International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 04 | April - 2023 Impact Factor: 8.176 ISSN: 2582-3930

Design And Fabrication of Experimental Manufacturing of Pellets from Waste Material

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Abstract -
Many developing countries produce huge amount of agro waste. The disposal of this waste is a major problem. The residues like wheat and rice husk, sawdust from carpentry shops, groundnut shells, and dry leaves from plants are available in a large quantity. Apart from the problems of storage, transportation and easy handling of this waste, burning of biomass in grates poses a greater problem of widespread air pollution. Biomass pellets are a well-liked sort of biomass fuel, generally made up of wood wastes, agricultural biomass, commercial grasses and forestry residues. In addition to savings in transportation and storage, pelletization of biomass facilitates easy and price effective handling. Dense cubes pellets have the flow ability characteristics almost like those of cereal grains. The even geometry and structure of biomass pellet helps in automatic feeding. Densely packed biomass pellets help in good durability in transport and storage. Pellets if densely packed and the moisture content is low the combustible properties can be increased.

***Keywords: Solar Energy, Wind Energy, PV Cell, Renewable Energy, Hybrid Power System, Electricity*.**

1. Introduction

India is a tropical country thus offers an ideal environment for Biomass production. There is a large quantity of agricultural potential, which makes huge amounts of agro-wastes. With an estimated production of about 460 million tons of agricultural waste per annum, biomass can supplement coal up to 260 million tons; which could save about Rs. 250 billion per annum .

Biomass pellets are a well-liked sort of biomass fuel, generally made up of wood wastes, agricultural biomass, commercial grasses and forestry residues. In addition to savings in transportation and storage, pelletization of biomass facilitates easy and price effective handling. Dense cubes pellets have the flow ability characteristics almost like those of cereal grains. The even geometry and structure of biomass pellet helps in automatic feeding. Densely packed biomass pellets help in good durability in transport and storage. Pellets if densely packed and the moisture content is low the combustible properties can be increased.

Biomass pelletization may be a standard method for the assembly of high density, solid energy carriers from biomass. Pellets are manufactured in several types and grades as fuels for electrical power plants, homes, and other applications. Because of the availability of vast size, shape and type of machine biomass pellets can be made of different size, shape and with different bulk density.. Pellets have a cylindrical shape mostly and are about 6-25 mm in diameter with 3-50 mm in length also the particle size of size <3.2 mm is preferred according to norms. Pellet fuel are used in boilers and household purposes they are not used as electricity generator because of low energy to volume ratio compared to other sources which make biomass pellet uneconomical for electricity generation.

Pallets formation from waste

2. Problem Identification

Globally, fossil fuels are the major source for production of energy. It takes millions of years for the formation of fossil fuels. So, it is said that the production is low in regard to the demand. Such fuels generate higher amount of air pollution which leads to environmental issues like global warming. Therefore, it is now necessary to switch over to the alternate energy sources. After coal and oil, biomass is the third largest primary energy resource in the world. The agricultural residues are increasing day by day due to the higher agricultural production. But, those residues are usually burnt directly which results into air pollution. So, for efficient use of biomass wastes, biomass briquettes can be formed. Biomass Briquetting is the densification of loose biomass available such as agricultural residues, municipal waste and paper waste, etc. Biomass wastes such as sawdust, coir pitch, coffee husk, rice husk, forest leaves, coconut shells, etc. can be used for production of biomass briquettes. This paper focuses on design and fabrication of automated biomass briquetting machine. The main aim to manufacture such a machine is to help waste management and also to use such waste in an efficient way. This machine is designed in a way that it remains highly efficient and low cost.

3. Objectives

- The main aim of this project to design and Fabricate Pallets machine for waste materials.
- Simplified mechanical handling
- Low cost of transportation due to high energy density
- Uniform combustion in boilers
- Reduced dust production
- Reduced possibility of spontaneous combustion in storage.

4. Materials And Methods

- **What Is Pellet?**

Pellets are closely related to briquettes except that they have a smaller diameter and are more adapted to small scale use. Ashden (2011) refers to pellets as very small briquettes. There are a few different definitions of a pellet, but the one used in this study is as follows; *"A Wood briquette (pellet) is a mass of ground fuel stuff moulded or pressed into a convenient unit with or without the aid of a binder"* (written by Natividad, 1982 cited by Vinterbäck, 2000). Pellets are a form of densified biomass with interesting opportunities for development of renewable energy. This solid fuel is mainly produced from wood residues but other biomass residues could be used. Pellets are an important renewable energy source that can easily be used in smallscale domestic systems. The dimensions of fuel pellets vary between 3 and 25 mm in diameter depending on the die block that is used in production. The length generally varies between 5 and 40 mm. If the product exceeds 25 mm in diameter it is called a briquette (Morten *et al.*, 2009). Two major factors have promoted the growth of the pellet fuel market. The first is the instability in price and consistent rise in the cost of fossil fuels, and the second is the increasing attention given to the effect of climate change on the environment caused by the use of fossil fuels. Other factors supporting the use of pellets are that they are a fuel that can be produced locally, from local wood and biomass residues. The local production of pellet can produce an affordable fuel, while creating local jobs and mitigating the Problem of deforestation in developing countries.

- **Characteristics of Pellet**

The main purpose of pelletizing a raw material is to reduce the volume and thereby increase the energy density. When densification has taken place, there are two quality aspects that need to be considered. Firstly, the pellet has to remain solid until it has served its purpose (handling characteristics). Secondly, pellet has to perform well as a fuel (fuel characteristics). The energy characteristics are other important issues when describing and comparing pellets with other fuels (Karlhager, 2008).

- **Biomass Raw Materials for Pelletizing**

Biomass raw material base for the production pellets (briquettes) has been thoroughly described by Hirsmark(2002). There are a number of biomass materials that can be used for pellet (briquette) production. Wood residues as saw dust, wood chips, planer shavings, recycled wood and pure wood can all be used after milling. Agricultural residues as straw, hemp or reed canary grass can be used. Short rotation coppice, e.g. Salix can also be used in pelletizing (briquetting) processes. Peat is another raw material suitable for pelletizing (briquetting) (Hirsmark 2002). There is no data of which raw material is the most important for briquette production (Karlhager, 2008). Hirsmark showed that saw dust and planer shavings are the two most common raw materials for pellet and briquette production though. In many developing countries which produce huge quantities of agro residues, the potential agro-residues which do not pose collection and drying problems, normally associated with biomass are rice husk, groundnut shells, coffee husk and coir waste (obtained by dry process).

At present, loose rice husk, groundnut shells and other agro-residues are being used mostly by small scale boilers in process industries (Grover and Mishra 1996). "Fig." 1, shows some biomass sources for pelletizing.

Fig.1: Biomass sources for pelletizing (Kiss and Alexa, 2014).

- **Biomass Pelletizing Process**

Pelletizing is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel. The densification of the biomass can be achieved by any one of the following methods: (i) Pyrolysed densification using a binder, (ii) Direct densification of biomass using bindersand (iii) Binder-less briquetting (pelletizing) (Karaosmanoglu, 2000). Depending upon the type of biomass, three processes are generally required involving the following steps:

I. Sieving - Drying - Preheating - Densification - Cooling – Packing

II. Sieving - Crushing - Preheating - Densification - Cooling – Packing

III. Drying - Crushing - Preheating - Densification - Cooling – Packing.

5. Methodology

The idea is to fabricate a machine which would have mixing, blending, and compressing chambers. The first section would be comprised of a hopper to feed the input, which would pass to cutting chamber. The cutter would cut the input material into powdered form. A sieve-like plate would be mounted below it to pass this powdered biomass to blending chamber. Here the binder and water would be added to the powdered biomass. Many naturally occurring binders may be used like wheat flour (wastage from mills), wet paper pulp, cow dung etc. The mixing would be done by helical blender, as it is the most efficient blender for handling highly viscous fluids. Due to the helix shape of the blender, the thick viscous mixture would then follow its helix to reach the next chamber.
The next part would be the final stage of the machine. The thick mixture would be passed onto a die. The rollers would be mounted such that there is a clearance between the rollers and the die. The die, being mounted on the central shaft along with the cutting blade and blender, would rotate during the operation. The rollers have their axis perpendicular to the central shaft axis, and the axle that passes through the rollers would be mounted in the casing.

The collection of cylindrical shaped briquettes would be done in the chamber under the die from which the briquettes would proceed to drying.

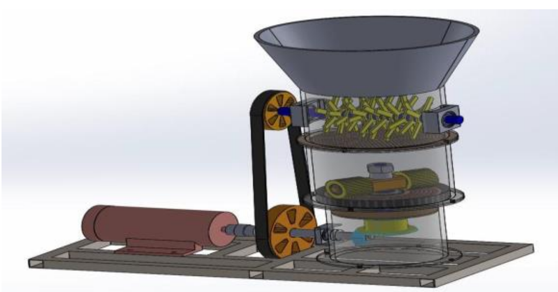

Fig: 1. *The pellet mill*

The pellet mill as schematically shown in Figure 1 consisted of the following parts:

1. Feed hopper: This is where the feeds were fed and extruded by the two pellet rolls to the die plate as pellets. It has outer and inner diameters of 280 mm and 220 mm, respectively, with a height of 150 mm. A stainless steel can be used to prevent sticking of feeds to the feed hopper and to allow easy cleaning. The outer diameter will be welding to eliminate any sharp edges that may be caused by the stainless steel sheet.

2. Cutting chamber: This is where leaves or another biomass material will cut by sharp edge cutter. This cutter will cover diameter around 250 mm. hence all the material which we are feeding will cut effectively and according our size requirement. Speed reduction can be given to the cutter for varying size of particle.

3. Pelleting chamber: After the material is properly mixed it will introduce in pellet chamber. This is where mixing and extruding of feeds was performed prior to being pushed through by the pellet rolls into the holes of the die plate. This part was made from mild steel (MS) plate with dimensions of 30 cm diameter x 12 cm high in order to withstand the rigorous force created by the rotating die plate and pellet rolls.

4. Pellet rollers: This part was responsible in compressing the formulated feeds before it was extruded in the die plate. The two corrugated pellet rolls will be put in with two bearings each and were inserted in a 4 cm cold rolled steel (CRS) shafting to allow them to freely rotate once the shaft rotated also. The pellet rolls, each with a dimension of 70mm diameter x 60 mm length

5. Die plate: It is the part that converted the formulated feeds into cylindrical-shaped solid materials or into pellets. The die plate will be fixed with help of casing. It can be made from a metal plate with 220mm diameter with 20 mm thickness in order to bear the weight and force created by the rotating pellet rolls. It has 440 holes each with a diameter of 5 mm.

6. Discharge chute: This is where the pelletized feeds were discharged for collection. It was made from 2mm thick MS plate with dimensions of 13 cm wide x 45 cm long.

7. Electric motor: It is used to rotate main shaft which contains mainly cutter, blender and pellet roll. This is responsible in driving the pellet roll to an appropriate speed that led to the conversion of mashed formulated feeds into pellets. A single-phase 1 HP electric motor can be used in order to drive the needed speed for operation of 1380 rpm and at the same time is able to bear overload should it happen.

6. Working Principle

The machine works on the principle that it uses a roll-type extrusion press. The formulated feeds are fed into the pelleting chamber by the pellet rolls. As the pellet rolls rotate, force is applied creating rearrangement of the particles in order to fill the voids or holes of the die plate. The pressure is increased in compression step, causing brittle particles to break and malleable particles to deform forcing them to be fed in the die and come out as pellets. The pellets then fall naturally due to impact created by the rotating die plate, hence, no need for a cutter.

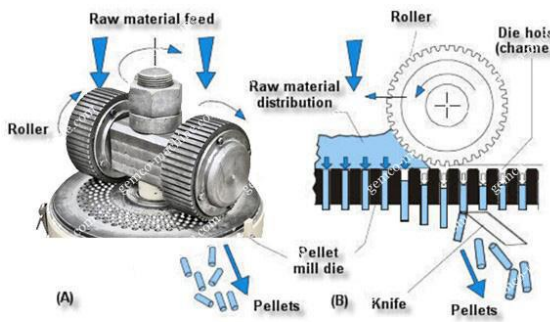

Fig: 2. *Working Principle*

After design of the machine, according to the required specifications, it was fabricated. The required material was procured and individual parts were manufactured using operations like turning, milling, slotting, drilling, etc. The frame was fabricated using pipes of size 1 inch which were joined using welding. Different parts were joined using bolted joints. The whole assembly is placed on a wooden board to minimize the effect vibration.

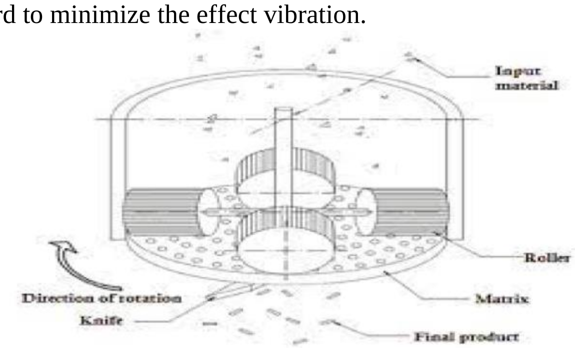

Fig: 2. *Internal Process*

7. **Materials and methods**

- ***Design criteria***

The pelleting machine should convert the pellet mixture of coffee husks and spent coffee grounds into densified pellets. It follows the principle of a rotating roller pellet mill where power is transmitted from the electric motor to a shaft or spindle with a reduced speed, and urges the roller dies to drift and press the pellet mixture. The machine was designed such that at least one person is required to control its operation, materials for construction were low-cost and locally available, and the fabrication procedures should include basic machining operations such as drilling, boring, and milling for ease of machine manufacturing.

- ***Design Details and Specification***

The pelleting machine (Figure 1) is a motor-operated machine powered by a single-phase 1.5-hp electric motor. The speed of the motor was reduced to approximately 30 rpm from 1800 rpm using a 1:60 speed reducer. It has an overall dimensions of 740 x 413 x 790 mm (*L x W x H*). High-tensile fasteners were used for assembly of the components to reduce risks of misalignment and breakage due to high pressure and temperature build-up during the pelleting operation.

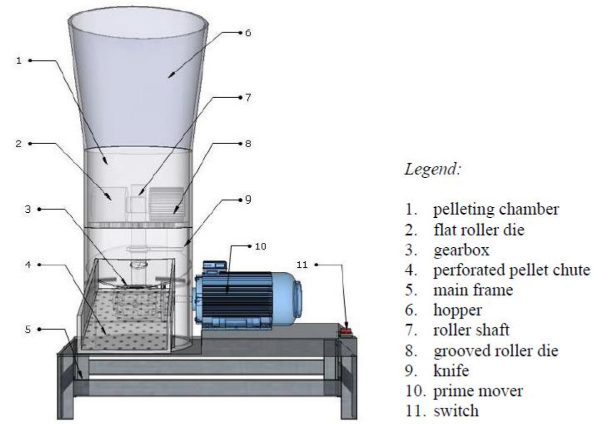

Figure 1**.** Representation of the biomass pelleting machine

The machine consists of several major components that allow a highly efficient pelleting operation. The pellet mixture is loaded on a frustum-shaped hopper with dimensions of 215 x 245 mm (*H x dia.)* that directs the mixture to the pelleting chamber, with a holding capacity of 1 kg. The pelleting chamber facilitates mixing and pressing of the pellet mixture using two roller dies – one grooved type and one flat type. The grooved type roller die has 24 teeth and each tooth is 2 mm x 5.67 mm *(H x W)*. The roller dies were made of cold-rolled steel 1080 and were attached to the shaft perpendicularly, allowed to freely rotate on its axis through deep-groove ball bearings. The pressed mixture is extruded into cylindrical-shaped solid pellets with approximately 6-mm diameter through the thick die plate, which is locked in position by bolts and nuts to prevent slippage during the operation. The thick die plate has 96 holes whose inlet and outlet diameters of each hole were 10 mm and 6 mm, respectively.

The high pressure build-up inside the chamber increases its frictional forces and so its temperature. A knife attached to the shaft cut the produced pellets from the die plate to a desired length of 10 mm. Upon extrusion, pellets are discharged to an outlet chute, inclined at 30°, with 4-mm perforations to separate the non-pelleted particles and fines from pellets.

- ***Testing and evaluation***

Pelleting was carried out in three trials using 1 kg of pellet mixture in each trial. The mixture was composed of the following: 28.6 percent coffee husks, 28.6 percent spent coffee grounds, 14.2 percent starch, and 28.6 percent water. The performance characteristics of the components of the machine including the speed of prime mover shaft, spindle, and roller shaft, the noise level, and the input power of the machine were determined. The machine was also evaluated in terms of its pelleting capacity and efficiency with the procedure adopted from the Philippine Agricultural Engineering Standards for hammer mill (PAES 217:2004).

The pelleting capacity refers to the weight of pellets produced per unit of operating time (kgh-1) while pelleting efficiency is the ratio of the weight of pellets produced on the pellet discharge chute to the total weight of biomass materials fed into the hopper (%), computed as follows,

pelleting capacity, $C_p = \frac{W_p}{T_p}$ (1)

pelleting efficiency, $Ep = \frac{Wp}{Wi}$ (2)

- ***Physical properties of pellets***

where *Cp* is the pelleting capacity (kgh-1), *Wp* is the weight of pellets produced (kg), *Tp* is the total time of pelleting (h), *Ep* is the pelleting efficiency, and *Wi* is weight of input biomass mixture (kg).

The physical properties of the pellets were described in terms of pellet length, pellet diameter, pellet mass and bulk density. The dimensions of each of the 100 randomly selected pellet samples from each trial were measured.

In determining the moisture content, three 50-gram samples of pellets from each trial were oven-dried at 110oC for 24 hours or until constant weight. The moisture content of each sample was calculated using the equations below:

$$\%\ MC_{wet}\ basis = \frac{(Mo-M_1)}{Mo} \times 100\% \quad (3)$$

$$\%\ MC_{dry} basis = \frac{(Mo-M_1)}{M_1} \times 100\% \quad (4)$$

where *%MC* is the moisture content (wet basis and dry basis), *Mo* is the initial mass of the pellet samples (g) and *M1* is the final mass of the oven dried pellet samples.

For the determination of the bulk density, cooled pellets were loaded into a funnel placed in a tared container with known volume. Pellets were allowed to free flow into the container. Excess pellets (above the top rim of the container) were removed by scraping off with a straight edge. The container and pellets were weighed and the weight per volume was reported as its bulk density.

8. Design Analysis

- ***Design Significance***

Poor handling of coal has affected the iron and steel industries, Railway Corporation and coal industries. However, the contemporary palletizing machine is so expensive that some industries in Nigeria cannot afford the price. With the design of pelletizing machine to form pellets as the case maybe, for good handling of powder material,\ there will be improved fugitive dust control, decrease in transportation costs and losses, reduction in the risk of coal freezing and lowered risk of spontaneous combustion/ usage.

- ***Design Analysis***

Considering the single phase induction motor with a speed of 400rpm, having a power of 1800kw, the diameter of the shaft from the motor is 20mm. To calculate the angular velocity of the motor;

W=2πN÷60= (2×3.142×400) ÷ 60

W=41.89/sec

To find the actual torque of the motor

Torque (T) = P/W

where

P=1800×1000

W=41.89

T=1800×10³×1000/41.89=42969.7 KN/m

Again to calculate for the torque transmitted

T=P × 60/2 Πn

T=1800 × 1000 × 60/2π×400

T=108000000/2513.3

T=42971.835 N/m

- ***Material Selection***

One of the basic factors that affect the choice of a project is the availability of materials, selection of materials, and the cost of the materials for the design or fabrication of the project. The materials selection for the design function depends on the following;

- The availability of these materials in our local markets.
- The strength of these materials
- The cost of these materials
- The possession of simple mode of the operation
- The appearance of these materials
- The ability of these materials to serve the purpose for which the project is intent to be designed.

- ***Design Of Key***

The key [7] is made of mild steel used in the locking of the gear to the motor shaft. It is inserted between the shaft and the hub of the gear acting as the pulley to connect both the gear and the shaft together in other to prevent relative motion between them. It is also inserted parallel to the axis of the shaft. The name of the key used in this design is square sunk key. Mathematically,

$W = T = D/4$

where,

W = width of the key

T = Thickness of the key

D = Diameter of the key

D = 20mm

$W = T$ = 20/4 = 5mm

NB: A key way which is a slot or recess in the shaft from the motor and the hub of the gear acting as the pulley to accommodate the key made. Basically keys are used as

temporary fasteners and subjected to consider crushing and shearing stresses.
Also note that during the design of the key, forces due to fit of the key where neglected and it was assumed that the distribution of forces along the length of the key is uniform. Now owing to the fact that
$L \times W \times T \times d/2 = L \times t/2 \times бc \times d/2$
$w/t = бc/2T$
where
W = width of the key
T = Thickness of the key
$бc$ = crushing stress of the key
$\tilde{\imath}$ = Shearing stress of the key
Therefore the key used in this design is equally strong in shearing and crushing. Know that the key material and shaft material are the same.
To find the speed of the driven $N2$
From $T2 = N\,1T\,1/N2$
$N2 = N1T1\,/T2$
where,
$T1$=no of teeth of drivers = 24
$T2$=no of teeth of driven=24
1= speed of driver =400
$N2$= speed of driven=200
Mean speed = 400 + 200/2 = 300rpm
N=300rpm
$N2 = 400 \times 24/24 = 400$rpm
$N = 300 \times 24/24 = 300$rpm
Therefore, if $N1 = N2$
$T1 = T2$
This means that gears transmits equal amount of speed.
The name of the gear is spur gear, with 50mmdiameter as pitch circle.
$Dp = mTp$
To find the modulus
$50/24 = m$
M=2.08
A. Design of Step Turned Shaft
The shaft used in this design is called a transmission shaft.
Now assuming the allowable shear stress as 42mpa the line shaft is rotating at 400rpm and transmitting 18kw.
To find the diameter of the shaft
$T = p \times 60/2\pi N = 18 \times 10^3 \times 60/2\pi \times 400$
=429.69 = 430 N-m or
= 430×10^3 N-mm
But $T = \pi/16 \times \tau \times d^3$
$430 \times 10^3 = \pi/16 \times 42 \times d$
$430 \times 10^3/16 = \pi\,42d^3$
$203.65 = d$
d = 5.8mm
NB: we assumed 20mm diameter of the shaft because of its rigidity and loading.

9. Results

- ***Preliminary testing and observation***

The performance of the pelleting machine varied with different mixtures of coffee husks, spent coffee grounds, binder, and water. Among the problems encountered were longer pelleting time primarily due to the congestion in the holes of the flat die plate, stacking up and hardening of the mixture, and occurrence of occasional stops when the spindle and roller dies operate. To overcome these problems, the large particle size of the coffee husks in the mixture were reduced to ease passage of pellets through the die plate. The amount of binder was also optimized to improve the firmness of the pellets and avoid cracking. This also helped reduce the chances of hardening of the mixture in the pelleting chamber. Lastly, to avoid congestion in the die plate, feeding of the pellet mixture was manually controlled.

- ***Performance Characteristics***

The performance of the pelleting machine was characterized with and without load wherein, no
significant difference was observed among parameters (Table 1). The average speed of the motor shaft was recorded at 1,799.0 rpm and the speed of the roller dies was 28.1 rpm. Noise levels were below bthe limit for agricultural machineries 26.5 db (<92 dB). The evaluation of the pelleting capacity and pelleting efficiency revealed an average value of 1.50 kgh- 1 and 92.49 percent, respectively. At this rate, the percentage losses reached only 7.5 percent of the total input mixture while 5.0 percent of mixture is lost during the pelleting operation. When compared with other pelleting machines, this average pelleting capacity of may be low primarily due to lower roller shaft speed that affects the rate of pelleting. Nonetheless, the recorded pelleting efficiency is a good indicator to the performance of the machine.

- ***Physical Properties of pallets***

The average length and diameter of the pellets produced were 9.86±0.63 mm and 5.71±0.41 mm, respectively (Table 2). The machine was designed to produce pellets with average length of 10 mm and average diameter of 6 mm. Statistical analysis showed that the 75th percentile of the 300 pellet samples has length ≥10.39 mm and diameter of ≥5.82 mm. The average mass of each pellet was also almost uniform at 0.12±0.001 g.
In terms of the moisture content and the bulk density, the average moisture content in dry and wet basis of the pellets is 16.65 and 14.27 percent, while the bulk density is 850 kgm-3. Similar raw materials (spent coffee grounds) upon pelleting were also reported by earlier researchers. A density of 1058-1255 kgm-3 and 6.2-11.78% for moisture content were reported for pellet's characteristics of spent coffee grounds. However International Organization for Standardization standardized the fuel specifications for solid biofuels, a density higher than 500 kgm-3 and a moisture content lower than 10% for pellet must be achieved for its safe storage and efficient combustion. This is supported by other research

works stating that a density of 700 kgm-3 and a moisture content of 8-12% for pellets is a typical bulk densities and moisture contents of biomass pellets and a pellet's density below 400 kgm-3 is a low density pellet for biomass making it difficult to store, transport and utilize.

Table 1. Observations on the pelleting efficiency and pelleting capacity of the pelleting machine,

Performance Characteristic	Mean[a]
Speed of the motor shaft	1799.0 rpm
Speed of the roller die(s)	28.1 rpm
Noise level	265. dB
Power input	2.0 kW
Current drawn	8.4 A
Voltage supply	238.3 V
Total weight of input	1000.8 g
Weight of pellets produced	925.7 g
Weight of fines	24.6 grams
Losses	50.5 grams
Percentage Losses	5.0%
Pelleting time	0.6 hr
Pelleting Capacity	1.5 kg h^{-1}
Efficiency	92.49%

a. *Difference in the mean values is not significant*

Table 2. Analysis of the physical properties of 300 pellet samples in terms of length, diameter, and mass for uniformity assessment,

Parameter		Physical Property		
		Length	Diameter	Mass
N	Valid	300	300	300
	Missing	0	0	0
Mean		9.8609	5.7053	.1160
Variance		.631	.0410	.001
Minimum		5.06	4.7600	.10
Maximum		12.45	6.1700	.20
Percentiles	25	9.3800	5.6100	.1000
	50	9.9000	5.7350	.1000

The developed biomass pelleting machine can produce pellets from a mixture of coffee husks and spent coffee grounds at an acceptable pelleting capacity and high efficiency. The pellets produced has uniform physical characteristics and low moisture content that reflect the reliability of the machine. Suitable for small-scale pelleting operation, the machine can be easily manufactured using locally available materials. The pelleting capacity can be increased by optimizing the speed of the spindle and roller dies, coupled with controlled feeding. It is recommended for further studies to include the analysis of the calorific value of the pellets and their proximate and ultimate composition using standard methods. Furthermore, to assure that the pellets will be safe for long-term storage, air-drying is recommended to reduce its moisture content after processing.

10. Advantages

- In terms of the product (Pellets):

1) An excellent substitute to conventional fuel at very optimal cost (Only manufacturing and raw material cost)
2) It is a flexible solution to fuel crisis as we can change the composition as per availability of raw material and use it for co-firing with conventional fuels.
3) The fuel pellets is easy to burn and have good calorific value due to compaction.
4) Pellets are easy to store and transport than loose biomass.

- In terms of the machine:

1) Machine is easy to troubleshoot and for maintenance.
2) Design is compact so consumes less floor space.
3) It can be easily operated by any non-technical person
4) The machine is wide open to future modifications and sophistication.

11. Conclusion

Biomass pellets can be economically produced with a production cost of $51/t, assuming a raw material cost of Rs10/t and drying biomass from 40% to 10% moisture using dry shavings as fuel. Raw material and personnel costs are the major cost factors on the pellet production cost followed by dryer and pellet mill costs. An increase in raw material cost substantially increases the pellet production cost. Scale of the plant, burner fuel options, and the fuel cost had a significant influence on the pellet production cost. Small-scale pellet plants are more expensive to operate, which eventually increases the pellet production cost. A larger scale pellet plant with a production capacity (10 t/h) would produce less\ expensive pellets. Among the five burner fuel options tested, coal or wet biomass may considerably reduce the pellet production cost. However, environmental impacts due to the combustion of these fuels require further investigation to control potential emissions.

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