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Development and Performance Evaluation of a Plastic Pellets Drying Machine

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ABSTRACT

The plastic pellets drying machine comprises of the induction gear motor, the drying unit and discharge unit. It was developed using locally sourced material to reduce drudgery in the drying of recycled material, infiltration of dirt and other surface defects, as well as splay marks and enhance production of adequate quantity and quality of processed plastic product. Performance test analysis that was carried out showed average drying rate (throughput) and drying efficiency for the Plastic Pellets Drying Machine are 1.04kg/hr and 75.9% respectively. Thus, the developed Plastic Pellets Drying Machine is a veritable option for both medium and large scale production.

Keywords: Performance Evaluation, Plastic Pellets, Drying Machine

1. Introduction

A drying machine is that which perform the function of drying plastic granules called pellets for the removal of water bubbles from it to enable it be used efficiently in the production of plastic products. Recycling is an aspect of environmental engineering. Environmental engineering deals with the development of technically reasonable solutions to environmental problems by designing, building and maintaining systems to control wastes produced by municipalities and industries. Plastics are not degradable materials; hence its accumulation after use generates an environmental problem. This research project will contribute in the improvement of the technology used in designing and manufacturing of pellets drying machine (pellets dryer) for the purpose of creating job opportunities and at the same time ensuring effective utilization of recycled materials.

Recycling also takes care of the enlarging waste disposal crisis that the society is tending towards too. For this, there is a need for an expansion of the recycled program as well as cheaper machinery to fix all the problems of recycled materials. The fundamental goals of any recycled system are to collect the pellets/granules so as to utilize it in the production of any plastic product. The performance of a pellets drying system is therefore characterized in terms of both environmental efficiency (e.g. the amount or % of water bubbles removed/dried) and economic efficiency (e.g. the costs of the drying system). Thus, the need to dry plastic granules is to be clearly understood, especially with regards to the economic and environmental issues raised by the use of plastics in developing countries. Raw materials used in the production of plastics are imported and very expensive. Drying machines that exist are using Germany and Japan advanced technology, high degree of automation and manufactured in China. They are also used for continuous processing (drying) with high processing efficiency. Producers of plastics in the informal sector are running a low output operation. This low output of production affects the quality of the product which is available to the consumer.

The machinery for this drying process must be:

i. Affordable to those working in the informal sector

ii. Less complex sand hence easy to operate, bearing in mind the technical ability of those involved in the informal sector.

iii. Cheap to maintain

iv. Just adequate for a low grade low cost drying process. Low grade here refers to the moderate concern given to some certain kind of contaminants (pigments used in impressing manufacturer's information on the recycled pellets).

Plastics

Plastics are one of the most commonly used plastics in the world today.

Plastic drying is bound to realize a lot of saving in production costs, conserved limited resources and alleviate the difficulties that could be experienced during further processing.

Hence, this research will give the design analysis, development, and as well evaluate the performance of a plastic pellets drying machine designed for plastic processing industries.

1.1 Objectives and Scope of Study

Specific objectives of this study are to;

i. Design and fabricate a Plastic Pellets Drying Machine.

ii. Performance Evaluation of the machine.

1.2 Justification

The development of the plastic pellets drying mobile machine will definitely make the processing of recycled plastic waste more economical in terms of labour, time and cost since drudgery will be reduced. Moreover, the profit margin of plastic investor will be enhanced because excessive waste of recycled materials which characterized this sector will be totally phased out. This will also provide employment for the populace and increase the external trade potential of Nigeria, as the prospect of recycling of plastic waste for further processing into any plastic product will be enhanced.

2. Design Analysis And Specifications Of The Plastic Pellets Drying Machine

2.1 Design Concepts and Considerations

1. The machine was designed to dry waste plastic recycled materials called plastic pellets in a manner to remove the moisture in the pellets without melting the pellets and enhance the production of adequate quality of plastic products during further processing.

2. The incorporation of a mechanical control to the system instead of an electronic control for the speed control to reduce cost.

2.2 Selection of The Drive and Determination of The Speed of The Drive

The speed of the machine was determined as 37rpm from the relation below given by Khurmi and Gupta 2009;

$$V.R = \frac{N_1}{N_2} = \frac{T_2}{T_1} \quad (1)$$

Where N_1 is speed of rotation of smaller sprocket in rpm

N_2 is speed of rotation of larger sprocket in rpm

T_1 is number of teeth on the smaller sprocket

T_2 is number of teeth on the larger sprocket

It should be noted that a motor gear box is used to reduce the speed of electric motor at 10:1. Speed reduction is necessary to reduce the speed of the electric motor and to increase torque. Thus, for the electric motor with gear box gives

$$\frac{N3}{N1} = \frac{10}{1} \quad (2)$$

Where N_3 = 1410 and is speed of electric motor

Hence N_1 = 141rpm.

From =

N_2 = 37rpm

2.3 Selection of electric motor for the operation of pellets drying machine

The power is determined as 1HP from the equation 2,

$$P = T\omega \quad (3)$$

Where ω is angular velocity in rad/s, T is torque and P as power respectively.

2.4 Shaft Design Consideration and Analysis

The diameter, d of the plastic pellets drying machine transmission shafts was determined from the maximum stress relations given by Khurmi and Gupta (2005) as:

$$d = \left[\frac{16}{\pi\tau} \sqrt{(k_b m_b)^2 + (k_t m_t)^2} \right]^{1/3} \quad (4)$$

Where; = allowable shear stress for steel shaft with provision for keyways = 40N/ ; = maximum twisting moments on the shafts; = maximum bending moment on the shaft; = combined shock and fatigue for bending; = combined shock and fatigue factor for twisting. The maximum twisting moments on the drying shaft is determined as 1.925 x 10-1Nm using the Equation given by Khurmi and Gupta (2005);

$$P = \frac{2T\pi N}{60} \quad (5)$$

The maximum bending moment on the driving conveyor shaft was computed as 3.08 x 107 N-mm using its force diagram shown in Fig. 1;

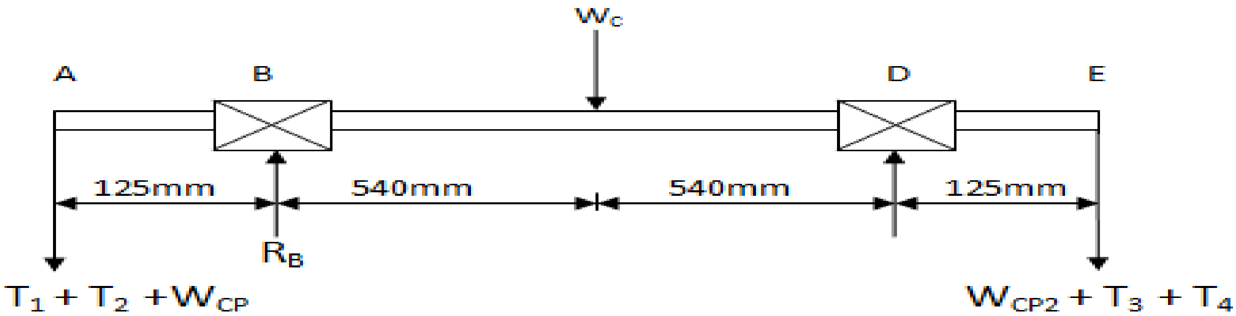

Fig 1: Force diagram of the driving conveyor shaft

The shaft is cylindrical with circular cross sections and sprockets and bearings on them. The shaft will be subjected to fluctuating torque and bending moments, and therefore combined shock and fatigue factors taken are taken into account.

i. Shaft subjected to twisting moment only

Torsion equation,

$$\frac{F_t}{r} = \frac{T}{J} = \frac{C\theta}{L} \quad (6)$$

Where, ft = torsional shear stress

R = distance from neutral axis to outermost fibre,

T = twisting moment (or torque) on shaft

J = polar moment of inertia

C = modulus of rigidity of shaft material

L = length of shaft

θ = angle of twist in radius on length, l

(ASME 1995).

Polar moment for round solid shaft

$$J = \frac{\pi}{32} \times d^4 \quad (7)$$

For $r = \frac{d}{2}$ and $f_z = f_t$

$$\frac{T}{\pi 32} \times d^4 = \frac{ft}{\frac{d}{2}}$$

$$T = \frac{\pi}{6} \times f_t \times d^3 \quad (8)$$

Twisting moment, t can be obtained from $P = \frac{2\pi NT}{60}$ (9)

Where, N = speed of shaft in rpm in the case of chain drive,

$T = (T_1 – T_2)R$ (10)

Where, T1 and T2 are tensions on the right side and slack side of the belt respectively

R = radius of sprocket

From P = Tω in equation (2);

But $T = \frac{\pi d^3 ft}{16}$

ii. Shaft subjected to bending moment only,

Bending equation is given by

$$\frac{M}{I} = \frac{F_b}{Y} \quad (11)$$

Where, M = bending moment
I = moment of merits of cross-sectional area of the shaft about axis of rotation.
fb = bending stress
y = distance from neutral axis to outermost fibre

but $I = \frac{\pi d^4}{64}$ (12)

then $M = \frac{f_b}{y} \times I$

$= \frac{f_b}{y} \times \frac{\pi d^4}{64}$

But y = $\frac{d}{2}$

M = $\frac{\pi d^3 f_b}{32}$ (13)

(for solid shaft)

For bending moment M, = Torque T

iii. Shaft subjected to combined twisting and bending moments based on maximum shear stress theory.

$f_s(max) = ½ (f_b)^2 + 4(f_t)^2$ (14)

but $f_b = \frac{My}{I} = \frac{32M}{\pi d^3}$

and $f_x = \frac{16T}{\pi d^3}$

Substituting into the previous equations;

$f_s(max) = 1/2 (32M/\pi d^3)^2 + 4 (16T/\pi d^3)^2$ (15)

$d^3 = 16M^2 + \frac{T^2}{\pi d^3\, 16M^2}$ (16)

2.5 Determination of Chain Length

The Length of Chain, L required was computed as 85mm from the following relations given by Khurmi and Gupta (2005) as

L = K.P (17)

Since the length of the chain must be equal to the product of the number of chain links (K) and the pitch of the chain (P). Hence the number of chain links may be obtained from the following expression;

$K = \frac{T_1 + T_2}{2} + \frac{2x}{p} + [\frac{T_2 - T_1}{2\pi}]^2 + \frac{p}{x}$ (18)

The Centre distance was obtained as 50mm from the relation below from Khurmi and Gupta

$x = \frac{p}{4}[K - \frac{T_1 - T_2}{2} + \sqrt{[(K - \frac{T_1 + T_2}{2})^2 - 8(\frac{T_2 - T_1}{2\pi})^2]}$ (19)

Considering fig.2.

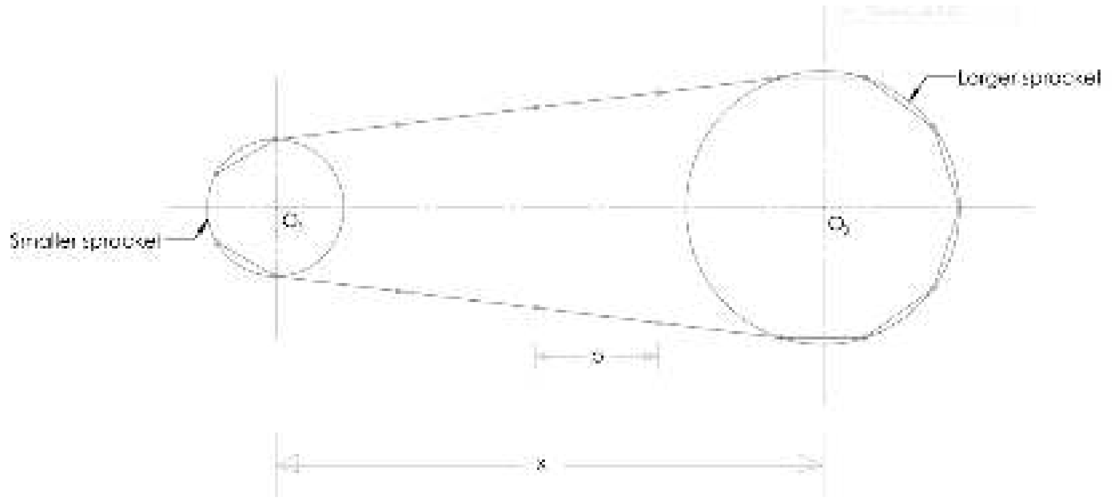

Fig. 2: Power transmitted by the chain.

2.6 Determination of Velocity Ratio of Chain Drive

The velocity ratio was determined as 3.81rpm from the equation below:

$$V.R = \frac{N_1}{N_2} = \frac{T_2}{T_1} \qquad (20)$$

Where; N_1 is speed of rotation of smaller sprocket, 141rpm

N_2 is speed of rotation larger sprocket, 37rpm

T_1 is number of teeth on the smaller sprocket 20

T_2 is number of teeth on the larger sprocket 76

Thus, the average velocity of the chain is given by

$$\mathbf{VR} = \frac{\pi DN}{60} = \frac{TPN}{60}$$

2.7 Determination of the Heating Power of the Heating Element

The heating power of the heating element is determined as ---- from the relation given below;

$$Q = mC_p\theta = IVT \qquad (21)$$

But $P = IV$

$Q = PT$

Hence $P = Q/T$

Where; P = power of heating element/heater band

Q = quantity of heat

m = mass of materials

C_p = specific heat capacity of the plastic

θ = temperature rise

I = steady state current

V = potential difference between the terminals of the heating coils in volts

2.8 Determination of the Heat Source/Quantity of Heat Needed for Drying

The drying temperature of most plastics is between $70^0C – 120^0C$. We choose 120^0 C target temperature of the heating chamber. The materials must be raised from room temperature 25^0 C to 120^0C. Assuming a polycarbonate of mass 25kg as recycled and bagged, so the quantity of heat needed to raise this temperature from 25^0C to 120^0C can be calculated thus;

Q = heat needed to raise the material to its drying point

$$Q = mC_p\theta \quad (21)$$

Where; m = mass of material and measured at 25kg

Cp = specific heat capacity of material and has been determined from standard table as 2.004KJ/KgK

θ = temperature change = 120 - 25 = 95^0C.

The heat source must be able to generate this amount of heat and the amount of heat that will be lost through the walls of the heating chamber.

2.9 Selection of Drive Sprockets

The plastic pellets drying machine uses a total of two sprockets for its drives, one each mounted on the induction motor and the other on the drying shaft. Due to its high transmission efficiency, and assurance of perfect velocity ratio as no slip takes place during chain drive, sprockets were selected. The number of teeth of the selected smaller and larger (driving and driven) sprockets for the induction motor and drying shaft are 20 and 76 respectively. The speed of the induction motor is 1410rpm thus the speed of the driving and driven sprockets are determined as 141rpm and 37rpm respectively from the relation given by Khurmi and Gupta (2005) as;

$$N_1T_1 = N_2T_2 \quad (22)$$

Where N_1 and N_2 are the respective driving and driven sprockets' speeds while T_1 and T_2 are the corresponding number of teeth of the sprockets.

3. Developmental Procedure/Description of the Plastic Pellets Drying Machine

The major components of the developed plastic pellets drying machine (Figure 3) include induction motor (low speed motor), heating element, thermocouple, temperature controller, jackets, shaft ring (conveying ring) and drying chamber. The detailed production drawings for this machine fabrication are contained in the Appendix

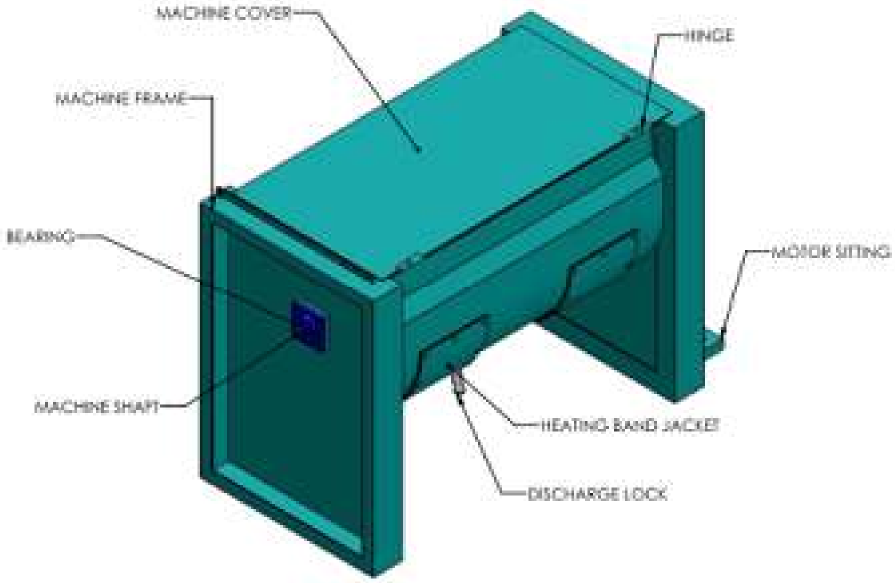

Fig. 3: The Isometric View of the developed Plastic Pellets Drying Machine.

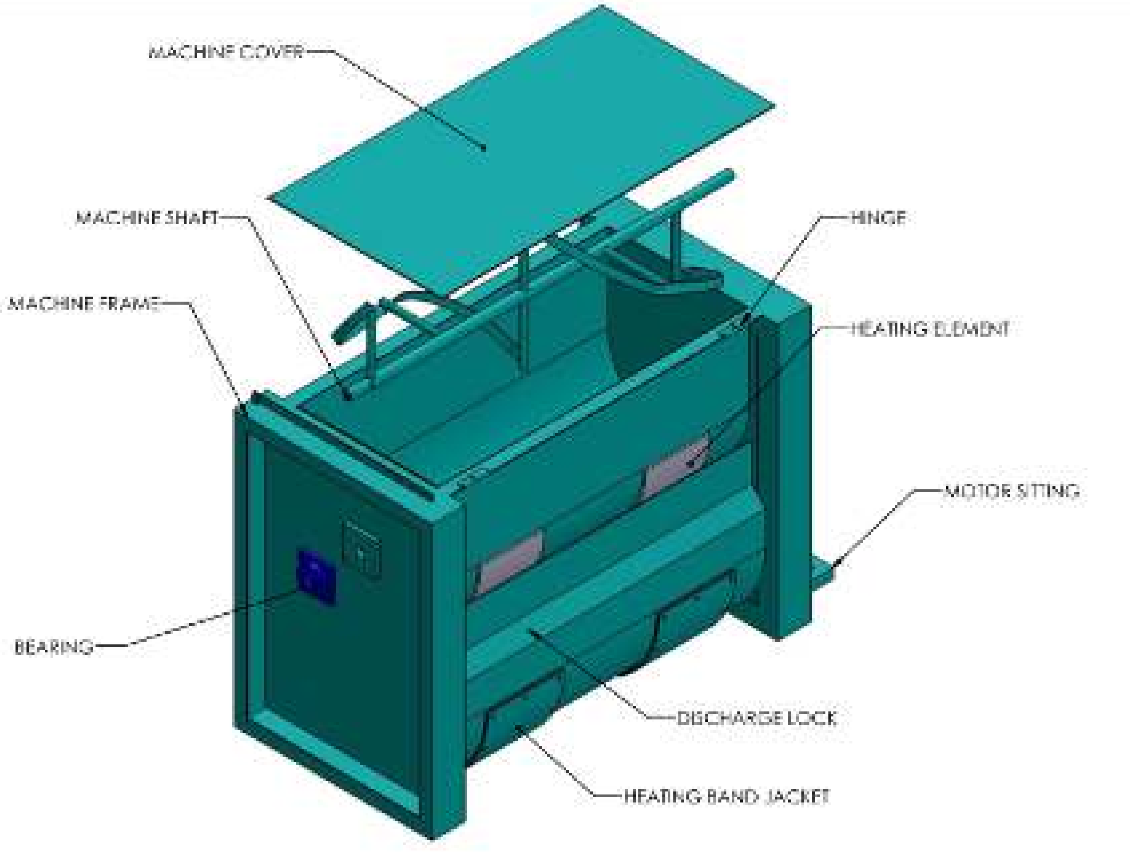

Fig. 4: Exploded View of the developed Plastic Pellets Drying Machine.

These components were assembled on a structural frame made from a 130mm x 80mm x 2.5mm mild steel U-channel and 50mm x 50mm x 2.5mm angular bar to give rigidity and stability that will withstand load vibration. The prime mover (induction motor) drives the shaft of the drying unit which in turn shuffles the material continuously.

The plastic pellets dryer powered by induction motor of power 1HP and at a speed of 1410rpm. The dimension of the plastic pellets dryer reads 1480mm × 775mm × 1070mm. The outlet is located at the bottom of the housing where the material is allowed to flush out. The heating compartment is where the heating element is attached to the housing with the help of the heat resistance wire. The machine is powered by an induction motor which has an induction gear via chain drive connected to the shaft that turns the conveying ring at a low and steady speed. The cover plate from where the pellets are fed is located at the top of the housing. The design of the Pellets dryer included the determination of the volume of the housing, heating chamber and heating elements and also the selection of a convenient material for the fabrication of the individual units. The bulk of the parts of the dryer were fabricated using mild steel plates, this is because it is the easiest to be joined among all other metals. It is a very versatile metal necessitating its use by many industries for fabrication of process unit equipment. Apart from its versatility, it is also very cheap and readily available compared to other metals.

3.1 Performance Testing Procedure

Recycled wet plastics pellets collected from the Enugu metropolis will be used for the evaluation of this machine. Evaluations of the machine will be carried out at a speed of 37rpm and temperature of 75^{0}c. The engine (induction motor) power and heating power of the heating element was designed to be 1Hp (746W) and 1000W respectively. The shaft diameter and length are given to be 40mm and 900mm respectively. The wet plastic pellets will be weighed to determine the weight before loading into the machine. The weighed samples of wet plastic pellets will be fed through the hopper into the drying chamber. The dried plastic pellets will be weighed after drying to know the amount of moisture removed and the drying rate was calculated to obtain the drying efficiency, moisture content (wet and dry basis) input and output capacities, in accordance to association of official analytical chemist (AOAC 2000). The performance evaluation will be carried out more times to obtain the average performance of the machine.

3.2 Development of Mathematical Model Procedures for Performance Evaluation of the Machine

The effects of shaft speed, temperature, power and torque parameters on system responses: specific mechanical energy (SME), drying efficiency and throughput were investigated. The temperature at the time of drying was recorded by a thermocouple embedded on the heating chamber. The objective was to understand the effect of shaft speed and drying system variables (power, speed, temperature and torque) on the performance of the machine.

From the table, the following independent factors or variables were considered; temperature, induction motor power, shaft diameter, heating power, shaft speed, torque etc. The dependent variables/responses of the machine were amount of moisture removed, moisture content (wet and dry basis), drying efficiency (DE), drying rate (throughput) specific mechanical energy (SME).

Amount of moisture removed M_w, (kg)

The amount of moisture to be removed from a given quantity plastic pellets to bring the moisture content to a safe usable/processing level in a specified time is calculated from the equation below according Khurmi and Gupta 2009);

$$M_r = M_o \frac{M_i - M_f}{100 - M_f} \quad (23)$$

where;

M_o = initial mass of the plastic pellets to be dried

M_i = initial moisture content, % wet basis

M_f = final moisture content, % wet basis

Moisture content (M_c)

The moisture content was determined by the gravimetric method according to the official methods of analysis employed by Association of Official Analytical Chemist (AOAC) 2009.

$$M_c = \frac{M_i - M_f}{M_i} \times 100 \quad (24)$$

where;

M_i = mass of plastic pellets before drying

M_f = mass of plastic pellets after drying

Moisture content of the wet basis

$$\%\ \text{wet basis} = \frac{moisture\ retained}{sample\ weight} \times 100 \quad (25)$$

Moisture content of the dry basis

% dry basis = $\frac{moisture\ retained}{weight\ of\ sample - moisture\ retained}$ x 100 (26)

Hence,
Average drying rate, M_{dr} (kg/hr)
Average drying rate, M_{dr} will be determined from the mass of moisture to be removed by electric heat and drying time by the equation below;

$M_{dr} = \frac{M_w}{T_d}$ (27)

Where,
M_{dr} = drying rate

M_w = moisture to be removed

T_d = time taken for drying to occur

Quantity of heat needed to evaporate water (KJ), Q

$Q = M_w \times h_{fg}$ (28)

Where;

M_w = amount of moisture removed

h_{fg} = the latent heat of evaporation of water (KJ/kg)

Note: amount of heat needed is a function of temperature and moisture content of the plastic pellets.

Drying efficiency DE,

DE = $\frac{wet\ basis}{dry\ basis}$ x 100 (29)

DE = $\frac{output\ weight\ of\ dried\ pellet\ resins}{input\ weight\ of\ wet\ pellet\ resins}$ x Throughput (30)

DE = $\frac{output\ weight\ of\ dried\ pellet\ resins}{time\ taken\ for\ drying}$ (31)

Specific Mechanical Energy,

SME = $\frac{power\ x\ time}{output\ weight\ of\ dried\ pellet\ resins}$ (32)

4. Results and Discussion

The plastic pellets drying machine performance test results shown in Tables 1 showed that its respective drying rate (throughput) and efficiency at a fixed temperature of 75^oC is 1.04kg/hr and 75.9% when electrically powered. Thus, the developed motorized plastic pellets drying machine has a very good throughput, moisture removal strength and drying efficiency for mass production. It is also affordable and energy saving.

Table 1: Results of the performance test of the Pellets Drying Machine at drying Temperature of 75°C (Electrically powered).

s/no	Weight of pellets before drying (kg)	Wet of pellets after drying (kg)	Time taken (mins)	Moisture loss (kg)
1	3.0	2.70	15	0.30
2	3.0	2.60	30	0.40
3	3.0	2.20	40	0.80
4	3.0	2.00	50	1.00
5	3.0	1.90	60	1.10
Average	3.0	2.28	40	0.72

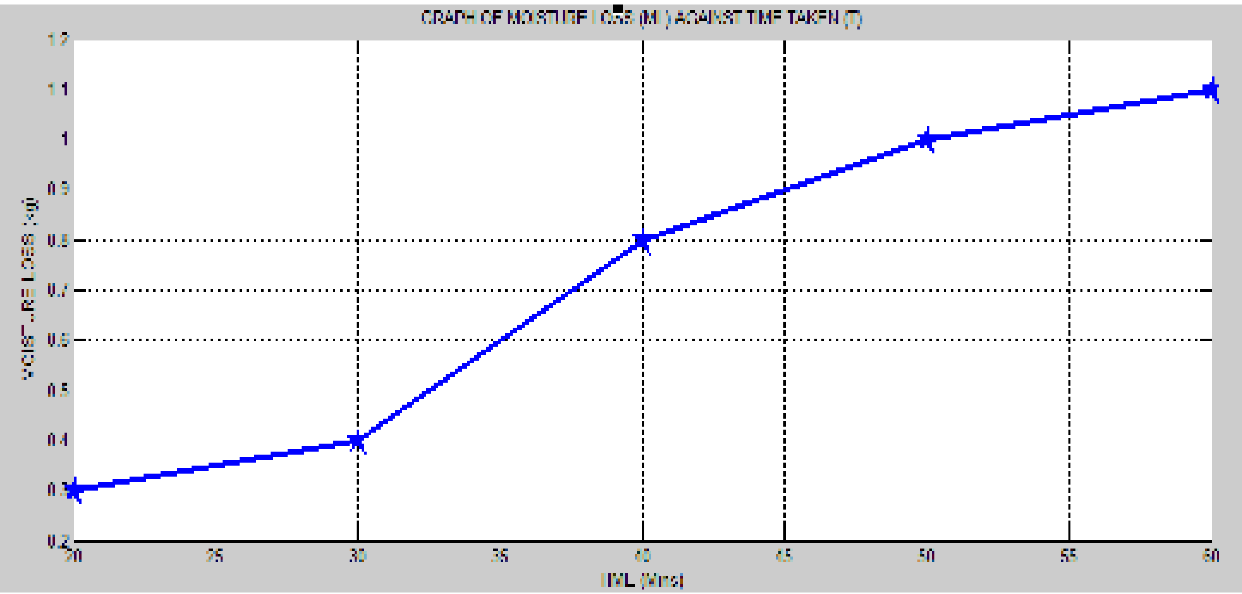

Fig. 5: Interval plot of moisture loss versus time taken

Fig. 5 shows various moisture losses for different time intervals. The time taken at 20, 30, 40, 50 and 60minutes respectively.

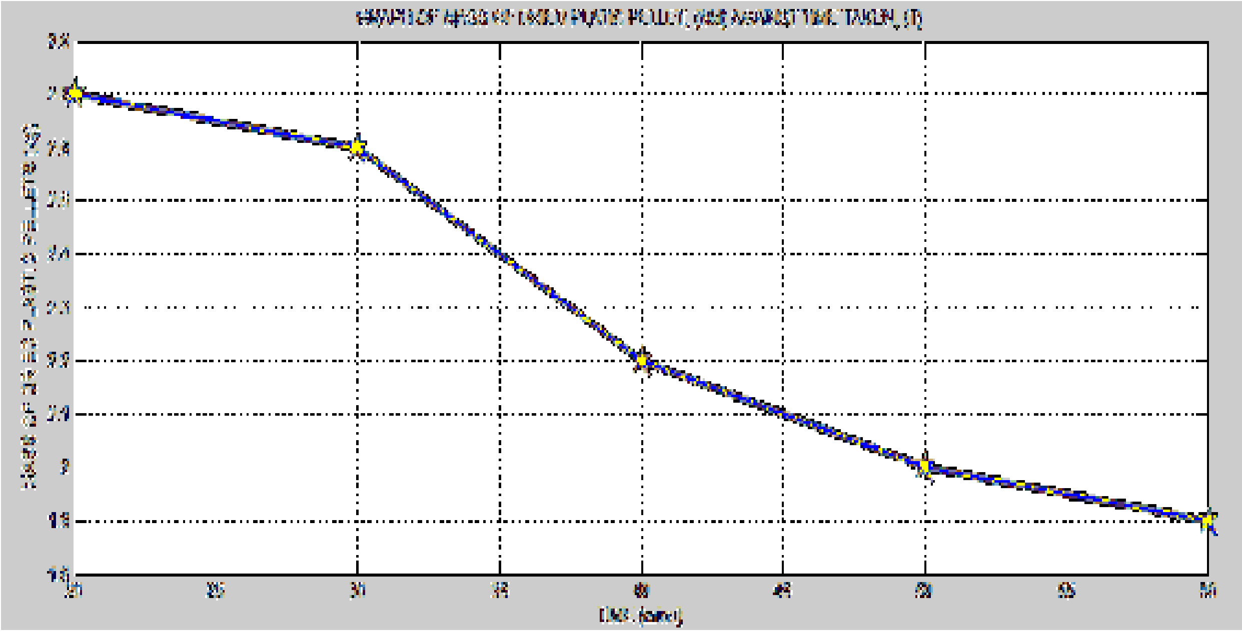

Fig. 6: Interval plot of mass of dried plastic pellets versus time taken

Fig. 6 illustrates the various mass of dried plastic pellets for different time taken. The time taken at 20minutes, 30minutes, 40minutes, 50minutes and 60minutes. Time taken at 60minutes has the highest moisture loss and least with time taken at 20minutes. This shows that the time taken at 60miutes has a very good threshing efficiency while the time taken at 20minutes of drying has the least.

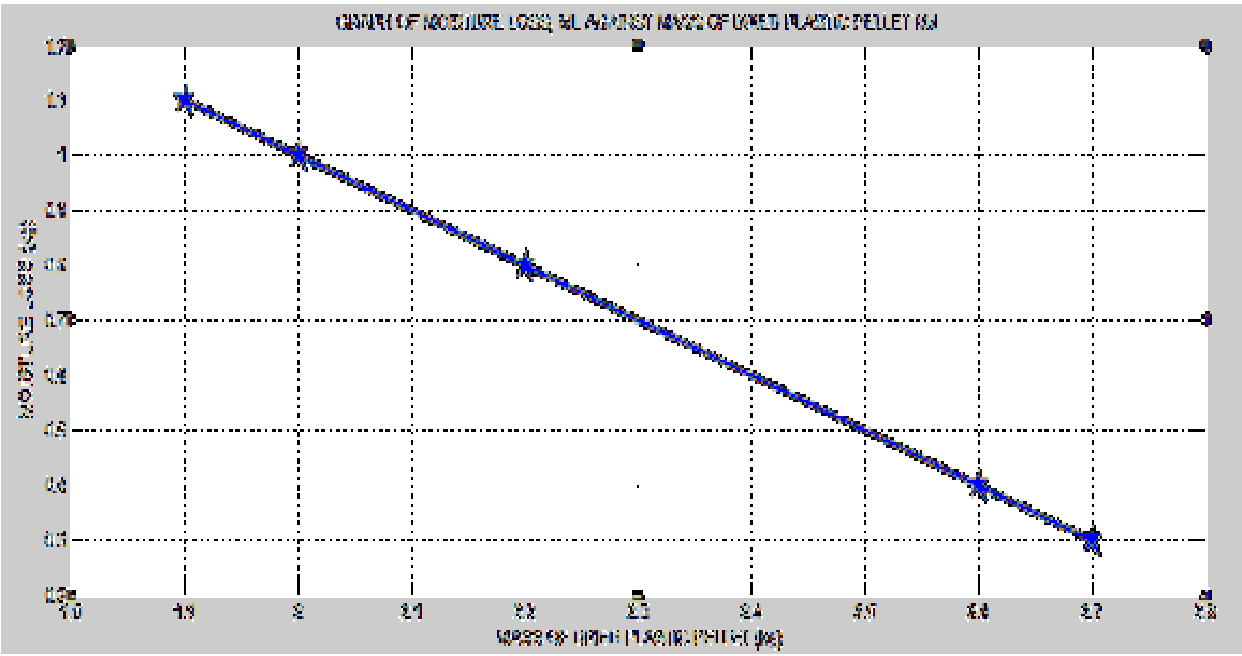

Fig. 7: Interval plot of moisture loss versus mass of dried plastic pellet

Fig. 7 shows the various moisture losses for different mass of dried pellets at different time taken. This shows that moisture loss will affect the mass of dried plastic pellets with high moisture loss indicating greater efficiency of the dryer.

From Table 2,
Percentage moisture content wet basis is given as

$$M_c = \frac{M_i - M_f}{M_i} \text{ x } 100 \tag{33}$$

$$M_c = \frac{3-2.28}{3} \text{ x } \frac{100}{1}$$

M_c = 24%

Percentage moisture content dry basis is given by;

$$M_d = \frac{Mw}{100-Mw} \, x \, \frac{100}{1} \tag{34}$$

$$M_d = \frac{24}{100-24} \, x \, \frac{100}{1}$$

M_d = 31.6%

Efficiency is deduced as;

$$\text{Efficiency} = \frac{wet\ basis}{dry\ basis} \, x \, \frac{100}{1} \tag{35}$$

$$\text{Efficiency} = \frac{24}{31.6} \, x \, \frac{100}{1}$$

Efficiency = 75.9%

Amount of moisture removed M_r, given by;

$$M_r = M_o \frac{M_i - M_f}{100-M_f} \tag{36}$$

$$M_r = 3 \, x \, \frac{24-1.1}{100-1.1}$$

Amount of moisture removed M_r = 0.69kg
Average drying rate D_r, is given as;

$$D_r = \frac{Mr}{t} \tag{37}$$

$$D_r = \frac{0.69}{0.67}$$

Drying rate, D_r = 1.04kg/hr

Specific mechanical energy SME, is given as;

$$SME = \frac{power\ x\ time}{output\ weight\ of\ dried\ plastic\ pellets} \tag{38}$$

$$SME = \frac{0.746 \, x \, 0.67}{2.28}$$

SME = 0.219KJ/kg

5. Conclusion and Recommendation

A plastic pellets drying machine was designed, developed and its performance evaluated at Enugu State University and Technology, Enugu using locally sourced standard materials. The machine eliminates drudgery and tedium in the processing and production of recycled plastic materials called plastic pellets as well as the excessive waste generated during the production of desired plastic products. The machine equally reduced the absorption of water during recycling process and enhanced the production of adequate quality and quantity of processed pellets. Adoption of this machine is recommended to facilitate recycling and recycled material for further processing into any plastic product in plastic processing industries as well as its degradation of the environment.

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