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DEVELOPMENT OF SPIN DRYER MACHINE

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ABSTRACT
A spin dryer is a dryer that uses centrifugal force and air interaction to dry BSG at ambient temperature, it is independent of sunshine. The major problem facing breweries in the country is how to utilize the spent grains after brewing due to its high moisture content. A spin spent grain dryer machine capable of drying 3kg of spent grain in 30min was designed, fabricated and evaluated. Fundamental design analysis and calculations were carried out to determine the selected materials for appropriate strength and sizes of the machine elements. The major parts of the machine include; internal basket with mesh diameter of 0.5mm, 2hp electric motor, the outer drum and the frame assembly. The results obtained after testing the machine shows the drying rate of the machine was 27.7g/min at a speed of 2840rpm and moisture content of 27.7% on weight basis. The efficiency of the machine was evaluated to be 72.3%. The operation of the machine is simple and its maintenance is also easy. It is thus found useful in the small scale spent grain processing industry.

Keywords: *Spin, Spent grain, Basket, Centrifugal force, Development.*

1.0 INTRODUCTION

Dehydration is one of the most important process of preventing post-harvested agricultural foods and seafood products from deterioration and wastage. In Nigeria, the problem of postharvest processing of raw food and food storage have prevented the micro and small scale farmers, food producers, and produce merchants from thriving well in their business. A large amount of agro-industrial waste is produced annually around the world from the beneficiated agricultural products or in food industrialization. The disposal of these residues in the environment results in a lot of inconvenience to the ecosystem, due to its significant nutritional value and high concentration of organic compounds that confers a high biochemical oxygen demand to the waste's degradation. In this context, brewing industry is among these activities, which includes in its production stages, the processing and fermentation of vegetable feedstock, such as barley malt and other grains, and hops, generating several by-products. Many factors, such as environmental policies, possible scarcity of non-renewable sources, and problems related to the improper use of renewable raw materials, leads to the development of new processes that could generate less waste or reused. Beer is the fifth most consumed beverage in the world apart from tea, carbonates, milk and coffee with an estimated annual world production exceeding 1.34 billion hectolitres in 2002 (Fillaudeau et al., 2006). In recent years, the use of solar energy has become other of the day. Solar radiation is the main source of energy for drying. The use of solar energy in the agricultural sector to dry grains, fruits, and vegetables is viable, economical and ideal for farmers in many developing countries. However, this pose problem for most products during rainy season, preservation by using only solar energy proves difficult (Barki et al., 2012). Hence, there is need for alternative means of drying. Spin dryer operate continuously at night and in cloudy days or when raining. It is very fast, it has been used for laundry purposes, this study modified the technology into spin grain dryer to solve problems which other dryers had in drying products; such as longer drying time, high cost of maintenance, complexity of operation and environmental factors and preservation of nutritive values.

2.0 METHODOLOGY

Stainless steel material was used for construction of parts of the machine that have direct contact with the brewer spent grain (BSG) because of its high resistance to corrosion. A 50 x 50 mm angle iron was used for the construction of the machine frame in order to give a rigid support and ensure stability of the machine when in operation (Gbabo et al., 2012). It is driven by a 1.5kw (2hp) motor, as the motor spins the basket, the moisture content is drain through mesh to the drum. The drum encloses the basket of mesh diameter 0.5mm, this outer casing collect water from the basket to prevent the splashing of the water and drain it through a spout. Stainless steel material is used to construct the basket in order to prevent corrosion of the material since it is in contact with water.

2.1 Description of Machine Parts

The Machine consist of the outer casing: This is made up of mild sheet of metal with diameter of 0.302m and 0.204m height. It is being mounted on the machine frame made up of angle iron assembly. A liquid outlet valve was fitted to the bottom side of the drum in order to allow out flow of extracted liquid from the grain and discharging it as shown in **Figure 2**. The basket is made of height 0.166m and diameter 0.194m. Its wall is smooth with perforated openings of diameter 0.5mm, in order to allow fluid drainage and prevent spent grain losses. This is a flat bar with ball bearing at its mid-point. This is to prevent the basket from wobbling while spinning.

Figure. 1.0: Vertical Section of Spin dryer Machine

2.1 Materials Selection

The properties considered in selecting the materials needed for the development of spin dryer according to (Gana et al 2013), are:

- Physical properties such as size and shape.
- Mechanical properties which include; strength, toughness, wear resistance etc.
- Chemical properties: this includes resistance to oxidation and all forms of corrosion since the machine is to be used in processing wet substance.

- Material availability: the materials used were selected based on their availability such that they can be obtained from the market with ease.
- Cost of materials: materials used can be made available at a cheaper price.
- Strength of material: to avoid operational failure, the strength of the materials used was ascertained.
- For construction of the proto-type, ordinary mild steel was used but painted to reduce corrosion.

2.2 Design Considerations and Specifications

The following parameters were used during the development of the machine:

- Density of mild steel = 7840 kg/m^3
- Power of electric motor = 2hp =1.5KW
- Selected length of shaft = 0.339m
- Acceleration due to gravity, g = 9.81g/m2
- Motor speed (N) = 2840rpm
- Allowable shear stress of mild steel is 56MPa for shaft without keyway (Khurmi and Gupta, 2005).
- Combined shock and fatigue factor applied to bending and torsional moment, k_b and k_t are 1.5 and 0.3 respectively (Khurmi and Gupta, 2005).
- Coefficient of friction between belt and pulley = 0.3

2.3 Theory of the design

The theory of design of spin dryer is based on the effect of a centrifugal force on the spent grains inside the basket. The spent grains were pushed towards the wall of the basket by centrifugal forces, which were compressed to the wall of the basket and the moisture content was removed as the basket was spinning (Gbabo 2005). A centrifugal force is a force which acts away from the centre of rotation. Centrifugal forces are commonly identified with the following effects such as when a passenger in a car is "thrown" to one side when a sharp turn is made, the passenger is in a rotating frame and thinks centrifugal force pushes him outward. Centrifugal force arises due to Newton's first law of motion known as law of inertia. (the tendency of a body to be in a state of uniform motion or in a state of rest)

2.4 Design analysis of components

The analysis of the design is aimed at determining the necessary parameters for selection of the various machine elements. The machine is designed to carry a maximum load of 3kg. This was done in order to avoid failures of machine parts during operation of the machine.

2.4.1 Determination of Power Required

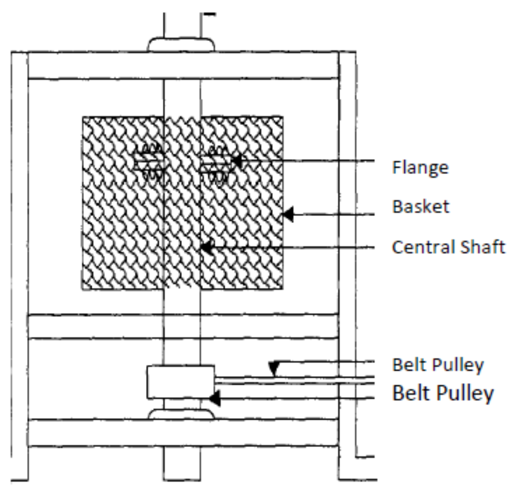

Figure 2: Vertical section of spin dryer

$P = F_T V$ 1

Where

P = the power required rotate the basket and its content (W)

F_T = the total weight of the basket, its content and central shaft (N)

Velocity of the basket at full speed (m/s) is given by equation 2 below:

$V = \frac{2\pi N}{60} = \frac{2*\pi*2840}{60} = 297.4m/s$ 2

The required torque is given by equation 3 bellow:

$T = Fr_b = 4.8*9.81*0.097 = 4.57Nm3$

The power required to spin the basket is a function of weight of the basket, its content and that of the shaft. It is given by equations 1 to 6 according to (Khurmi and Gupta 2005).

$P = \frac{2\pi NT}{60} = \frac{2*\pi*2840*4.57}{60} = 1359.14W$ 4

$\omega = \frac{2\pi N}{60} = \frac{2*\pi*2840}{60} = 87.96rad/sec$ 5

Where; P= power required by the machine (W)
F = the total force required (N)
T = the torque (Nm)
M =total mass (4.8kg)
ω = angular velocity of the basket(rpm)
M_1 = mass of material to be dried (3kg)
M_2 = mass of basket (0.3kg)
M_3 = mass of shaft and pulley (1.5kg)
π = constant
g= acceleration due to gravity =9.81m/s^2
d_b = Diameter of the basket(m)
r_b= radius of the basket (m)
N = number of revolution per minute of the basket (rpm)

2.5 Centrifugal force generated in the spinning basket

Centrifugal force is the force which acts radially away from the centre of rotation. It is set up in the basket due to rotation of the basket while in operation. In line with the principle of centrifugal force, the direction of the force is from the centre of the basket towards the circumference of the basket as shown in **Figure** 1. This is given by equation 6 as:

$F_c = Mr_b\omega^2 = 4.8*0.097*87.96^2 = 3.602KN$ 6

2.6 Stress in the spinning basket

The stress in the basket is due to the action of the centrifugal force on the wall of the basket which is computed in order to assist in the determination of the thickness of the basket. It was determined using the equations reported by (Gbabo et al, 2003)

$\sigma_b = \frac{M\omega^2 r_b}{\pi D_b H_b} = \frac{M\omega^2}{2\pi H_b} = \frac{4.8x87.96^2}{2x\pi x0.166} = 35.6KN$

σ_b = stress on the wall of basket (N/m^2)

H_b= height of the basket (m)

2.7 Design of basket thickness

The thickness of the basket to withstand the centrifugal force generated is given by the equation reported by (Gbabo and Igbeka 2003)

$t_b = \frac{\sigma_b d_b}{2\tau_b} = \frac{35600x0.194}{2x56000000} = 0.063mm$ 8

t_b = thickness of the basket (mm)
σ_b = stress on the wall of the basket (Pa)
d_b = diameter of the basket (m)

τ_b = shear stress of stainless steel used for the basket (Pa)

2.8 Design of Shaft

Shaft is a rotating member of circular cross-section solid or hollow in nature, which transmits power and rotational motion. Elements such as gears, pulleys (sheaves), flywheels, clutches, and sprockets are mounted on the shaft to transmit power from the driving device (motor or engine) through a machine. It is the member on which press fit, keys, dowel, pins and splines are usually attached to. Shaft rotates on rolling contact bearings or bush bearings. Various types of retaining rings, thrust bearings, grooves and steps in the shaft are used to take up axial loads and locate the rotating elements. Couplings are used to transmit power from drive shaft (e.g., motor) to the driven shaft (gearbox and wheels).

2.8.1 Torque on the shaft (twisting moment)

The high speed rotating shaft is attached to the basket is subjected to a twisting

moment. In order for the shaft not to fail, the value of the torque generated must be within the permissible limit. This was determined as expressed by (Gbabo et al 2003).

$$T_s = \frac{60P}{2\pi N} = \frac{60x1500}{2x3.142x2840} = 5.04Nm \quad 9$$

T_s = Torque on the shaft (Nm)
N = speed of the shaft (rpm)
P = power transmitted (Watt)
π =constant (3.14)

2.8.2 Torsional shear stress

The torsional shear stress of the shaft was computed as a function of the twisting moment, diameter and second moment of area as expressed by (Webb 1982):

$$\tau_t = \frac{T_s d_s}{2J}$$

τ_t = the torsional shear stress (N/m^2)

d_s = diameter of shaft (m)

$J = \frac{\pi d_s{}^4}{32}$ where J is the polar moment of area(m^4)

By substituting J into equation above we have

$$\tau_t = \frac{16T_s}{\pi d^3} \quad 10$$

2.8.3 Diameter of Shaft

The diameter of the shaft to transmit power to the internal basket is dependent on the

torque (T_s) on the shaft and the permissible shear stress of the material of make. According to American Society of Mechanical Engineers (ASME) code for the design of

transmission shafts, the maximum permissible working stresses in tension or compression may be taken as 112 MPa for shafts without allowance for keyways and that of maximum permissible shear stress may be taken as 56 MPa for shafts with allowance for key ways. From equation 10, diameter of the shaft can be calculated as:

$$d^3 = \frac{16T_s}{\pi\tau_t} = \frac{16x5.04}{\pi x56000000} \rightarrow d = 0.018m \quad 11$$

2.8.4 Length of the Belt

Belts are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds.

In an open belt drive, both the pulleys rotate in the same direction.

$$L = \frac{\pi}{2}(d_1 + d_2) + 2X + \frac{(d_1 - d_2)^2}{4X} \quad 12$$

$$L = \frac{\pi}{2}(9.9 + 5.5) + 2x27.2 + \frac{(9.9 - 5.5)^2}{4x27.2}$$
$$= 78.8cm$$

d_1 and d_2 = diameter of the driver and driven pulleys (9.9 and 5.5cm)

x = Distance between the centres of two pulleys (27.2)

L = Total length of the belt.

2.9 Belt Velocity Ratio

Velocity ratio of belt is the ratio between the velocities of the driver and the driven pulley.

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad 13$$

N_2 = Speed of the driver pulley

N_2 = Speed of the driven pulley

2.9.1 Power Transmitted by the Belt

Power transmitted by belt is the product of effective driving force at the circumference of the driven or driven pulley $(T_1 - T_2)$ and the velocity of belt (v).

$$P = (T_1 - T_2)\ v \quad 14$$

$$2.3\log_{10}\left[\frac{T_1}{T_2}\right] = \mu\theta \quad 15$$

T_1 and T_2= tensions in the tight and slack side of the belt respectively.
θ = angle of lap of the belt with pulley in radian, where

$$\theta = \frac{L_1}{r_1} \quad 16$$

r_1 and r_2 = radii of the driving and driven pulley

L_1 = length of belt lapping the pulley (18.8cm)

3.0 Results and Discussion

The BSG were obtained from Nigerian Breweries Ibadan. Brewery BSG were collected from the spent grain silo shortly after being removed from the mashing process. The performance of BSG spin dryer was evaluated in accordance with procedures reported by (Gbabo et al. 2012). Four groups of experiments were carried out to investigate the performance of the machine. The experiments were carried out at Etsu Yahaya Abubakar Farm centre Bida, Niger State Nigerian on 8th July, 2019.

3.1 Design of the experiments

In the first set of experiments, the speed level of 2840rpm was taking and various masses of 0.5, 1, 2 and 3kg of BSG was introduced into the basket for a period of 30seconds respectively. Mass of BSG after spinning were in each case read and rate of dehydration was evaluated and recorded in table 2 bellow.

Table 2: Mass of water removed and rate of dehydration at 2840rpm for 30min

Mass of moist BSG Before spinning (kg)	Mass of BSG after spinning (kg)	Mass of water removed (kg)	Rate of dehydration(g/min)
0.5	0.292	0.208	6.93
1.0	0.585	0.415	13.8
2.0	1.376	0.624	20.8
3.0	2.169	0.831	27.7

The equation for determining drying rate was given by (Adamade et al., 2014).

$$R_t = \frac{M_m - M_d}{t} = \frac{3-0.831}{30} = 27.7\text{g/min} \quad 17$$

R_t = rate of dehydration of water(Kg/s)
M_m = Mass of BSG before spinning (kg)
M_d = Mass of BSG after spinning (kg)
t = time taken for dehydration (min)

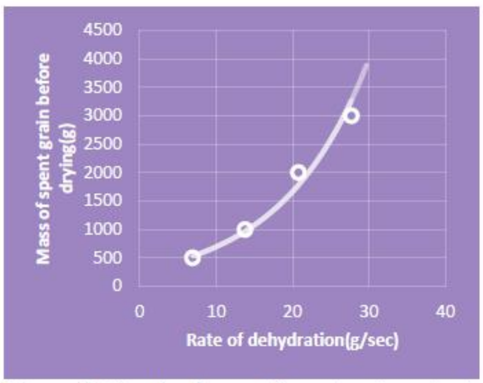

Figure 3: Graph of mass of spent grain against rate of dehydration at speed of 2840rpm for 30sec.

From the graph of mass of wet spent grain against rate of dehydration of spent grain at constant speed of 2840rpm and 30sec, it is observed that the out flow rate of moisture content of the spent grain increases with increase in mass of the moist spent grain up to the maximum loading capacity of the dryer. This is indicated by upward sloping of the graph from left to right.
In the second experiment, the dehydration time for a mass of 3kg of BSG at four speed levels were determined and recorded in table 3 bellow

Table 3: Time taken to dehydrate 3kg of BSG & water removed at four speed levels

Speed(rpm)	Time (min)
2840	93.80
1420	130.70
710	201.10
355	306.60

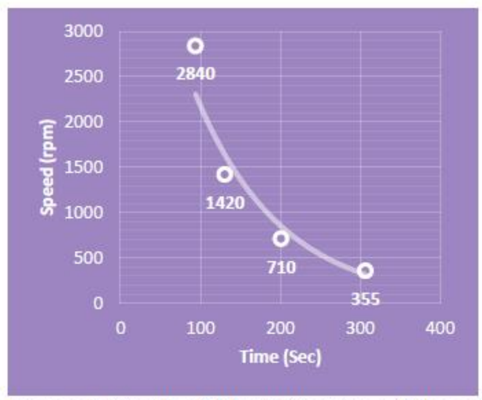

Figure 4: Graph of dehydration time of 3kg of spent grain against speed

From graph of speed against time taken to dry spent grain, we observed that the higher the speed, the lower the time take to dry spent grain and the lower the speed, the longer the period of dehydration of spent grain. This is indicated by the downward sloping of the graph from top left hand corner to the right.

3.2 Efficiency of the Dryer

Efficiency point out the how best the machine can carry out the drying of the sample. It is expressed as the ratio of output to the input.

There are some factors that affect drying efficiency some of which are ambient air condition, type of material to dry and design and operation of the dryer. The equation for computing the efficiency was given by (Adamade et al., 2014).

$\eta = \frac{M_d}{M_m} \times 100\% = \frac{2.169}{3} \times 100\% = 72.3\%$ 18

$\eta =$ Efficiency of the spin dryer

3.3 Moisture Content (M_c)

Water is found in all food products. Too little or too much can alter food properties. Moisture content can affect the physical and chemical properties of food, which directly correlate to the freshness and stability of food products for consumers. It determines the food quality, shelf life and legal labelling requirements. The moisture content on wet basis is given by the equation 19 bellow according to (Odunukan, R. O. et al 2013).

$M_c = \frac{M_m - M_d}{M_m}\, x100\% = \frac{3-2{,}169}{3}\, x100\% = 27.7\%$ 19

4.0 Conclusion

The objective of this project was well achieved as the spin dryer was able to dry moisture content in the spent grains within a possible time-frame. The dryer was found to be effective, easy to operate and affordable. The dryer has loading capacity of 3kg and can dry 3kg of spent grain in 30min, it has no heat source.

The dryer was able to keep consistent drying time considerably. The moisture content of the spent grain was found to 27.7% on weight basis; this is in agreement with (Elshatey et al 2004) whose equilibrium moisture content is within the range of 20 – 30%. This was achieved by spin dryer in approximately 5 – 8min, this is significant when compared with that reported by (K.S. Tonui et al., 2014) which took 4h drying daily in 3days to achieve the same purpose using solar dryer. The developed dryer is compact easy to maintain and be move from one place to another easily. Efficiency of the dryer was found to be 72.3% and drying rate of 6.93g/min which is in agreement with many other modern drying technologies. It is faster than the open sun drying method and solar dryer which has thermal efficiency estimated to be about 57.7% with average drying rate of 0.0077 kg/h, according to (K.S. Tonui et al., 2014).

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