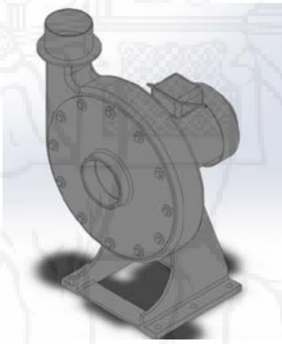


Figure 5 Foam Material Conveying Set

2.2.5 Foam Containing Set

The foam containing set is responsible for storing foam scraps to supplying foam into the extrusion set. Therefore, the foam containing set has to be strong. The production process is not complicated and suitability for work. The material storage part uses fabric materials and the material supply part uses steel plate because of the easy and cheap.

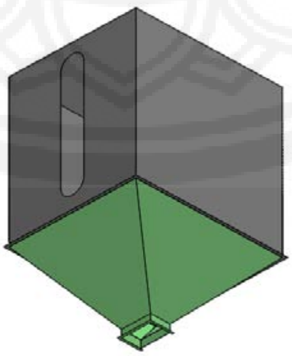


Figure 6 Foam Containing Set

2.2.6 Extrusion Set

The extrusion set (Henson, 1988) has function for reducing the foam volume by using heating to compressing the viscous foam through the die head. The die head had to made from strong materials, able to endure high temperatures and pressures and easily to mold forming. The extrusion set uses steel materials because of the steel is strong and endure high temperatures. The component of extrusion set is comprised of barrel, single screw, heating equipment and die head.

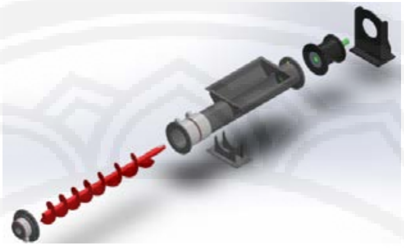


Figure 7 Extrusion Set

2.2.7 Danger Preventing Set

The danger preventing set has function for protecting against the danger of the transmission power set and power source set and prevents heating from the extrusion set. The danger preventing set can be open easy for maintenance and visibility of the machine. The operator will be safety, when the operator still working. Thus, the danger preventing set has to strong, stable and transparent. The danger preventing set made from steel plate.

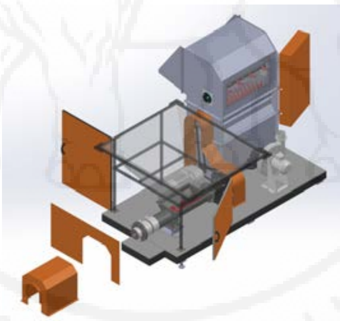


Figure 8 Danger Preventing Set

2.2.8 Power Transmitting Set

The power transmitting set is responsible for conveying the rotating motion between two or more shafts. The power transmitting set has to be strong and support for transmission. The steel roller chain is selected to use in the power transmitting set because of cheap price, can handle a lot of pulling force and can be used in high temperature environments.

Figure 9 Power Transmitting Set

2.2.9 Power Source Set

The power source set has function for driving the mechanical components to work as intended. So, the power source set has to strong, stable, less maintenance and convenient to install. The alternating motor selected to use for power source set.

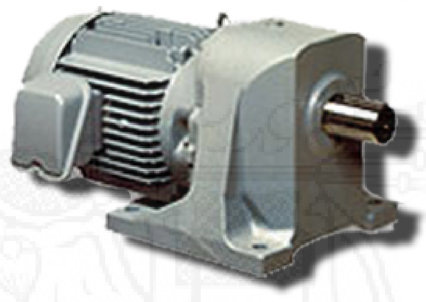


Figure 10 Power Source Set

2.2.10 Temperature Controlling Set

The temperature controlling set is responsible for controlling the temperature of the heater. The temperature controller is selected to use because of it is stable and suitable for simple work controls.

Figure 11 Temperature Controlling Set

2.2.11 Work Control Set

The work control set has function for on-off the electrical control devices. The work control set is considerate in the safety of use, easy to operate and is in the suitable position. Therefore, the structure of the work control set as steel plate because it is strong and easily molded. The component of work control set is composed of light indicating the operating status of the machine, temperature adjustment screen and temperature display, temperature control switch, main motor and blower control switch, machine control switch of machine and emergency stop switch.

Figure 12 Work Control Set

2.3 Theory of Computation

2.3.1 The coarse spinning shaft and fine spinning shaft computation can be calculated based on the following equation.

- Torque on a Shaft

$$F = \frac{m\,x\,v^2}{r} \tag{1}$$

where F = Force (N), m = Mass (kg), v = Velocity (m/s), r = Radius of Hitting Set.

- Maximum Torque on a Shaft

$$\mathrm{T} = \mathrm{F} \times \mathrm{r} \tag{2}$$

where T = Torque (N·M), F = Force (N), r = Radius of Stirring Set.

- Bending Moment on a Shaft

$$M_b = F \times \frac{L_a}{2} \tag{3}$$

where M_b = Bending Moment (N·M), F = Force (N), L_a = Length of Force (N)

- Decrease the Bending Moment on a Shaft

$$M_b, red = \sqrt{{M_b}^2 + 0.75(\alpha_0 + T^2)} \tag{4}$$

where M_b, red = Decrease the Bending Moment, T= Torque, α_0= Specific Value.

2.3.2 *The size of the conveying pipe and the air pressure used for conveying can be calculated based on the following equation.*

- Material Transfer Velocity or Air Velocity

$$\frac{ms}{\rho f \cdot Vst \cdot A} = \left(\frac{1}{10^{\delta}}\right)\left(\frac{Vst}{\sqrt{g \cdot D}}\right)^{x} \quad (5)$$

where D= Diameter of Pipe, Vst = Velocity of Material (m/s), g= Gravity (m/s^2), ms= Material Mass (kg/s), ρf= Air of Pipe (m^2), A= Area of Pipe (m^2).

- Speed of the Material When Unloading.

$$\text{Vs} = \text{V}(1 - 0.088 \times d^{0.3} \times \rho p^{0.5}) \quad (6)$$

where Vs= Velocity of Material while Transfer (m/s), V= Material Transfer Velocity (m/s).

- Pressure Loss due to the Acceleration

$$\Delta P_a = \rho \text{f}\, v^2 \left(0.5 + \frac{\mu \cdot Vs}{V}\right) \quad (7)$$

where ΔP_a= Pressure loss due to acceleration (Pa), V= Material transfer velocity (m/s), Vs = Velocity of material while transfer (m/s), ρf = Air Density (kg/m^3), μ = Phase Density.

- **Pressure Loss due to Vertical Material Handling**

$$\Delta Pz = \frac{\mu.\rho f.g.z.v}{Vs} \quad (8)$$

where ΔPz =Pressure lost due to vertical (Pa), z = Vertical material transfer distance (m).

- Pressure Loss due to Flow Along the Pipe

$$\Delta PL = \frac{\rho f x V^2 x L}{2\, xD}(\lambda \text{f} + \mu + \lambda S) \quad (9)$$

where ΔPL = Pressure loss from flow with the pipe, L = Total length of pipe, D = Diameter of pipe, λS = Coefficient of friction between pipes and air, λf = Coefficient of friction between pipes and material.

- Pressure Loss due to the Flow through the Bend Pipe

$$\Delta Pb = \frac{NxBxV^2 xL\,(1-)}{2} \quad (10)$$

where ΔPb = Pressure loss due to flow through the bend pipe (Pa), B= Pressure loss coefficient in the bend pipe, N = Quality of bend pipes in the system.

2.3.3 The motor power can be calculated based on the following equation.

- Work Force Resulting from the Coarse Spinning Set

$$P1 = F1 \times V1 \tag{11}$$

where P1= Power of Hitting Set (watt), F1= Force from Hilling Set (N), V1= Velocity (m/s).

- Work Force Resulting from the Beat Set

$$P2 = F2 \times V2 \tag{12}$$

whereP2= Power of Stirring Set (watt), F2= Force from Stirring Set (N), V2= Velocity (m/s).

- Power Generated by Extrude Screws

$$P3 = F3 \times V3 \tag{13}$$

where P3= Power of Screw Extruder (watt), F3= Force from Screw Extruder (N), V3 = Velocity (m/s).

- Power Lost from Power Unit Efficiency

$$P = \eta \times P_{motor} \tag{14}$$

where P = Power Lost from the Performance of the Power Unit, η = Actual Performance, P_{motor}= Active Power of the Motor.

2.3.4 The size of the chain can be calculated based on the following equation.

- Power to Choose the Chain

$$P = W_p \times N_s \tag{15}$$

where P = Power to choose the chain (watt), W_p= Power that the chain can actually. N_s= Factor.

- Velocity of Chain

$$V = P \times Z1 \times N \tag{16}$$

where V= Velocity of chain (m/s), P = Pith distance of chain, N = Number of teeth or pinion.

- Force in the Tangent Line

$$Ft = \frac{W_p}{V} \tag{17}$$

where Ft = Force in the Tangent Line, W_p = Power that the chain can actually, V = Velocity of the Chain Sprocket (m/s).

The theory of computation is described about the equation for criteria of choosing the size of hitting and stirring set, foam containing set and extrusion set. The size of hitting and stirring set are used the equation 1, 2, 3, 4, 11 and 12. The size of foam containing set is used the equation 5, 6, 7, 8, 9 and 10. The extrusion set is used the equation 13, 14, 15, 16 and 17.

2.4 EPS Foam Recycling Machine Process

When starting the process of EPS foam recycling machine, the EPS foam cubes are putted into hopper. The size of foam cubes should to be less than 700 mm x 1,000 mm x 150 mm. The foam cubes are flow in the hitting set, to reduce the size of foam cubes. After finish hitting set process, the foam cubes are flow in the stirring set until the size is reduce equal 35 mm x 35 mm x 35 mm. The foam cubes will fall into the pond and continue to containing set. The containing set is responsible for storing foam scraps to supplying foam into the extrusion set. The next process is extrusion, The foam cubes are flow in the extrusion set, to reduce the foam volume by using heating to compressing the viscous foam through the die head. The EPS foam recycling machine can melt the EPS foam cube with a diameter of 50 mm, approximately 1 kg per minute.

Results

The EPS foam recycling machine has size equal to 2,019 mm x 2,720 mm x 2,900 mm. The EPS foam recycling machine consist of eleven main parts such as machine structure, machine base, hitting and stirring set, foam material conveying set, foam containing set, extrusion set, danger preventing set, power transmitting set, power source set, temperature controlling set and the work control set. The size of foam cube can be pass containing set equal to 35 mm x 35 mm x 35 mm. The EPS foam recycling machine can melt the EPS foam cube with a diameter of 50 mm, approximately 1 kg per minute. Figure 13 shows the fully developed the ESP recycling machine. The machine has to evaluated based on the performance and ability. During the testing process, there are some problems were encountered.

In the 1st testing, the problems of the arrangement of the spinning blades were perpendicular in each other. The blades and the foam are touch bring occur high resistance. While in the spinning, the foam is blocks, as a result in a conflict between the blade set, fine spinning and foam cubes. The spinning blades is not able to beat large foam cubes. Therefore, the researcher swaps the spinning blades into a spiral to increase the efficiency of the blades to be able to beat spin the large foam cubes.

The 2st testing, the problem was the speed of the spinning set, it was too high due to the less number of sprocket. As a result, the spinning set will hit the foam cubes outward. Therefore, the chain sprocket of 36 teeth is used to reduce the revolving speed of the spinning beat set.

The 3rd testing, the Coarse spin set and fine spin set can be spun up to a maximum size of 700 mm x 1,000 mm x 150 mm. The test results are in the scope.

The 4th testing, the foam cube screening set can filter the foam cube size through the spinning process, with an average size of 35 mm x 35 mm x 35 mm. The testing results are in the scope.

The 5th testing, the efficiency of the EPS foam recycling machine is tested at melting temperature HEATER 1 = 200 ℃, HEATER 2 = 200 ℃, HEATER 3 = 200 ℃ in 1 minute. The testing results are medium performance.

The 6th testing, the efficiency of the EPS foam recycling machine is tested at melting temperature HEATER 1 = 270 ℃, HEATER 2 = 270 ℃, HEATER 3 = 270 ℃ in 1 minute. The testing results are good performance.

The 7th testing, the efficiency of the EPS foam recycling machine is tested at melting temperature HEATER 1 = 260 ℃, HEATER 2 = 270 ℃, HEATER 3 = 250 ℃ in 1 minute. The testing results are good performance.

The 8th testing, the efficiency of the EPS foam recycling machine is tested at melting temperature HEATER 1 = 260 ℃, HEATER 2 = 270 ℃, HEATER 3 = 250 ℃, the foam can be melted to the core and the average

weight is achieved as in a goal set. The goal set is the size of foam cube can be pass containing set equal to 35 mm x 35 mm x 35 mm. The EPS foam recycling machine can melt the EPS foam cube with a diameter of 50 mm, approximately 1 kg per minute.

For all testing, the 8th testing results are very good performance because the ESP recycling machine can filter the foam size passing the stirring process with the average size about 35 mm x 35 mm x 35 mm and can melt EPS foam approximate 1 kg .per minute. The researcher select the 8th testing setup and more testing as shown in Table 1.

Figure 13 EPS Foam Recycling Machine

Discussion

The ESP foam recycling machineis good performance for filter the foam size passing the stirring process with the average size about 35 mm x 35 mm x 35 mm and could melt EPS foam approximate 1 kg. per minute. The EPS foam recycling machine in this research is cheaper than the foam recycling machine in the market and easy to operate. The EPS foam recycling machine can solve the problem of the KPM Center Molding Company Limited. The KPM Center Molding Company Limited can decrease the volume of foam scraps, increase the area to store foam scraps, decrease the cost of transportation and increase the value of the foam scraps.

Conclusion and Suggestions

This paper is proposed design and construction a EPS foam recycling machine for the KPM Center Molding Company Limited. The researcher studied the data from the experiments and the related theories to design and construct the EPS foam recycling machine. The material of the machine consisting of many main parts such as size of machine 2,019 mm x 2,720 mm x 2,900 mm, machine structure, machine base, hitting and stirring set, foam material conveying set, foam containing set, extrusion set, danger preventing set, power transmitting set, power source set, temperature controlling set and the work control set etc. From the tests and the real use of this ESP foam recycling machine, the results show that ESP recycling machine can be really used satisfactorily as the set conditions. The rough-stirring set, and the fine-stirring set can break foam pieces with the maximum size 700 mm x 1,000 mm x 150 mm. The ESP recycling machine can filter the foam size passing the stirring process with the average size about 35 mm x 35 mm x 35 mm and melt EPS foam about 1 kg per minute.

Table 1 The results of the efficiency of the EPS foam recycling machine

No.	Results	Weight	Foam Cube	Note
1		1 kg.		Able to melt form and the average weight of the foam according to the target.
2		0.946 kg.		
3		1kg.		Able to melt form and the average weight of the foam according to the target.
4		0.946 kg.		
5		1.109 kg.		Able to melt form and the average weight of the foam according to the target.

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