DESIGN, CONSTRUCTION AND PERFORMANCE ANALYSIS OF BREWERY WASTE DRYER

Odunukan, R. O., Akinyemi, D. O., Tanimola, O. A. & Bankole, Y. O
Department of Agricultural and Bio-Environmental Engineering, Lagos State Polytechnic, Ikorodu
NIGERIA

ABSTRACT

This paper focused on the design and construction of Rotary dryer. The dryer can dry successfully brewery spent grain (BSG). It hinged on the high cost of wheat offal and maize grain in animal feeds to provide least cost and nutritious brewery waste feeds for animal. Rotary dryer that can dry brewery waste continuously was designed, constructed and tested to evaluate it performance. The dryer with its components was evaluated with three trials and its efficiency was 78% with temperature of 160^{o}C and output capacity of 377kg/hr. This paper recommended that for efficient performance of the dryer; It should be used industrially, air blower should be introduced and with one single phase gear reduction motor.

Keywords: Design, construction, performance, Brewery Waste Dryer.

INTRODUCTION

Food industries globally are faced with political and social pressure to reduce their level of pollution. Almost all developed and underdeveloped countries are trying to adapt to this reality by modifying their processes so that their residues can be recycled. Most large companies no longer consider residues as waste, but as a raw material for other products (Afshar*et al*, 2011). The brewing industry however, generates relatively large amounts of by-products and wastes; spent grain, spent hops and yeast being the most common. However, as most of these are agricultural products, they can be readily recycled and reused. Thus, compared to other industries, the brewing industry tends to be more environmentally friendly (Femi-Ola, Daniels and Olajiga, 2013). Thiago, Pedro and Eliana (2014) opined that wet brewer's grains are the most common residue of brewing. They are considered to be good sources of non-degradable protein and water-soluble vitamins. They are readily used in feeding both ruminant and mono-gastric animals. They can be fed as wet or dried feed to animals especially pigs.

The nutritional content of the material vary from plant to plant and depending on the type of grain used (barley, wheat, corn, etc.) in the initial brewing process as well as proportions being fermented and fermentation process being used. Some breweries will dry the brewer's grain and sell it as dried brewer's grain, while others will have it available as wet brewer's grain. Both types have similar feeding characteristics if the wet brewer's grain is fed shortly after it is produced. Wet brewer's grains are sterile material when it leaves the brewery. The material is produced from products that are food grade quality and are subject to extensive heating for extended periods of time during the mashing process. The heating of the grains serves to increase the palatability and the establishment of high levels of by-pass proteins. Brewer's grains, in fact, are rated as having one of the highest values of bypass protein in commonly available feed stock. Wet brewers' grains have high water content;75-80%, they spoil quickly, bulky and their transportation is expensive. They are mostly advised to be used in farms close to the brewery; limited distances of 167 – 333 km. Brewers' grains are prone to bacterial and fungal contamination (Thomas, et al.., 2010). In order to increase the shelf life of brewers' grains, the brewery waste dryer is used in dehydrating these feed materials.

The dryer helps to reduce both bacterial and fungi contamination of the feed. It also, reduces or removes moisture from the brewers' grain spent and thereby enabling it to be stored for future used. The drying method can either be natural (sun drying) or mechanical/electrical (oven, steam or rotary dryer) method. Drying of brewery waste has always been done traditionally through sun drying or spreading it on the ground for some period of time to reduce the moisture content to a safe moisture level. But various problems and challenges had arisen using this method. Therefore, fabrication of a cabinet dryer will be a better alternative for effective dehydration of the brewers' grain. This paper focused on the design and fabrication of rotary dryer purposely for the dehydration of waste generated from breweries. The dryer performance and efficiency were also evaluated.

MATERIALS AND METHOD

The following factors were considered before the selection of materials; strength of the materials suitable for the fabrication, durability, cost, ease of handling and heat resistance. The basic materials for construction include:

i. Power Source. The major source of power is the electricity. The electrical energy is converted to heat energy for drying
ii. Mild Steel or Carbon steel. A low range carbon (0.3%) steel with good strength, worked on, welded into endless varieties of shapes.
iii. Heating element to converts electrical energy into heat energy
iv. Thermocouple; temperature measuring device consisting of two dissimilar conductors that contact each other at one or more spot.

Design Analysis

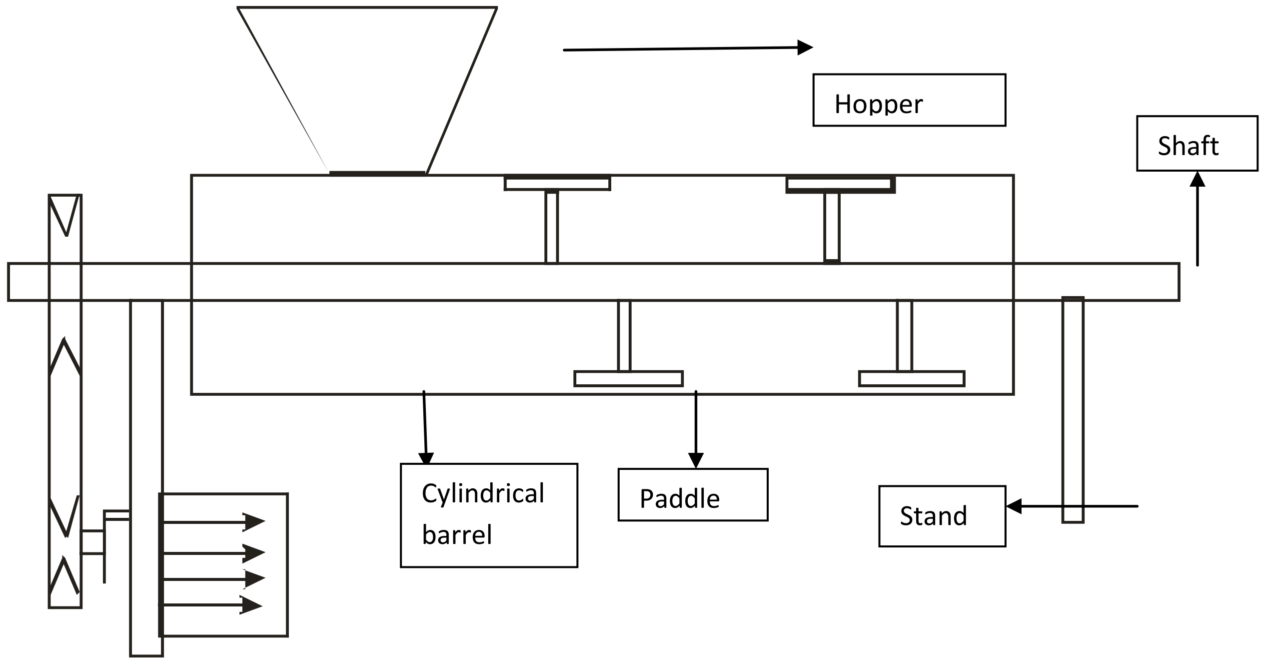


Fig. 1: Schematic drawing of the design concept

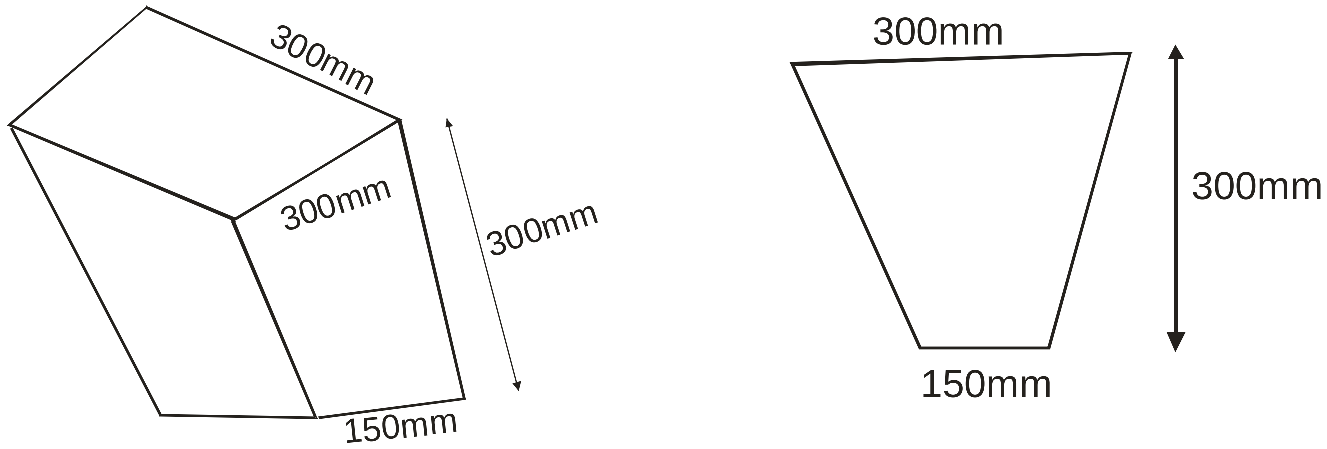


Fig. 2: The hopper Volume of the hopper

$$V = \frac{1}{3}\left(A_1 + A_2 + \sqrt{A_1 + A_2}\right) h$$

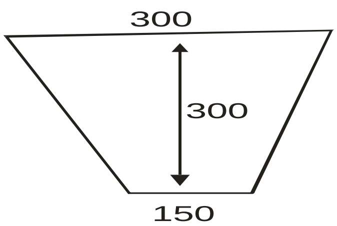
Where,
V = the Volume of the hopper
A_1 = Area of the upper base
A_2 =Area of the lower base
h =Height of the hopper
B= 300mm, b= 150mm, h= 300mm
A_1= B×B=0.3×0.3 = 0.09
A_2 = b×b = 0.15× 0.15 = $0.0025m^{2}$[

$$V = \frac{1}{3}\ (0.09 + 0.225 + \sqrt{0.09 + 0.225})0.3$$

$$\frac{1}{3}(0.1125 + \sqrt{0.1125})\ 0.3$$

$= 0.05m^2$

Weight of the materials of the hopper in (mm)



Shape Area of each faces of the hopper is Trapezium

$$i.e\ A = \frac{1}{2}\frac{A + B}{h}$$

$$= \frac{1}{2}\frac{0.3 + 0.15}{0.3}$$

= $0.0675m^2$

Area of the Four Faces

Total surface area = 0.0675x4 = $0.27m^2$
Using 3mm thick mild steel plate material volume
W = mg

Where,
w = weight,
m = mass,
g = gravitational forces,
= 7850 x 0.00081
= 6.3585 x 9.81
= 6.3585kg
= 62.38N
(Where Density of mild steel = 7850kg/m^3)

Cylindrical Barrels

There are (3) three concentric Cylindrical Barrels

Cylinder (1)

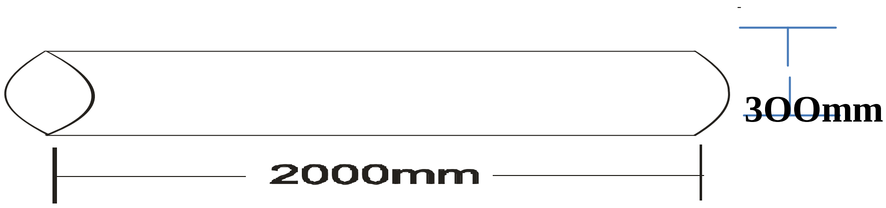


Fig. 3: The inner cylinder

$$L = 2m, r = \frac{d}{2} = \frac{0.3}{2m}$$

Volume of the Cylindrical Barrel
V = πr2 = L
Where,
v= volume of the cylinder,
l= length of the cylinder
r= radius of the cylinder
= 3.142 x $\left(\frac{0.3}{2}\right)^2$ x 2.
= 0.1414m

Weight of the Material of the Cylindrical Barrel

Total surface Area = Area of the curved part
= 2πrl
= 2 × 3.142 ×$\frac{0.3}{2}$×2
= 1.8850m^2
Weight of the materials of the cylindrical barrel
Mass = Density x volume
= 7850 × 0.005655
= 44.392kg
But W = Mg
∴ W = 44.392 × 9.81
= 435.486N

Cylinder 2

Weight of the materials of the bar set.

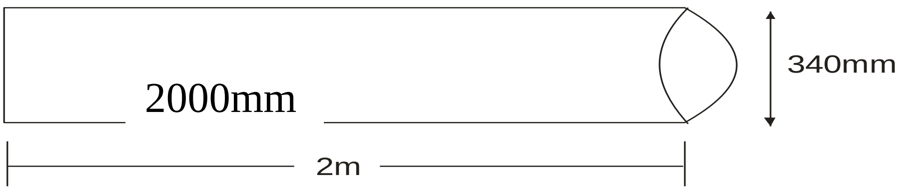


Fig. 4: The middle cylinder

Area of the curved parts = 2 π r L

$= 2 \times 3.142 \times \frac{0.34}{2} \times 2$

= 2.13628m^2
Volume of the materials of the cylinder barrel
V = Area x Thickness
= 2.13628 x 0.003
= 0.00640885m^3
Weight of the material of the cylinder barrel
Mass = volume x density
Mass = 0.00640885 x 7850
= 50.3095kg
W = 50.3095 x 9.81
= 493.536N

Cylinder 3

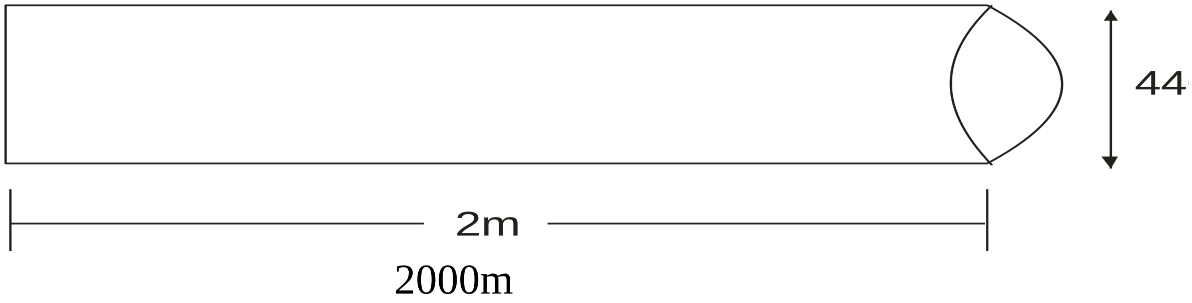


Fig. 5: The outer cylinder

Area of the curved part = 2πrl

$$2.3142 \times = \frac{0.44}{2} \times 2$$

= 2.76460m^2
Volume of the materials of the cylinder barrel
V = Area x thickness
= 2.76460 x 0.003
= 0.0082938m^3
Weight of the materials of the cylinder barrel
Mass = Volume x density
= 0.0082938 x 7850
= 65.10637kg

W = Mg
= 65.10637 x 9.81
= 638.693N

Weight of the Brewer Spent Grains to Be Dried

Assuming the cylindrical barrel is filled up to the one quarter ($^1/_4$) of its volume at a time for proper mixing and even distribution of heat within the product during the drying process.
Therefore, the volume of the barrels (Inner)
Occupied by the Brewer Spent grains

$$= \frac{0.1414}{4} = 0.03535m^3$$

The Density of Brewer Spent Grains

The mass of the brewer spent grains is this
= volume of Density

$$= \frac{0.03535}{1352} = 47.7kg$$

But W=m x g = 47.79x 9.81 =468.82N

Belt Drive

This is the continuous operation which requires low speed operation in order to ensure even distribution of heat within the product. Hence, speed of 20rpm is recommended. It is required to design an open type V-belt drive connected to 2.24kw (3hp), 100 rpm gear electric motor to a rotating shaft running at 20rpm. The center to center distance is 500mm, while the groove angle is 40^0 and the coefficient of frictions is 0.2. Using the standard table (15: 2494 - 1974) the cross section of the belt for this application is type A the mini pitch diameter for the pulley is 75mm. the width is 13mm and the thickness is 8mm. the belt density is 0.95gm/CC

Diameter of the Driver Pulley

$d_1Vi = d_2V_2$

$$d_i = \frac{d_2 v_2}{v_1}$$
$$= \frac{75 \times 100}{10}$$
$$= 375mm$$

Belt Length

$$L = 2(500) + \pi\frac{(375+75)}{2} + \frac{(375+75)2}{4(500)}$$
$$= 1000 + 706.858 + 4$$
$$= 1751.85$$

Angle of wrap (∝s)

$$\propto S = 180 - 2sin{-}^{1}\frac{(D-d)}{2c}$$

$$\propto S = 180 - 2sin\frac{(375-75)}{2(500)}$$

= 180 – 2sin^{-1} 0.3
= 145.085^{0}
=2.53 radian

$$V = \frac{\pi dn}{(60)(1000)}$$

$$= \frac{\pi(75)(100)}{60 \times 1000}$$

= 0.3927ms^{-1}

Mass of the belt per unit length

$$M = (0.95)(10^{-5})(100)(\frac{13}{10})(\frac{8}{10})$$

= 0.988kg/m

Mv^2 = 0.0988 x (0.3927)^2

= 0.015236

3.3.7 Tensions in the belt

$$But\frac{T_1 - MV^2}{T_2 - MV^2} = e\ f\alpha\sin(\frac{1}{2\theta})$$

$$\frac{T_1 - 0.015236}{T_2 - 0.015236} = 4.3905$$

Also Power Transmitting In the Belt

$$Kw = \frac{(T_1 - T_2)}{1000} =$$

$$\therefore 2.24kw = \frac{(T_1 - T_2)0.3927}{1000} \quad (2)$$

Solving equation (1) and (2) simultaneously

T_1 – 0.015236 = 4.3905 (T_2 – 0.015236)

T_1 = 0.015236 = 4.3905 T_2 –0.0668937858

T_1 = 4.3905 T_2 – 0.05165779 (1)

Substituting T1 in equation 2

$$2.24 = \left(\frac{T_1 - T_2}{1000}\right) 0.3927$$

2.24 x 1000 = (4.3905 T_2 – 0.05165779 – T_2) 0.3927

5704.0998 = 3.3905 T_2 –0.05165779

5704.0998 + 0.05165779 = 3.3905T2

T_2 = 1682.39N

Substituting T2 in equation

T_1 = 4.3905 (1682.39) – 0.05165779

T_1 = 7386.48N

Therefore, the tension acting in the belt is 1682.39N and 7386.48N

T_1 + T_2 = 1682.39 + 7386.48

= 9068.37N

Weight of the Paddles

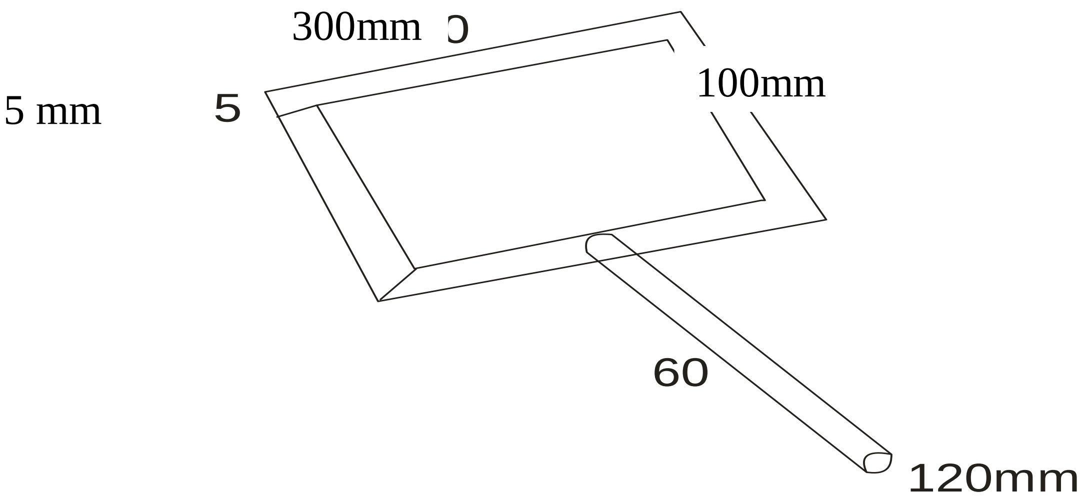


Fig. 6: The paddle

The paddle is a composite shape of cuboids and cylinder

Volume of the cylinder = $\pi r^2 L = \pi \times (0.020)^2 \times 0.06$

= 0.0000.1.884 956m^3

= 0.0001884956m^3

Volume of the cuboid = lbh = 0.3x0.1 x 0.005

= 0.0015m^3

Total volume of the paddle = 0.0000 188955 + 0.00015

= 0.0001684956m^3

Mass of the paddle = Density x Volume

= 7850 x 0.00016884956

= 0.132547kg

There are six (6) paddles

Total weight of the 6 paddles = 0.132547 x 6

= 0.79528kg

Weight = Mass x Acceleration due to gravity

Weight of the paddles = 0.79528 x 9.81

= 7.80N

Design of the Central Shaft

Weights acting on the central shaft are:

A. Tensions due to belt

B. Weight of the paddles

C. Weight of the brewer spent grains, which shall be evenly distributed on the shaft.

The shaft is inclined in order to facilitate the discharge of the dried brewer spent grains after the drying operation.

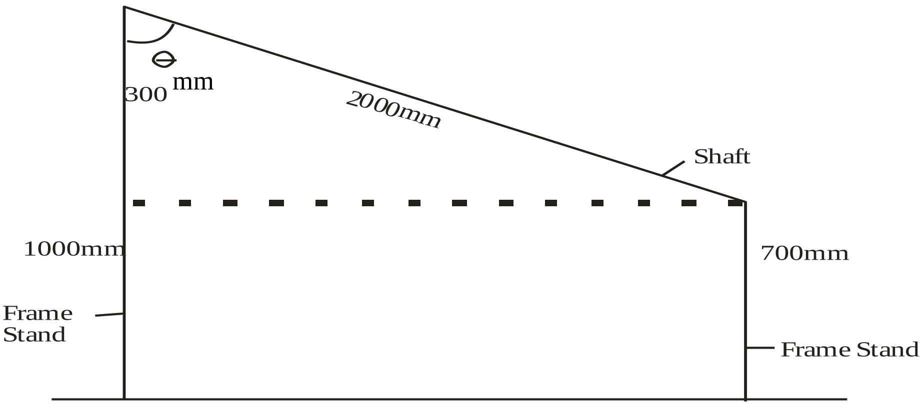


Fig. 7: The shaft

$$cos\theta \frac{300}{200} = 0.15$$

$\Theta = Cos^{-1} 0.15$

$\Theta = 81.37^{0}$

All the forces are acting vertical downward hence; they must be resolved based on the angle of inclination of the shaft.

Angle of inclination = 90° – 81.37°
= 8.63°
Belt tensions =9068.87 Cos 8.63°
= 8966.26N
Force due to paddles = 7.80 Cos 8.63
= 7.71N
Weight due to the spent grains = 468.82 Cos 8.63
=467.51N

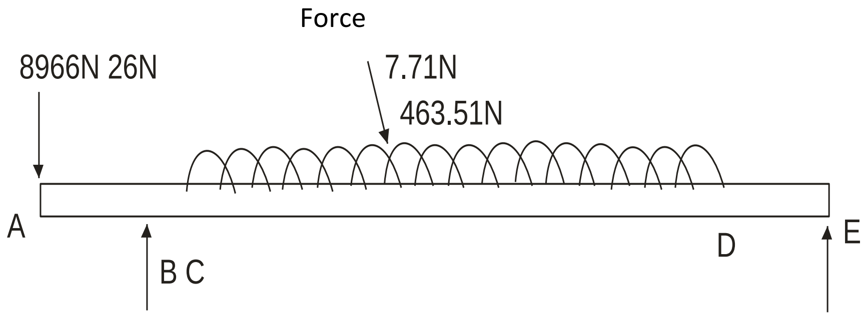


Fig. 8: The central shaft

The horizontal components of all the forces are zero. An inclined shaft supporting a pulley at point A is powered by a means of a vertical belt on the pulley. The shaft supports uniformly distributed load of 7.71N (Weight of paddles) and 463.51N (weight of Brewers spent grains). The shaft is assumed to be made of plain carbon steel with an ultimate tensile strength 650N/mm^2 and yield strength 380N/mm2. The pulley is keyed to the shaft. The diameter of the shaft is determined according to ASME Code given that K_b = 1.5 and K_t = 1.0.

Thus $0.30S_y$ t = 0.30 x 380 = 114 N/mm^2

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$0.18\ S_y\ t = 0.18 \times 650 = 117 N/mm^2$

Whichever is minimum is considered, which is $114 N/mm^2$

Therefore, Tmax = 0.75 x 114 = 85.8 N/mm^2

Diameter of the Shaft

$$\frac{16}{\pi Emax}(K_b\ M_b)^2 + (K_e\ M_E)^2$$

$$d^3 = 16 \quad \frac{(1.5 \times 896626)^2 + (1.0 \times 1069516.815)^2}{\pi \times 85.5}$$

d = 46.78mm.

Therefore the diameter of the central shaft is 47mm or 50mm approximately.

Stress Analysis

$$Stress = \frac{force}{area}$$

Force is the total weight of the various components on the supporting frame stands.

Table 1: Total weight of the various components on the supporting frame stands

IPONENTS	GHTS (KG)
ht of hopper materials	
ylinder barrels (1)	9
ylinder barrels (2)	4
ylinder barrels (3)	9
wo circular end plates	
wo circular disc flange	
er spent grains	2
Tensions	87
es	
	1
AL WEIGHT	**9.65**

Heating Requirements

The drying temperature has been made not exceed 140°C in order to retain the nutrients within the Brewer spent grains. The drying time is determined using relation below:

$$t = \left(\frac{ln}{2\pi rntan\theta}\right)$$

Where;

L = length of the dryer = 2000mm

N = number of start paddles = 1

R = width of paddles = 5mm

N = rpm of shaft = 20

Θ= angle of inclination of paddle = 12^0

t = product retention time or product resident time.

$$t = \frac{2000 \times l}{2 \times \pi \times 5 \times 20 \times tan12°}$$

Components of the Drying Unit

This consists of 3 major components, namely:

The Drying Chamber

This is made of cylindrical barrel of dimension 2m length and diameter 0.3m. It is made up of mild steel. The selection of mild steel is due to its strength and heat transfer properties. The drying chamber is well insulated to reduce heat loss.

The Heating Element

The heater supplies heat for the drying of the Brewer spent grains. The heater is electrically powered. To ensure that the spent grains are properly dried within the specified drying temperature, the right power rating is determined.

The Control Panel

The control panel is simply the unit that controls the system and maintains constant temperature in the drying chamber. It is made up of the

- Off and on switch
- Signal light
- Thermostat (Thermocouple)

Selection of the Heating Element

Volume of the cylindrical barrel = $0.1414m^3$ mass of the brewer spent grains at a time = 47.79kg.

Moisture Content

$$moisture\ content = \frac{M_w - M_d}{M_d} \times 100$$

Where,
M_w = weight of wet brewery spent grain
M_d = weight of dry brewery spent grain
Mw = Mass of wet Brewer spent grains = 47.79kg
M_d = mass of dry Brewer Spent grains

$$\frac{47.79 - Md}{Md} \times 100 = 76\%$$

Moisture content of Brewer spent grains determine = 76%
Mass of water = mass of wet brewer spent grains – removed.
Mass of dry Brewer Spent grains
= 47.79 – 27.14
= 20.65kg

Quantity (Q) of Heat Required to Removing the Moisture Content

$$Q = M \times Cp \times D_t$$

Where M = Mass of water = 20.65kg
Cp = Specific heat capacity of water = 4.182Kg 1Kgk

D_t = temperature difference between the dried Brewers spent grains and the initial temperature of the cylindrical barrel.
Assuming the ambient temperature is 30^0c and the suitable drying temperature range of brewer spent grain is 50 – 140^0C.
Hence the temperature difference = 140 – 20 = 110^0C

$$Q = MCp\,D_t$$

= 20.65 x 4.182 x 110
= 950.09KJ

$$power = \frac{quantity\ of\ heat}{time\ (seconds)}$$

$$= \frac{9501.09}{15 \times 60}$$
$$= 10.56kw$$

Therefore, heating element of about 11Kw shall be used.

Determination of Insulation Thickness

Fiber glass is recommended as the insulation material to be used.

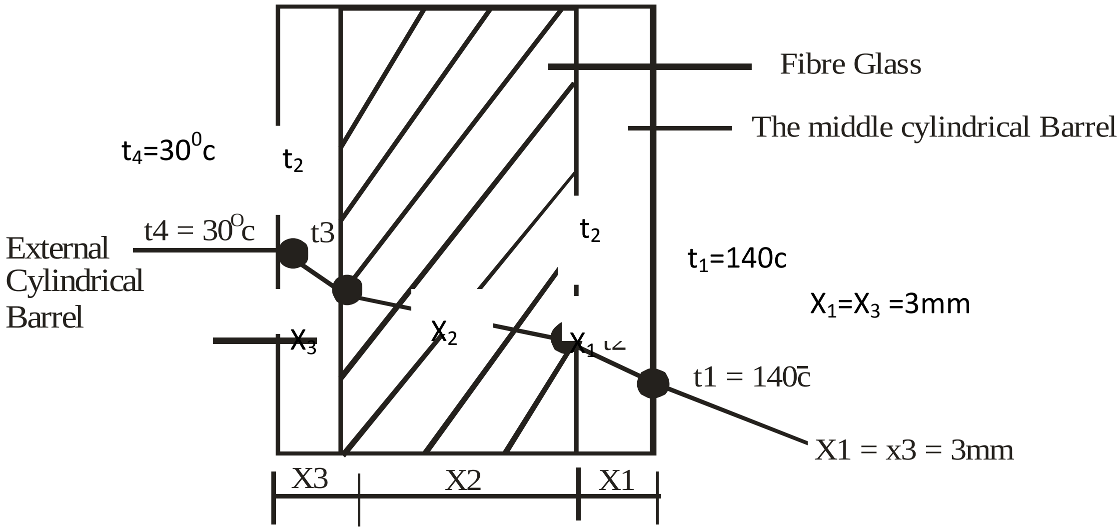

Fig. 9: The insulator

Assuring a loss of 10% of the quantity of heat produced, thus we calculate the required thickness for the fibre glass.
Quantity of heat produced per second = 11000W
10% of the heat produced per second (q) = 1100W.
Quantity of heat lost per unit area

$$(q) = \frac{\lambda_1}{x_1(t_1 - t_2)}$$
$$= Also\ q = \frac{\lambda_2}{x_2(t_2 - t_3)}$$
$$= also\ q = \frac{\lambda_3}{x_3(t_3 - t_4)}$$

And then $q = U(t_1 - t_4)$
Where $X_1$and λ_3 are thermal conductivity of mild steel = 46w/m^{0}C.
λ_2 = thermal conductivity of fibre glass = 0.04w/m^{0}C
x_1/ x_2 = The respective thickness of mild steel and fibre glass.
Using the equation

$$q = \frac{\lambda_1}{x_1(t_1 - t_2)}$$
$$= 1100 = \frac{46}{0.003(140 - t_2)}$$

$t_2 = 139.928^0$C

$$q = \frac{\lambda_2}{x_2(t_2 - t_3)}$$
$$= q = \frac{46}{0.003(t_3 - 30}$$

$1100 = 15333.333 (t_3 – 30)$
$0.071 = t_3 – 30$
$t_3 = 30.071^0$C

$$= Also\ q \frac{\lambda_2}{x_2(t_2 - t_3)}$$
$$= 1100 = \frac{0.04}{x_2(139.928 - 30.071\ )}$$

$1100x_2 = 4.394$
$x_2 = 0.039$m
= 40mm

Therefore, fibre glass of 40mm thickness should be used as the insulating material to achieve a minimal heat loss of 10% from the dryer.

RESULTS

The machine performance was evaluated after designed and constructed, using brewery spent grain at 75% moisture content. Table 2 presents the result.

Table 2: Result of performance dryer

S/N	TEMPERATURE (°C)	TIME (MIS)	INITIALWEIGHT (KG)	FINALWEIGHT (KG)
1.	140	5	40	33
2.	160	5	40	31
3.	180	5	40	30

$$moisture\ content\ on\ dry\ basis = \frac{M_w}{M_d} \times 100$$

Where,

M_w = weight of wet brewery spent grain
M_d = weight of dry brewery spent grain

For sample i:

The efficiency=$\frac{output}{input}$ x 100%

Eff =$\frac{33}{40}$ x100

= 82.5%

Output capacity = Kg/hr.

$= \frac{output}{time}$

$$= \frac{33}{0.083}$$

= 397.5kg/hr.

Input Capacity

$$= \frac{input}{time}$$

$$= \frac{40}{0.083}$$

$$= 482kg/hr$$

For sample ii:

The efficiency =$\frac{output}{input}x100\%$

$= \frac{31}{40}$

= 77%

Output capacity = Kg/hr

$$= \frac{output}{time}$$

$$= \frac{31}{0.083}$$

$$= 373.5kg/hr$$

Input Capacity

$$= \frac{input}{time}$$

$$= \frac{40}{0.083}$$

$$= 482kg/hr$$

For sample iii:

The efficiency $= \frac{output}{input} \times 100\%$

$$= \frac{30}{40} \times 100$$

Output capacity = Kg/hr

$= \frac{output}{time} = \frac{30}{0.083}$ = 361.4kg/hr)

Input Capacity

$= \frac{input}{time}$

$= \frac{40}{0.083}$

= 482kg/hr

The averageefficiency

$$= \frac{82.5 + 77 + 75}{3}$$
$$= \frac{234.5}{3} = 78\%$$

The average temperature

$$= \frac{140 + 160 + 180}{3}$$
$$= \frac{480}{3}$$
$$= 160℃$$

The average output capacity

$$= \frac{397.5 + 373.5 + 361.4}{3}$$
$$= \frac{1132.4}{3} = 377kg/hr$$

DISCUSSION

Using brewery spent gain, three different tests were carried out on the machine. 40kg of the brewery spent grain were used on each occasion using the same time duration (5 minutes) but the temperature of the samples on each occasion were varied at 140°C, 160°C and 180°C respectively for each of the test. Result obtained from the first samples showed that the overall efficiency and output capacity of the machine were 82.5% and 397.5kg/hr. respectively. From the second sample, an efficiency and output capacity of 77% and 373.5kg/hr. were obtained respectively. While results from the third sample revealed that an efficiency and output capacity of 75% and 361kg/hr. were obtained respectively. Finally, the calculated average efficiency, output capacity and temperature obtained from the tests carried out on the machine were given to be 78%, 377kg/hr. and 160°C respectively.

CONCLUSION

In general, it has been illustrated that brewery spent grain can be dried successfully with the constructed rotary dryer. Either on a batch process or continuous process and the rotary dryer can dry more depends on the quantity of spent grain to be dried at a time. The dryer has an average efficiency of 78%, with an output capacity of 377kg/hr. and temperature of 160°C
For efficient performance of the dryer the following recommendation are required.

1. It should be used industrially
2. It should be used with introduction of air (blower).
3. The three phases gear reduction motor can be converted to single phase because three phases is not common in most places.
4. The speed of the gear reduction motor should be totally reduced to allow the materials to stay longer in the drying chamber

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