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Development and Testing of Rotary Dryer for the Indigenous Cottage Sugar Industry in Nigeria

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ABSTRACT

A 1000kg capacity per day Rotary sugar dryer was designed and fabricated in Nigeria by the National Cereals Research Institute Badeggi in 1989. This was done in order to dry sugar in granulated form in the indigenous small scale sugar plant that was developed in the country. It basically consists of an air inlet fan unit, rotary drum, drying assembly, heating unit, fixed tray and framework. An electric motor of 2.0 Kw was selected as source of power to the rotary drum while a 1.25kw electric motor provided power to the air inlet fan assembly. Also twelve (12) electric heating elements of 1.8kw were installed in the heating unit to provide the required heat energy to dry the sugar. Test results of the dryer shows that the machine had maximum sugar granulated efficiency of 97.8% for 35kg and 45kg of sugar per batch at an initial moisture content of 16.5%. The self sugar discharge mechanisms was very effective and the machine was generally found to be easy to maintain by local artisans due to it's simple design features.

***Keywords* :** Sugar dryer, designed, fabricated, sugar plant, efficiency

INTRODUCTION

Drying is a very essential unit operation in processing sugarcane into sugar. This is because the moisture content of brown sugar after leaving the centrifuge which varies between 0.5 to 2.0% need to be reduced to about 0.05% (Mathur, 1993) for safe storage. In order to achieve this objective, various types of dryers have been developed. Mathur (1975) enumerated some of these dryers. These include the screw or scroll, grasshopper and belt or slat conveyor types that convery and dry the sugar simultaneously. Others are the rotary and centrifugal dryers. The rotary dryers are mainly composed of rotary drum with separate heating facilities while the centrifugal dryer uses dry and superheated steam to effect drying of the sugar inside the centrifugal basket.

Several research activities on development of new drying technologies and modification of existing ones are being carried out. For instance, a study on a tripple-pass dryer using superheated steam to provide thermal balance required by factories showed that the required thermal index of 130KCal/kg of evaporated water was achieved and was used for drying other divided products (Dear, 1992). The history and features of evaporative steam drying was studied (Winnestedt, 1994) and observed that although this technology has not gained wide industrial application despite it's introduction into the sugar industry since 1800, it's favourable environmental aspects are gaining wide acceptance. In addition superheated steam was successfully utilized in drying beet pulp in order to save energy and pollution in beet sugar factories (Nulsen and Renussen, 1994). Ord and Staut (1994) and Annon (1995) carried out studies on the performances of rotary and fludized-bed sugar dryers/coolers in factories and recommended some modification such as increase in drum size and fan speed in order to improve their efficiencies.

Valid mathematical models for predicting temperature and moisturte profiles of low purity raw and refined sugar in rotary dryers were developed (Tait et al., 1994). Also in related studies, variables such as airflow rates, air channeling, sugar properties and slight geometry affecting the advance of sugar cascading through an inclined rotary drum with counter current air flow were investigated and mathematical equations relating these variables were modelled (Steindle, 1994). Further research work on sugar drying has also resulted in the development of a mathematical model combining all aspects of sugar drying embracing bulk sugar transportation and mass and energy transfer.

It is clearly observed that all these dryers have sophisticated features requiring high degree of technical expertise which are scarcely available in third world countries. Thus since sugar production technology in Nigeria and Africa in general is at it's infantry stage of development, there was need to develop a suitable dryer that would be easily adapted in cottage sugar factories which the government of Nigeria is trying to encourage through the formulation of some concerted favourable policies. As a result, this paper highlights the design, features and test results of a rotary sugar dryer that

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was developed for the first indigenous cottage brown sugar plant in the country.

Machine Components

The Rotary Sugar dryer is made up of the following components as shown in Figs. 1 - 9.

1. Inlet Fan Unit : The inlet fan assembly is incorporated at the rear of the machine and consists of the fan housing that encases the fan blades. A 1.25kw electric motor which is connected to the fan blade with the aid of pulleys and belts provides power to the inlet fan Unit. This assembly freely fits into the heating assembly (D).
2. **Heating Unit :** This is a rockwool insulated rectangular housing. Twelve heating elements of 1.8kw each were fixed into the housing such that the ambient air blown in by the fan could gain some heat energy from these heaters. In order to vary the quantity of heat generated for different drying conditions each of the heating elements was provided with separate control switches. A thermometric gauge was installed at the plenum area to record the inlet temperature of the air entering the drying assembly.

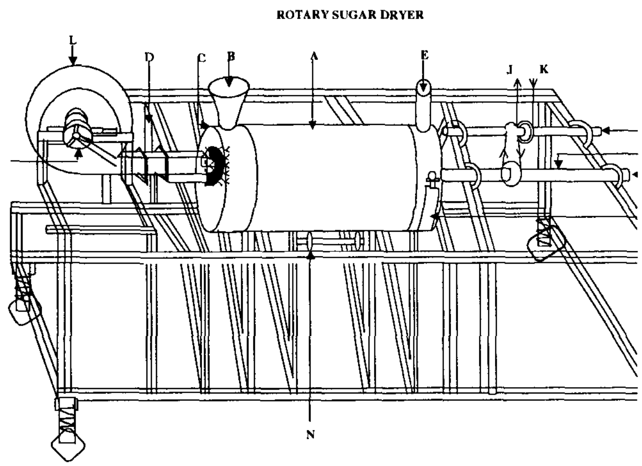
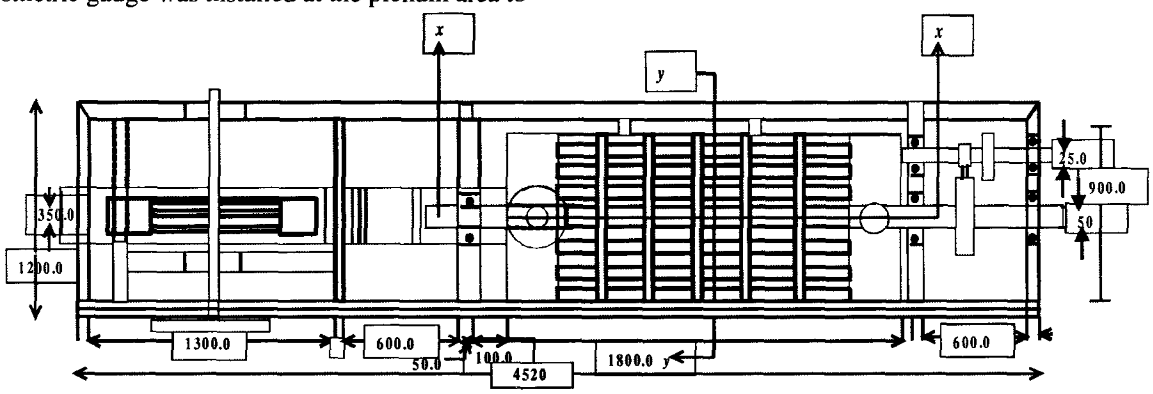
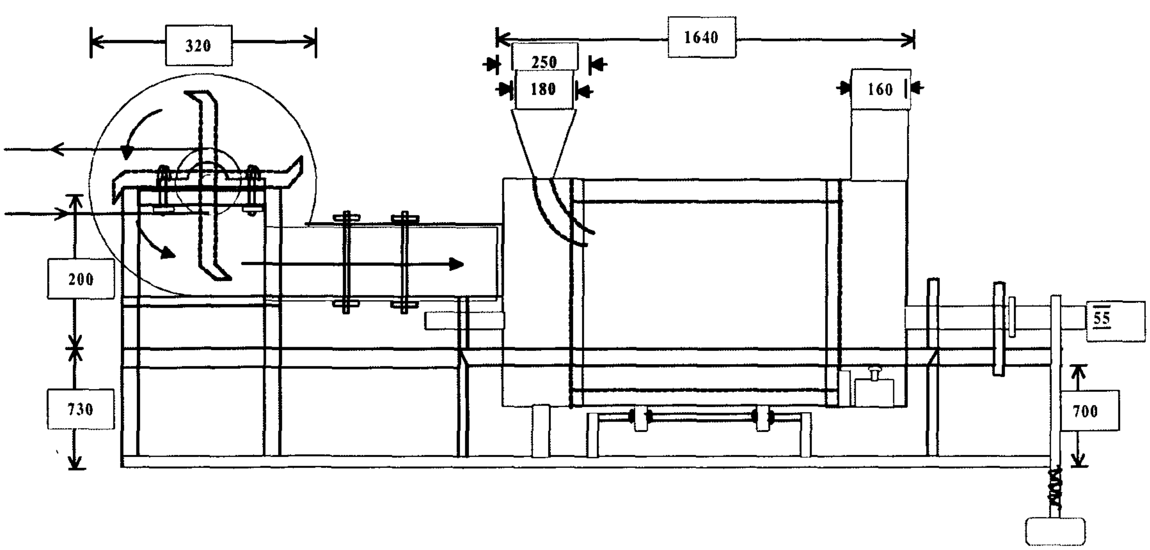


Fig 1. : Oblique View



All dimensions in mm



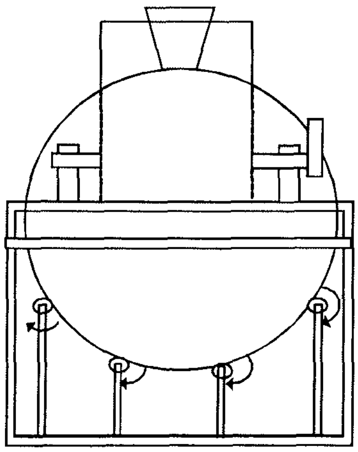


Fig. 4 : Front View

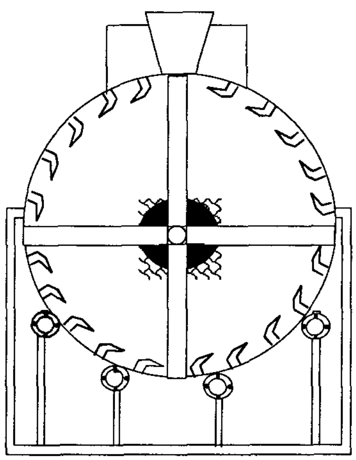


Fig. 5 : Cross Section y - y

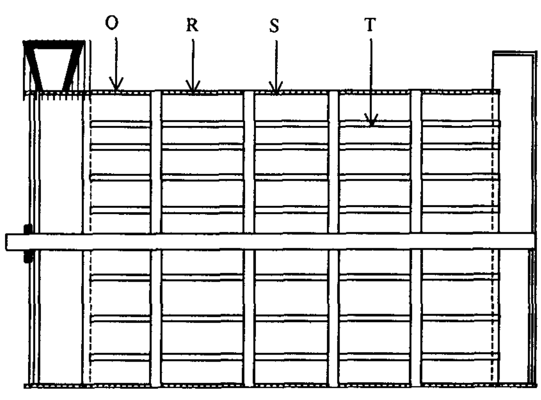


Fig. 6 : Cross Section x - x

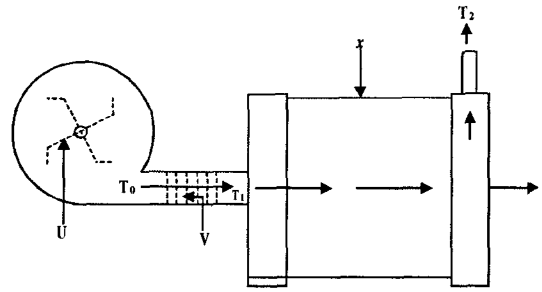


Fig. 7 : Side View of Dryer Showing Drying Flow Direction

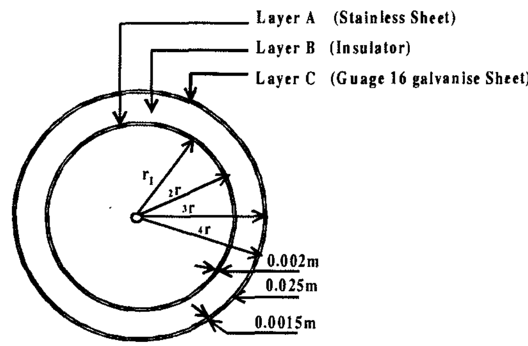


Fig. 8 : Cross-Section of Rotary Drum

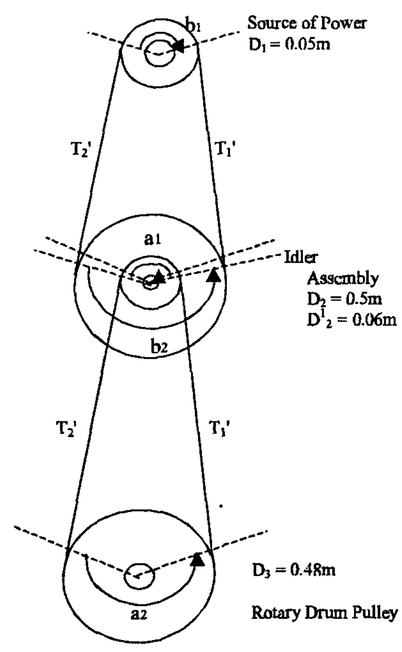


Fig. 9 : Pulley and Belt arrangement for Speed Reduction

LEGENDS

A - Rotary Drum	B - Detachable Hopper	C – Screen	D - Electric Heating Unit	E – Moist Air Exhaust
F - Idle Shaft	G - Central Shaft	H - Dried Sugar Outlet	I - Spring	
J - Belt Linking Central and Idle Shaft		K - Belt Long Idle Shaft and Electric Motor		L – Fan Housing
M - Fan Pulley	N - Rollers	P - Frame	Q - Outer Drum	R – Inner Drum
S - Insulator	T - Louvres	U - Inlet Fan	V - Electric Heater	X – Drying assembly

All dimensions in mm

The whole heating assembly tapers towards the plenum area in order to be freely accommodated in a central circular opening of the rotary drum. Also a variable speed control switch was incorporated for adjusting the flow rate of air entering the drying assembly.

3. Rotary Drying Unit : The rotary drying unit basically consists of an insulated stainless horizontal drum (A) that rotates at 15.00 revolution per minute. The internal part of the drum is lined with Louvres (T) made of stainless sheet at an angle of 90o (perpendicular) to the periphery of the drum in order to convey and discharge crystals at varying heights as the drum rotates.

The rotation of the drum is made possible by a 17.5mm shaft (G) carried at either end by 68.00mm diameter ball bearings.

A drive assembly of 2.5kw, 3-phase electric motor and a system of pulleys transmit power to the drum through the shaft.

A rear fixed plate with screen (C) designed to accommodate the tapered plenum end of the heating housing assembly is fixed at the rear of the drum while another one is fixed at the front to prevent escape of sugar crystal.

4. **Moist air Exhaust Unit :** The moist air exhaust assembly (E) removes extracted moisture from the sugar crystal. It is a centrifugal fan that siphons the moist air from the drum and delivers to the ambient environment.

5. **Framework :** The framework (P) of the machine is made of angle irons. Screw type height adjustment mechanisms were also incorporated at the ends of the stands. These features are incorporated in order to incline the machine at 45o to enable discharge of dried sugar after each batch.

Design Calculation

The machine was designed to have a through-put of 1 ton/day (1000kg/day). Based on this, the following data were obtained from literature and experimental results in the National Cereals Research Institute, Badeggi Laboratory. Based on these, the following design computations were made:

Required output of dryer (Ca) = 1000kg/day

Expected moisture content of wet sugar after centrifugation (mc) = 2.0% wb (NCRI, 1988).

Expected moisture content of dried sugar = 0.5% db (Hugot, 1972).

Highest relative humidity in NCRI (R.H) = 52% (NCRI, 1989)

Lowest ambient temperature in NCRI (To) = 26.7oC (NCRI, 1989).

Required drying temperature of sugar (T1) = 118.33oC (Kreg, 1975).

Required temperature of dried sugar (T2) = 48.33% (Kreg, 1975).

Density of NCRI brown sugar of (æb) = 1562.5kg/m3 (NCRI, 1988).

Selected diameter of Rotary drum (d) = 0.65m.

Recommended air flow rate (v) = 0.2028m3/Sec (Hugot 1972).

Design Theorem

The mass of dry matter is the mass of sugar that contains no moisture and is expressed using an established conventional equation as follows:

$$DM = M_2 - X_2 \qquad \text{............ (1)}$$

$$\text{Where, } X_2 = MC_2 \times M_2 \qquad \text{............ (2)}$$

$$\therefore DM = M_2 - MC_2 \times M_2 \qquad \text{............ (3)}$$

Where,

M_2 is final mass of sugar at 0.5% moisture content (Kg).

MC_2 is final storage moisture content (%)

Mass of Sugar Crystal to be Dried Per Day

The expected mass of dried sugar is 1000kg per day.

It means the initial mass of sugar (before drying) will be more since it contains more moisture. So the initial mass of sugar (wet) to be introduced into the dryer was calculated from the conventionally established equation as follows :

$$\frac{X_1}{XX_1 + DM} = MC_1 = MC1 \qquad \text{............ (4)}$$

Where,

X_1 is initial mass of moisture (Kg)

DM is the computed mass of dry matter (Kg)

MC_1 is initial moisture content (%)

Amount of Moisture to be removed

The amount of moisture expected to be removed was computed as the difference of the mass of moisture of the wet sugar and dried sugar as shown below :

$$Mr = Mw - Md \qquad \text{............ (5)}$$

Where,

Mr is Mass of moisture to be removed (kg)

Mw is Mass of wet sugar (kg)

Md is mass of dried sugar (kg)

Volume of Wet Sugar

The volume of wet sugar was computed in order to determine the required number of batches and the expected dimensions of the drum.

$$Vw = \frac{Mw}{\zeta s} \quad .... (6)$$

Where,

Vw is volume of wet sugar (M3)

Mw is mass of wet sugar (Kg)

ζ s is density of NCRI brown sugar (kg/m3)

Number of Batches Required

The number of batches required to dry the wet sugar was calculated as follows:

$$N_B = \frac{M_w}{N_b} \quad .... (7)$$

Where,

N_B is number of batches required

Mw is Mass of wet sugar (Kg)

M_b is mass of sugar recommended for drying/batch (Kg)

Volume of Dryer

The actual volume of the dryer selected is five and a half times the volume of sugar to be dried per batch in order to enable the sugar crystals fall at considerable heights as the drum rotates in order to ensure enough exposure of the sugar crystals to heat.

$$Vd = \frac{V_w}{N_B} \quad .... (8)$$

Where,

Vd is the actual volume of dryer (m3)

N_B is number of batches per day

Length of Dryer

$$Ld = \frac{V_d}{A_d} \quad .... (9)$$

Where,

Ld is length of dryer

Vd is volume of dryer as obtained from equ, (5)

Ad is area of dryer

Heat Required for Drying

This computation was done in order to determine the quantity of electric heat energy suitable to dry the required mass of wet sugar. This is the sum of the expected heat loss through the walls of the drum and the insulator and the actual heat required to dry the wet sugar (assuming there was no heat loss) which is dependent on the pshycometric ambient condition of the air.

Heat Loss Through the Walls of the Dryer

Heat loss through the inner wall, insulators and outer wall of the dryer was expected hence it is considered in the design. Due to symmetry, any cylindrical surface concentric to the axis of the tube is an isothermal surface and the direction of heat flow is normal to the surface (Rayner, 1987). The flow of heart is assumed to be steady due to the uniformity of the drying chamber (rotary drum) and minimal obstruction to the flow of air. Therefore applying the continuity theorem, the radial heat flow per given length of tube through successive layers was assumed to be constant while the temperature or heat loss gradient slopes towards the outer wall.

Considering the rotary drum as a cylinder (Figs. 7 and 8) made of different materials, Fourier's Law of heat conduction was applied.

$$T_1 \quad R_A \quad T_2 \quad R_B \quad T_3 \quad R_c \quad T_4$$

$$\frac{\ln(\frac{r_2}{r_1})}{2\pi K_A L} \quad \frac{\ln(\frac{r_3}{r_2})}{2\pi K_B L} \quad \frac{\ln(\frac{r_4}{r_3})}{2\pi K_C L}$$

where Fig. 5.3

$$K_A = \frac{\ln(\frac{r_2}{r_1})}{2\pi K_A L} \qquad K_b = \frac{\ln(\frac{r_2}{r_1})}{2\pi K_B L}$$

$$K_C = \frac{\ln(\frac{r_2}{r_1})}{2\pi K_C L}$$

are thermal resistances of the inner rotary drum, insulator and outer drum Heat loss Iq)

$$q = \frac{2\pi L(T_1 - T_4)}{\frac{\ln(\frac{r_2}{r_2})}{2_A} + \frac{\ln(\frac{r_2}{r_2})}{2_B} + \frac{\ln(\frac{r_2}{r_2})}{2_C}}$$

Where,

q is the total heat loss

KA is the thermal resistance of the inner drum

$$= \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi K_A L}$$

K_b is the thermal resistance of the insulator

$$(\text{Crock wool}) = \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi K_B L}$$

Kc is the thermal resistance of the outer drum

$$= \frac{\ln\left(\frac{r_4}{r_3}\right)}{2\pi K_C L}$$

L is the length of the dryer

T_1 is inside of the dryer

T_4 is the Temperature of the surrounding (ambient)

Where,

r_1 is internal radius or the inner cylinder of the drum

r_2 is external radius of inner cylinder of the drum

r_3 is external radius of insulator (rockwool)

r_4 is external radius of outer cylinder of the drum

R_A is thermal conductivity of stainless steel Sheet

R_B is thermal conductivity of insulator (rockwool) = 0.04w/m°C (Holman, 1983)

R_C is thermal conductivity of iron sheet = 57w/m°C Holman, 1983)

Quantity of Heat Required for Drying

The following factors which affects the efficiency of the electric heaters were considered in the computation:

(i) The Relative Humidity of the environment

(ii) Mass flow rate of air

(iii) The Temperature of the environment

(iv) The required temperature to which the air inside the dryer is to be raised.

Fig. 7 shows how the ambient air receives heat from the electric heaters before entering into the rotary drying chamber with the aid of the fan.

where,

T_o is Ambient temperature of the environment (ok)

T_1 is temperature of heated up air

T_2 is Final temperature of air leaving dryer (oK)

From the psychometric chart, the thermodynamic properties were determined as follows :

Enthalpy of air at a temperature of 26.7°C and relative Humidity of 52.0% at ambient condition (h1) = 57.0KJ/kg of dry air

Specific volume of inlet air (V_s) = 0.954m³/kg

Enthalpy of air entering the dryer after being heated up at constant humidity ratio of 0.0112 to a temperature of 118.33°C, (h_2) = 156.0KJ.

Recommended Volumetric flow rate of air (Vf) = 0.2028m3/sec.

Total Quantity of heat required

This is the total sum of the theoretical heat required to dry the sugar and the expected heat loss from the dryer. It is computed using the relationship below (Othmer and Huang, 1985)

$$= M_a (h_2 - h_1) + EHL \quad \text{............ (10)}$$

Where, EHL is Expected heat loss

Substituting $M_a = \frac{V_f}{V_s}$ in equation (10)

$$Q = \frac{V_f}{V_s} (h_2 = h_1) - EHL \quad \text{............ (11)}$$

$$\therefore \text{Quantity of heaters required} = \frac{A}{Hc}$$

Where,

Q is the total heat requirement (KJ)

h_1 is the enthalpy of the ambient air (KJ/Kg)

H_2 is the enthalpy of the final enthalpy of the air after drying (KJ/Kg)

M_a is the mass flow rate of air Kg/Sec.

V_f is the volumetric flow rate of air (m³/Sec)

V_s is the specific volume of air (m³/Sec)

H_3 is the power of each electric heater (Kw)

H_C is the rated heat capacity of each heating element

Rate of Moisture Removal

The rate of moisture removal from the wet sugar crystals depends on the mass flow rate of air and difference in humidity ratio of the air at inlet and exhaust of the dryer.

$$Mm = \frac{V_f}{V_s}(H_1 - H_2) \qquad (12)$$

Where,

$V_f = 0.2028$ m3/sec

$V_s = 0.954 \times 3$/kg of dry air

H_1 is Humidity ratio at inlet of air = 0.041

H_2 is Humidity ratio at exhaust = 0.0112

Time Required to Dry Initial Mass of Wet Sugar to 1000kg

The time required to dry the initial wet sugar to the final dried sugar (1000kg) is necessary in order to know the total drying time.

$$T_1 \frac{M_w}{M_m} \qquad (13)$$

Where,

T is total time required to dry the sugar

M_w is mass of moisture to be removed = 170.58kg

M_m is recommended rate of moisture removal = 0.006^3kg/sec (Hugot, 1976).

Time Required to Dry a Batch

The time required to dry a batch of sugar is computed using the equation shown below.

$$T = \frac{T_T}{N_B} \qquad (14)$$

Where,

T_T is Time required/Batch

T_T is total time required

N_B is number of batches

Shaft Diameter

The diameter of the shaft selected for transmission of power to the rotary drum was computed as a function of the torque imposed by the drum and it's content and the shear stress of the material used for the construction of the shaft (Gbabo, 1991).

0.333

$$ds = \frac{(0.333)}{\zeta_s} \qquad (16)$$

$$\text{Where T is Torque} = \frac{F_T \times D}{2} \qquad (17)$$

$$\therefore d_s = \frac{(8 \times F_T \times D)}{2} \qquad (18)$$

where,

F_T is the force expected to be exerted on the shaft

D is the diameter of the rotary drum (m)

To calculate the torque imposed on the shaft, the total mass of the sugar, inner and outer cylinder drum, rods and insulator used for the design of the rotary drum were determined first as shown :

Mass of Sugar = 150kg/batch

Mass of stainless sheet used for internal lining of the drum :

$$Ms = P_s C_s L_s t_s \qquad (19)$$

Where,

P_s is Density of stainless sheet = 8,500 kg/m3 (Ryder, 1982)

C_s is circumference of internal drum

L_s is the length of drum

t_s is thickness of stainless sheet (guage 14)

Mass of Steel Rods

$$N_r = N\zeta V \qquad (20)$$

$$= \frac{NP_r d^2 L_r}{4}$$

where,

N_r is no. of rods connecting shaft to the drum = 24

$æ_r$ is density of steel rod = 8750.0 kg/m3 (Ryder, 1982)

d is diameter of steel rod = 0.0125m

L_r length of steel rod $= \frac{0.065}{2} = 0.325$m

(Neglecting the space occupied by diameter of steel shaft).

Mass of Sugar Conveying Louvres

$M_c = Næ_c V_c$ .... (22)

Where, $V_c = L_L b_L t_L$

$\therefore M_c = N_c æ_c l_L b_L t_L$ .... (23)

N is Number of Louvres = 20

Where,

$æ_c$ is Density of stainless sheet = 8,500 kg/m3 (Ryder, 1982)

L_L is length of louver (s) = 1.58m

b_L is Breadth of louver (s) = 0.01m

t_L is thickness of louver (s) = 0.002m

Mc is Mass of louvers

Mass of External Covering

$M_g = æ_g C_g L_g T_g$ .... (24)

Where,

$æ_g$ is Density of galvanized sheet = 7500kg/m^3 (Ryder, 1982)

C_g is circumference of galvanized sheet

L_g is length of Drum = 1.60m

T_g is thickness of galvanized sheet.

The selected size depended on the shaft size and expected load.

Pulley and Belt Sizes for Power Transmission to Rotary Drum

V-belts were used to transmit power from the motor to the rotary drum. In order to reduce the speed of the motor from 1,450 rpm to the recommended speed of the rotary drum of 15rpm, a pulley speed reduction system was designed. Thus the power transmission of the system is in two stages as shown in Fig. 9.

Size of Rotary Drum Pulley

First, the speed of the idler shaft N2, was calculated using the following conventionally established equation.

$$N_2 = \frac{N_1 D_1}{D_2} \quad .... (25)$$

The speed of the big idler pulley N_2 = The speed of the small idler pulley $N_2 1$ = 120rpm because they are on the same shaft.

Thus the diameter of the rotary drum pulley was determined as shown below :

$$D_3 = \frac{N^1{}_2 D^1{}_2}{N_2} \quad .... (26)$$

Lengths of belt for power transmission from motor to pulley speed reduction system

Electric motor to big idler pulley

The length of belt to transmit power from the electric motor to the big pulley of the speed reduction system was determined using this generally established equation

$$L_1 = D_2 + D_1 + 2C_1 + \frac{(D_2 - D_1)^2}{4C_1} \quad .... (27)$$

Where,

L_1 is the length of belt required to transmit power from the electric motor to the big idler pulley (m).

D_1 is the diameter of the electric motor pulley (m)

D_2 is the diameter of the big idler pulley (m)

C_1 is the center to center spacing between the electric motor and big idler pulleys (m)

Idler Shaft Pulley to rotary drum pulley

The length of belt that transmits power from idler shaft to rotary drum was determined as follows :

$$L_2 = (D_3 + D^1{}_2) + 2C + \frac{(D_3 - D^1{}_2)}{4} \quad .... (28)$$

Angle of Contact Between Belt/Motor Pulley and Belt/Idler Pulley/drum

$$â_1 \text{ and } B_1 = 180° + \frac{2\sin^{-1}(D_2 - D_1)}{2C_1} \quad .... (29)$$

Angle of Contact Between Belt/Big Idler Pulley and Belt/Rotary drum Pulley

$$\&_1 \text{ and } \&_2 = 180° - \frac{2\sin^{-1}(D_2 - D_1)}{2C_1} \quad .... (30)$$

Where,

$â_2$ is the angle of contact between big idler pulley and belt.

D_1 is diameter of motor pulley

D_2 is diameter of big idler pulley

C_2 centre to center spacing between motor and idler pulley

D_{12} is diameter of small idler pulley

D_3 is diameter of rotary drum pulley

$\hat{a}_1$, $\hat{a}_2$, $\&_1$ and $\&_2$ are angles of lap between belts and pulleys of the electric motor, big idler, small idler, and rotary drum.

Belt Tensions

The belts that transmits power from the motor to the machine are subjected to tension due to the frictional resistance between the belt and pulley. The tension of the belt on the tight and slack side are expected not to be lower or exceed a particular limit in order for power transmission from the electric motor to the machine to be effective. These tensions were determined using the mathematically established equations (Gbabo, 1991).

$$T_1 = U \qquad ....(31)$$

$$\frac{T_2}{W} = \frac{(T_1 - T_2)}{60} v \qquad ....(32)$$

Where,

T_1 is tension on the tight side
T_2 is tension on the slack side
U is coefficient of friction between belt and pulley
V is velocity of belt (m/sec).

FAN SIZE

The size of fan to blow air into the rotary drum depends on the recommended volumetric flow rate of the air and is obtained from established standards (Zeug, 1982)

In order to select the appropriate fan size, the required velocity of air in the rotary drum was calculated. Considering Air conveying duct as (1), and Rotary drying Unit as (2) in Fig. 7,

$$A_1, V_1 = A_2, V_2 \qquad ....(38)$$

Where,

A_1 is Area of air conveying duct

V_1 is Velocity of air in air conveying duct

V_2 is the recommended Volumetric flow rate of air in the rotary drying unit = 0.203m^3/sec (Zeug, 1982)

Volumetric flow rate of air conveying duct

$= A_1 V_1$

$= 0.16 \times 0.1 \times 4.038$

$= 0.0646$ m^3/sec

From Appendix 1, the appropriate fan size corresponding with the value of the volumetric flow rate obtained from equation 38 is selected.

MATERIALS AND METHODS

Four samples of sugar weighing 35kg, 45kg, 55kg and 65kg were introduced into the dryer in three replicates. The dryer was put on for the moisture content of the sugar to be reduced from 16.5% to 5%. The sugar samples were then weighed and further separated into granulated and aggregated fractions. The weight of the granulated and aggregated fractions were also taken. The following parameters were determined using the conventional formula as follows and the results are presented in tables 1 and 2.

APPENDIX I : Volumetric flow rate and recommended diameter of fan

Volumetric flow rate in dryer (m3/sec)	Recommended fan diameter (m)
0.01 - 0.03	0.09 - 0.13
0.031 - 0.05	0.14 - 0.17
0.051 - 0.07	0.18 - 0.2
0.071 - 0.09	0.21 - 0.23
0.091 - 0.110	0.24 - 0.26
0.111 - 0.130	0.27 - 0.30
0.131 - 0.150	0.31 - 0.33

Adopted from Zeug (1982)

$$Mm = Mw - Md \qquad ....(39)$$

Where,

M^m is mass of moisture removed during drying (Kg)
Mw is mass of wet sugar (Kg)
(ii) Mass of aggregated Sugar :
Md is mass of dried sugar.
$Ma = Mw - Md \qquad ....(32)$
where, Ma is mass of aggregated sugar
Mw and Md have been defined in equation (39)
Where, æcyg is Granulation efficiency (%)
Md and Mw have been defined in equation (39)

iv) Drying rate :

$$\frac{Mm}{dt} \qquad ....(42)$$

where,
Dr is drying rate (Kg/min)
Mm is Mass of moisture removed during drying (Kg)
Dt is drying time (mins)

v) Ratio of aggregated Sugar to total Sugar :

$$\frac{Mas}{Mts}$$

Where,
Rat is ratio of aggregated sugar to total sugar
Mas is Mass of aggregated sugar (Kg)
Mts is Mass of total sugar (Kg)

Table - 1: Rotary dryer data

S. No.	Mass of wet Sugar (kg)	Mass of dried Sugar (kg)	Mass of moisture removed (kg)	Time for drying from 13% m.c. to 5% m.c. (mins)	Granulated sugar (kg)	Aggregated sugar (kg)	Granulation efficiency (%)
1	35	30.5	4.5	32	29.7	0.6	97.38
	35	30.76	4.3	29	30.0	0.5	97.72
	35	30.5	4.5	28	30.0	0.5	98.36
2	45	38.4	6.6	30	37.0	0.5	97.35
	45	38.0	7.0	32	37.2	0.8	97.89
	45	38.5	6.6	28	37.8	0.7	98.18
3	55	46.0	9.1	31	43.2	2.5	93.91
	55	47.6	8.1	32	44.0	3.2	92.44
	55	47.9	9.0	34	46.0	2.8	92.9
4	65	58.3	11.5	32	53.6	4.3	91.93
	65	56.0	12.0	34	51.6	4.1	92.14
	65	55.7	11.3	34	51.8	3.6	93.0

vi) Ratio of granulated Sugar to total Sugar :

$$Rat = \frac{Mas}{Mts}$$

Where,

Rgt is ratio of granulated sugar to total sugar.

Mgs is mass of granulated sugar (Kg)

Mts has been defined in equation (43)

RESULTS AND DISCUSSION

The result of tests carried out on the dryer is presented in Table 1 and 2. It shows maximum sugar granulation efficiency of about 97.8% for 35kg and 45kg (wet weight) while at 55kg and 65kg merssercuit load, the granulation efficiencies of the dryer reduced to 93.08 and 92.26 respectively. It is also clear that no remarkable difference on the average drying time for the samples was observed while the ratio of aggregated sugar to total sugar was more for the greater quantity (55kg and 65kg) of sugar than those of the lower quantity.

From these results, the performance of the dryer was generally acceptable and found very adaptable in the indegeneous cottage sugar factory.

REFERENCES

Annon (1995). B.MA Fludized bed Sugar dryers/coolers BMA Sugar Division, Postfach, Braunschweig, Germany.

Deur, O. (1992). Technology of drying by three (3) Pass drum. Industries Alimentaires at agricoles **109(7-8)** 515-517 Societe Promil.

Gbabo, A. (1992). Development and testing of centrifuge to separate sugar crystals and palm oil. An M.Sc. Thesis in the department of Agric. Engineering, University of Ibadan, Nigeria.

Hugot, E. (1976). Handbook of Cane Sugar Engineering Elservier Publishing Company, Amsterdam.

Kreg, E. (1975). Principles of Sugar Technology, Vol. III, Elservier, Amsterdam.,

Maltur, R.B.L. (1993). Sugar Storage and Construction of Godowns. In: Handbook of Cane Sugar Technology. Oxford and IBH Publishing Co. PUT Ltd. New Delhi, India.

NCRI (1988). Modification of Sugar Centrifuge. In: 1988 Annual Research Review meeting report. Sugar Cane Research Programme, National Cereals Research Institute, Badeggi.

NCRI (1988). Psychometric data in NCRI. Meteorological Department, National Cereals Research Institute, Badeggi NCRI.

Ord, K.C. and Stuart, P.R. (1994). Enhancing a Small Sugar Dryer's Performance. In: Proceedings of the 1994 Conference of Australian Society of Sugar Cane Technologist, Townsville, Queensland, 26th – 29th April, Waston Ferguson and Co. Brisbane, Australia.

Othmer, D.F. and Huang, H.N. (1985). Corelating Vapour pressure and latent heat data In: Hand book of Cane Sugar Technology Oxford and IBH Publishing Co. Pvt. Ltd. 66 Janpata, New Delhi.

Rayner, J. (1989). Conduction through a flat plate or wall In: Basic Engineering Thermodynamics. Longman Singapore Publishers (Pte) Ltd., Singapore.

Ryder, G.H. (1982). Engineering Properties of metals In: Strength of materials. Macmillan Press limited, London.

Steindle, R.J., Sheehan, M. and Camoron, I.T. (1994). A material transport model for rotary drum Sugar dryers. In: Proceedings of the 1994 Conference of the Australia Society of Sugarcane Technologist, Townsville, Queensland, 26th – 29th April, Watson Ferguson and Co. Brisbane, Australia.

Tait, P.J., Schikel and Greig, C.R. (1994). The development and application of generalized model for Sugar dryer In: Proceedings of the 9th International drying Symposium, Gold Coast, Australia 1 – 4 August, 1994. Schultz Tait Greg and Associates, P. O. Box 647, Mt Ommeney, Brisbane, Qld 4074, Australia.

Wimmerstedt, R. (1994). Steam drying – History and Future. In: Proceedings of the 9th International Drying Symposium, Gold Cost Australia 1-4th August. 1994. Vol. A. Department of Chemical Engineering, University of Lund, P. O. Box 124, 22100, Lund, Sweden.

Zeug, E. (1982). Sugar drying in the tropics In: Sugar Azucar, Volume 87 number 10, Rispam Communications Inc. Editorial and Executive office, 452 Hudson Terrace, Eaglewood Cliffs, New Jersey.