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Design a refuse-derived fuel (RDF) printing machine with a 50 kg/hour capacity using the Pahl and Beitz method

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ABSTRACT

Coal fuel usage is growing in Indonesia now, although it has a slew of negative consequences. Sawdust, palm oil, and wood may all make briquettes and alternative biomass fuels to coal. Briquettes with the proper size and forms need mechanical technology equipment that uses screws. The equipment developed in this study is a 50 kg/hour RDF (Refuse Derived Fuel) printing machine. A drive is an electric motor; a screw serves as a material press, and a die serves as a material press. The tool was designed using the Pahl and Beitz approach. The machine is constructed utilizing a mechanical system since it enables the creation of an easy-to-operate machine design. The machine makes 50 mm diameter briquettes with a length of 122.4 m and a capacity of 50 kilograms per hour. This page explains the machine in depth in order for interested readers to comprehend and operate it simply.

ABSTRAK

Pada saat ini penggunaan bahan bakar batu bara di Indonesia semakin meningkat, padahal penggunaannya memiliki banyak dampak buruk. Serbuk gergaji, kelapa sawit, dan kayu dapat dimanfaatkan menjadi briket dan bahan bakar biomassa sebagai alternatif batu bara. Pembuatan briket dengan dimensi dan bentuk sesuai memerlukan alat yang berteknologi mekanis menggunakan *screw*. Alat yang dirancang dalam penelitian ini berupa mesin cetak *RDF (Refuse Derived Fuel)* dengan kapasitas 50 kg/jam. Motor listrik digunakan sebagai penggerak, *screw* sebagai penekan material, dan *die* sebagai pencetak material. Metode yang digunakan untuk merancang alat adalah metode Pahl dan Beitz. Mesin dibuat menggunakan sistem mekanik karena mampu menghasilkan desain mesin yang mudah dioperasikan. Mesin menghasilkan briket dengan diameter 50 mm, panjang 122,4 m, dan kapasitas 50 kg/jam. Artikel ini menjelaskan pembuatan mesin dengan rinci agar pembaca yang tertarik dapat mudah memahami dan mengoperasikannya.

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1. Introduction

The increasing population growth of Indonesia impacts the increasing use of fossil fuels to meet daily needs. This increase leads to a decrease in fossil fuels, which are non-renewable fuels. The Indonesian economy will be disrupted and can have a huge impact, especially on the industrial sector. This condition causes the need for a new fuel source that can meet the needs of the community. The utilization of alternative fuel sources that are renewable and environmentally friendly is an important thing to do. At the beginning of its development, wood was the most widely used fuel source because it was easy to obtain and simple to use. However, the massive use of wood as fuel has a destructive impact on the environment because it will reduce the number of trees in the forest, a water catchment area. One alternative fuel is briquettes.

Sawdust is a waste of the sawmill industry, which causes many problems in its handling. Sawdust waste is usually left to rot, stacked, and burned without any added value and harms the environment. One effort to overcome this problem is the manufacture of sawdust briquettes. Briquette is a fuel made from powder or small pieces of wood compacted using a briquette press. The material to make briquettes must be mixed with adhesive so that the shape becomes solid. The pressure required to print briquettes must be appropriate so that the resulting briquettes meet the quality. Some of the raw materials used to make briquettes include peanut shells, rice husks, sawdust, waste, and coconut shells. At this time, the manufacture of briquettes still uses much human power with hydraulic and pneumatic systems. Therefore, a simple briquette press is needed using a mechanical system, namely refuse derived fuel (RDF) printing machine with a capacity of 50kg/hour [1].

2. Research Methodology

2.1. Research Method

The method used in this study is the Pahl and Beitz method. The stages carried out in this research are:

a. Identify the problem
b. Conduct literature studies and field studies
c. Making the initial concept of the machine
d. Analyze needs
e. Determine the required specifications
f. Selecting a concept with the Pahl and Beitz method
g. Making mechanical calculations
h. Drawing the final design drawing

2.2. Identify the Problem

The first step in this research is to identify the problem. Based on the use of coal, which is increasing every day for fuel, it is also the cause of the destructive impact of using coal fuel, which requires an RDF utilization to overcome these problems. Next, this research is to study literature and data processing by learning about theories related to RDF, machine components, design, and other supporting theories. The design method used is the Pahl and Beitz design method.

2.3. Function Structures

2.3.1. Function Block

The first stage of concept design is to create a function block by determining the input to be processed to produce output, and it can be seen in Figure 1. At this stage, the structure of the overall product function is carried out, then described in sub-functions, and, if possible, can be broken down into sub-functions.

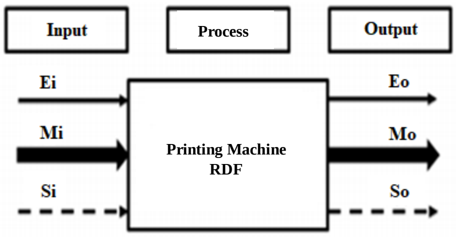

Figure 1. Function block

Where:

Ei	: Energy in	(Electrical energy)
Eo	: Energy out	(Mechanical energy)
Mi	: Material in	(Sawdust)
Mo	: Material out	(Charcoal briquettes)
Si	: Button in	(On)
So	: Button out	(Off)

2.3.2. Function Tree

After the function block creation stage, the next step is to create a function tree, as shown in Figure 2. In the function tree, the plan that will be used is described. The plan is described in Figure 2 and divided into sub-functions.

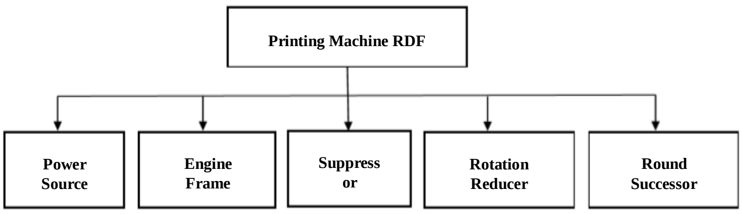

Figure 2. Function tree

2.3.3. Function Diagram

An overview of the RDF printing machine design system with a 50kg/hour capacity is shown in Figure 3. The system to be created will use sub-functions in the function tree. For the machine to produce the desired product, a force is required to press the material. This design concept uses a mechanical screw concept, where the screw will rotate due to the pulley generator that occurs in the motor force, and the material will press towards the die to produce briquettes.

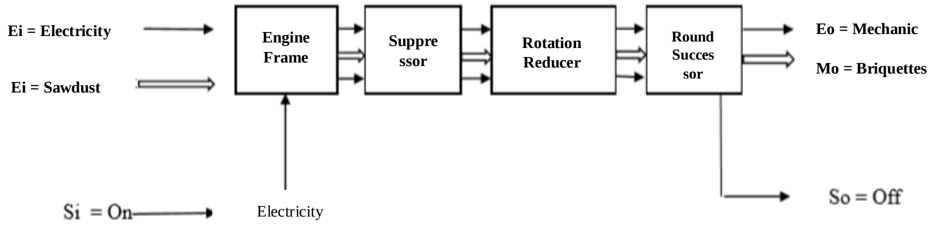

Figure 3. Function diagram

2.4. Concept Design

After getting the product specifications, the concept design is carried out by making several concepts that meet the requirements of the specified specifications. Several concepts are determined by selecting the type of component and the component working system at this stage. The concept determined then made a simple sketch image to provide a basic overview of the product. The concepts were developed again after being evaluated. The evaluation must meet various criteria such as economic, technical criteria, consumer desires, and other required criteria. After evaluation, concepts that do not meet the criteria are not continued to the next stage. Concepts that meet the criteria and specifications will be selected as the best concept to proceed to the next stage.

2.4.1. Morphology

At this stage, the concepts will be made using a systematic way, where the sub-functions will be selected sequentially using arrows as a sign of the direction of the concept selection. Each sub-function will choose the available alternatives by following essential aspects, and each selection must be interconnected so that the concepts created can work well.

Table 1. Morphology

No	Sub-function	Alternative A	Alternative B	Alternative C
1	Hopper	Cone	Parallelogram	Prism
2	Electric Motor	AC Electric Motor	DC Electric Motor	
3	Power Switch	Gears & Chains	Pulleys & Belts	Gear
4	Process Machine	Piston	Screw	Rack Gear
5	Machine Frame Profile	Pipe	L Profile	Box Profile

Where :

Line : Variant 1

Line : Variant 2

Line : Variant 3

Variant 1 : 1-C,2-A,3-B,4-B,5-C.

Variant 2 : 1-A,2-A,3-A,4-A,5-C.

Variant 3 : 1-C,2-A,3-B,4-C,5-C.

Variant 1 uses a prism-shaped hopper in its container. AC electric motors use pulleys and belts as a medium for transferring power, using threads on the process machine, and the frame using a box profile.

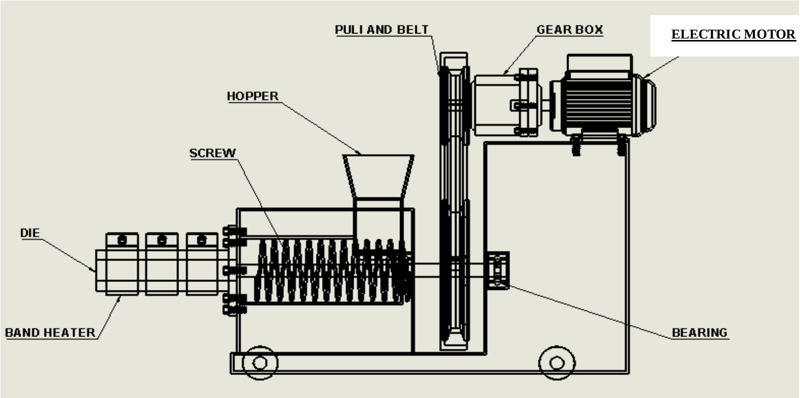

Figure 4. Sketch for variant 1

Variant 2 uses a cone-shaped hopper on the container. The manufacture of an AC electric motor in this variant uses gears and chains as a medium for transferring power, uses a piston in the process machine, and uses a box profile on the frame.

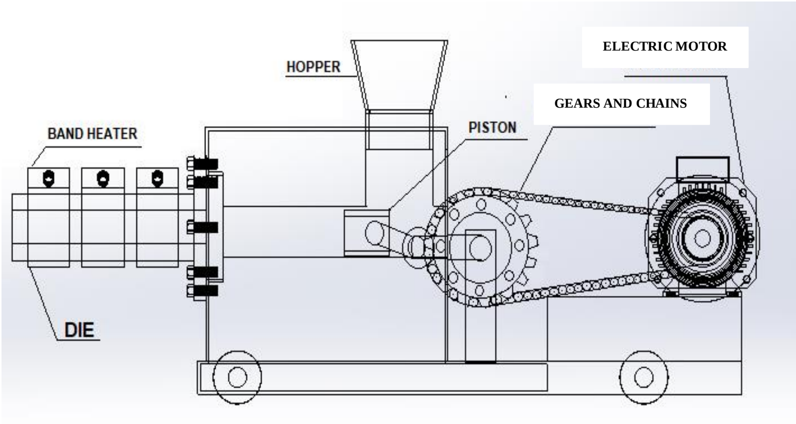

Figure 5. Sketch for variant 2

Variant 3 uses a prism-shaped hopper on the holder. The manufacture of an AC electric motor in this variant uses pulleys and belts as the power transfer medium, uses rack gear in the process machine, and this variant uses a box profile on the frame.

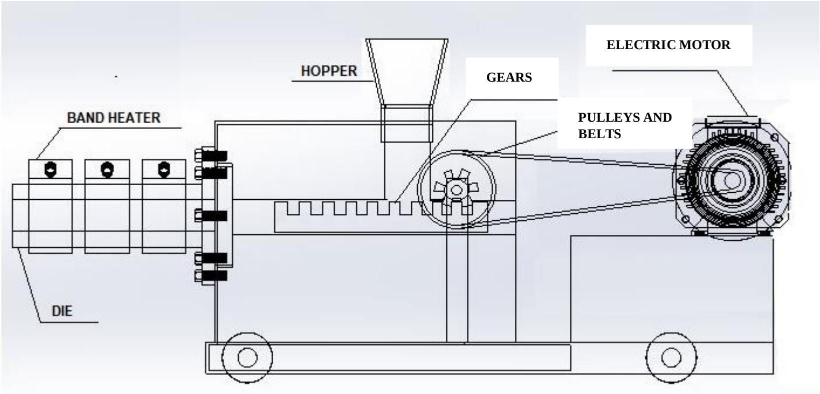

Figure 6. Sketch for variant 3

2.5. Basic Decision Selection

Concepts that have met the criteria and specifications determined will then be selected as the best concept. Concepts will be selected by assessing essential aspects according to product function so that the best concept can be determined from other concepts. Basic decision selection has stages of selection to assess the concept to be selected. These stages are:

2.5.1. Product Concept Criteria

The criteria that are taken into account at this stage are looking at the consumer desires that have been obtained in the previous stage, these desires will be sorted according to the priority level and given a value according to their importance. Designs will be selected taking into account the following criteria:

1. Geometry; Product width and length, and product height
2. Material; Durable and material quality

3. Production; Easy to find components and produce
4. Maintenance; Maintenance frequency and costs
5. Assembly; Easy detachment and assembly
6. Operation; Safe and easy operation

2.5.2. Product Weighting

Each assessment criterion will be given a weight that follows the level of importance of each of these criteria. The more critical the criteria, the higher the weight value.

1. Geometry (0,15); Product width and length (0,5; 0,075), and product height (0,5; 0,075)
2. Material (0,17); Durable (0,6; 0,075), and material quality (0,4; 0,075)
3. Production (0,16); Easy to find components (0,6; 0,075), and easy to produce (0,4; 0,075)
4. Maintenance (0,16); Maintenance frequency (0,7; 0,075), and costs (0,3; 0,075)
5. Assembly (0,14); Easy detachment (0,4; 0,075), and easy assembly (0,6; 0,075)
6. Operation (0,22); Safe operation (0,5; 0,075), and easy operation (0,5; 0,075)

2.5.3. Evaluating the Product Concept

At this stage, the idea will be evaluated by comparing it to other product concepts and weighing the benefits and drawbacks of each.

Table 2. Scale

Scale	
Value	**Description**
1	Bad
2	Pretty Good
3	Good
4	Best

2.5.4. Calculating the Conceptual Value of a Product

After the concept has been rated, each concept will be calculated the total value, then checked which concept has a greater rating and determine which concept will be selected. The concept criteria used are the Scoring concept criteria.
\

Table 3. Concept of scoring

No	Selection Criteria	Weight	1		2		3	
			Rating	Weight Value	Rating	Weight Value	Rating	Weight Value
1	Strength	22%	3	0.66	2	0.44	2	0.44
2	Material quality	17%	2	0.35	5	0.85	4	0.68
3	Care	4%	4	0.16	2	0.08	3	0.12
4	Safe to operate	9%	4	0.36	3	0.27	3	0.27
5	Easy to operate	13%	3	0.39	3	0.39	2	0.26
6	Affordable prices	22%	5	1.1	4	0.88	4	0.88
7	Design shape	13%	5	0.65	3	0.39	4	0.52
Total		100%	3.66		3.3		3.17	
Ranking			1		3		2	
Continuing the process			Yes		No		No	

3. Results and Discussion

3.1. Calculation of Material Velocity

The formula may be used to calculate the speed of the material on the screw conveyor (v)

$$V = \frac{Sn}{60}\ (\text{m/s}) \tag{1}$$

The design of an RDF printing machine with a 50kg/hour capacity comprised of the following components:

a. Charcoal 77% = 100g
b. Adhesive 23% = 30g
c. Diameter = 50mm

Pyrolysis has been used to convert sawdust and glue into up to 50kg of charcoal briquettes and volume of charcoal briquettes : $\frac{50\text{kg}}{208\ \text{kg/m}^3} = 0.2404\text{m}^3$. Thus, with 50 kg of charcoal briquettes $= 0.2404\text{m}^3$. For diameter 50mm, $A = \pi \times r^2 = \pi \times 25^2 = 1964.2\ \text{mm}^2$, and $\frac{0.2404\times10^9\ \text{mm}^3}{1964.2\ \text{mm}^2} = \frac{122390.7952\ \text{mm}}{10^3} = 122.3908\ \text{m}$, then the necessary speed is calculated. For $S = 26.24$ mm and $v = \frac{122.3908\text{m/hour}}{3600s} = 0{,}0340\text{m/s}$, then $n = \frac{0{,}0340\ \text{m/s} \times 60}{0{,}026\text{m}} = 78{,}4615\ \text{rpm}$.

3.2. Capacity Calculation for Screw Conveyors

The screw conveyor's capacity is determined by the diameter (D), the screw pitch (S), the shaft rotation (n), and the load efficiency depending on the screw area. Formula 1 may be used to determine the capacity of a screw conveyor.

For diameter screw (Dscrew) $= 150$ mm $= 0{,}15$ m, and shaft diameter (Dshaft) = 30 mm = 0.030 m

$$\text{Dmean} = \frac{\text{Dscrew} + \text{Dshaft}}{2} = \frac{150 + 30}{2} = 90\ \text{mm} = 0.09\ \text{m}$$

$$Q = 60\,\frac{\pi.D^2}{4} S \times n \times \psi \times\ \gamma \times \text{C (ton/hour)}$$

$$Q = 60 \times \frac{\pi.(0.09)^2\ \text{m}}{4} \times 0.026 \times 78.4615 \times 0.4 \times 0.2404 \times 0.8$$

$$Q = 0.0599\ \text{ton/hour} = 59.9019\ \text{kg/hour}.$$

3.3. Calculation of the Capacity of a Screw Conveyor

Formula 2 may be used to determine the projected power required to drive the screw conveyor.

$$N_0 = \frac{QL\omega}{367}$$

$$N_0 = \frac{59.9019\ \times 0.35 \times 25}{367} \qquad (2)$$

$$N_0 = 1.4281\ \text{kW}$$

Since 1 kW = $1{,}3410$ hp so $1{,}4281$ kW $= 1{,}9151$ hp.

3.4. Calculation of the Torque on a Screw Conveyor

Formula 3 may be used to determine the torque needed on the screw shaft at (n) revolutions per minute.

$$M_0 = 975\ \frac{N_0}{n}$$

$$M_0 = 975\,\frac{1.4281\ \text{kW}}{78.4615\ \text{rpm}} \qquad (3)$$

$$M_0 = 17.7463\ \text{kgm} = 177.463\ \text{Nm}$$

3.5. Analyses of Screw Conveyor Loads

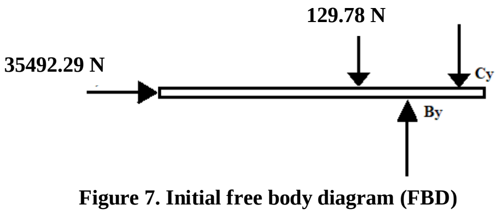

Figure 7. Initial free body diagram (FBD)

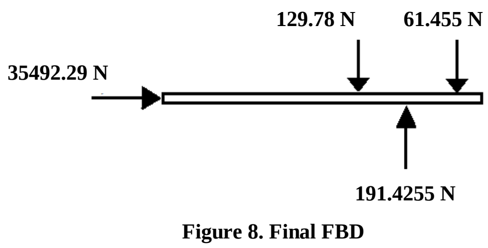

Figure 8. Final FBD

$\sum fx = 0\,; Ax\ = 35492.29\ N = 0$

$\sum fy = 0\,; (-129.78\ N) + By + Cy = 0$

$By + Cy = 129.78\ N$

$\sum Mc = 0\,; (By \times 200) - (129.78 \times 295) = 0$

$$200\ By - 38285.1 = 0$$

$$200\ By = 38285.1$$

$$By = \frac{38285.1}{200} = 191.4255\ N$$

$By + Cy = 129.78\ N$

$191.4255 + Cy = 129.78\ N$

$191.4255 - 129.78\ N = Cy$

$Cy = -61.6455\ N$

3.5. Calculation of the Shaft

Formula 4 may be used to determine the diameter of the shaft that will be utilized.

$$d_s = \left[\frac{5{,}1}{\tau_u} \times k_t \times c_b \times T\right]^{\frac{1}{3}} \quad (4)$$

Where, $k_t = 1.5$; $c_b = 1.2$;

Thus $\tau_u = \frac{\sigma_B}{Sf_1 \times Sf_2}$

$Sf_1 = 6.0$

$Sf_2 = 3.0$

So $\sigma_B = 80\text{kg/mm}^2$(Nickel chrome steel JIS G 4102/SNC21) and $\tau_u = \frac{80\ \text{kg/mm}^2}{6.0 \times 3.0} = 4.4444\ kg/mm^2$

$T = 9.74 \times 10^5 \frac{p_d}{n}$

$p_d = ?$

$n = 78.4615\ rpm$

$p_d = f_c \times p$

$f_c = 0.8$

$p = 1{,}4281\ \text{kW}$

and $p_d = 0.8 \times 1.4281\ \text{kW} = 1{,}1425\ \text{kg. mm}$

so $T = 9.74 \times 10^5 \frac{1.1425\ \text{kg.mm}}{78.4615\ \text{rpm}} = 14182.6883\ \text{kg. m}$, and

$$d_s = \left[\frac{5.1}{4.4444 kg/mm^2} \times 1.5 \times 1.2 \times 14182.6883\ \text{kg. mm}\right]^{\frac{1}{3}} = 30.8269\ \text{mm}$$

The shaft diameter obtained is 30.8269 mm and is rounded to 31.5 mm. With a shaft of 31.5 mm, the width and height of the pegs are 10×8 mm, and the length is 22 mm, it can be seen in Table 4.

3.6. Determination of Bearings

To calculate the precise diameter and breadth of the bearing, we must first measure its diameter. The $\frac{l}{d}$ comparison table illustrates how to get the desired outcomes.

Where $d = 31.5$ mm and $l = 2.5$

then $\frac{l}{d} = d \times l = 31.5 \times 2.5 = 78.8\ mm$

The diameter and width of the bearings are 31.5 mm and 78.8 mm.

3.7. Determining the Pulley and Belt

Equation 5 may be used to calculate the ratio of rotation of the drive and driven shafts.

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (5)$$

Where $N_1 = 1400$ rpm and $N_2 = 78{,}4615$ rpm

Using a gearbox on a CHCZ type electric motor with a scale ratio of 1:10, the 1400 rpm motor becomes 140 rpm.

$$\frac{140\ \text{rpm}}{78.4615\ \text{rpm}} = 1.78$$

Thus, the ratio of the screw's pulley diameter scale to the motor's is 1:1.78. The motor pulley must have a minimum diameter of 95 mm. The obtained pulley screw is x. $95 \times 1.78 = 169$ mm.

Table 4. Shaft made of alloy steel

Shaft Standard	Symbol	Tensile strength (kg/mm^2)
Nickel Chrome Steel	SNC 2	85
(JIS G 4102)	SNC 3	95
	SNC 21	80
	SNC 22	100
Molybdenum Nickel Chrome Steel	SNCM 1	85
(JIS G 4103)	SNCM 2	95
	SNCM 7	100
	SNCM 8	105
	SNCM 22	90
	SNCM 23	100
	SNCM 2	120
Chrome Steel	SCr 3	90
(JIS G 4104)	SCr 4	95
	SCr 5	100
	SCr 21	80
	SCr 22	85
Molybdenum Chrome Steel	SCM 2	85
(JIS G 4105)	SCM 3	95
	SCM 4	100
	SCM 5	105
	SCM 21	85
	SCM 22	95
	SCM 23	100

3.8. Determining the Heater Band

In designing the RDF printing machine, the temperature of the charcoal briquettes is 250ºC within 1 hour. For the planned results to be appropriate, specific sizes and specs are needed on the band heater. The heater type is planned for the diameter and width of the heater band, namely 50.8 mm and 76.2 mm, with no head area at terminals with a size of 38.1 mm × 76.2 mm. The formula used is as follows:

$$\text{Heat area} = \pi \times D \times W \quad (6)$$

Where $D = 10$ cm

$W = 7.62$ cm

So Heat Area $= 3.14 \times 10\ \text{cm} \times 7.62\ \text{cm} = 239.268\ \text{cm}^2$

With No-Heat Area 3.81 cm × 7.62 cm $= 29.0322\ \text{cm}^2$, then the heat area on the band heater obtained is

$$239.268\ \text{cm}^2 - 29.0322\ \text{cm}^2 = 210.236\text{cm}^2$$

Thus, $210.236\ cm^2 \times 6.5 = 1366.5327$ Watt. From the following results, the band heater on the market is CBH01033 with 1500 Watts. The design of the RDF printing machine with a capacity of 50kg/hour is presented in the picture below based on the findings of the design study conducted:

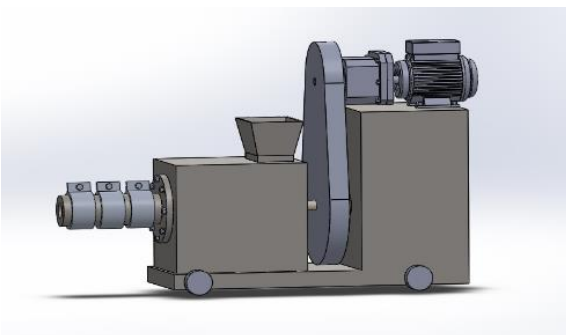

Figure 9. Printing machine with a capacity of 50kg/hour

4. Conclusions

The results of the design research found that the RDF printing machine design with a capacity of 50kg/hour. This design was chosen because the criteria and concepts of the machine were made following the geometry, material, production, maintenance, assembly, and operation that were easy to understand and operate. The electric motor used is the EM 90L-4 Motor with 3 phases, 2 hp, 1400 rpm. The gearbox uses CHC25, and the screw uses SNC21 material for a screw material rate of 78.4615 rpm and a screw conveyor capacity of 59.9019 kg/hour. The shaft used uses SNC21 material, and the torque required on the screw shaft is 177.463 Nm. The bearing uses an R.20 bearing with a bearing diameter and width of 31.5 × 84 mm, the die uses S45C material, and the band heater uses CBH01033.

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