Research Article

DRYING OF BAGASSE INTO THE FLUIDIZED BED VERTICAL DRYER USING HOT AIR FLOW THROUGH NOZZLES

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Abstract

Sugar cane bagasse can be used as fuel in boilers to produce steam and electricity. After many stages of sugar cane milling process the byproduct bagasse is available in solid form with higher percentage moisture content. The length of smaller sized bagasse named as pith is varied from 2mm to 6mm. The process of separating larger size of bagasse and smaller one is known as depithing. The burning smaller size particle of bagasse is called as pith, and it can be used as fuel in the power plant boilers. Due to high moisture content (48% to 52%) the pith needs excess amount of air or oxygen for attaining complete burning. If sufficient amount of air is not supplied slower rate of burning takes place. The slower rate of burning is due to utilizing some amount of heat to evaporate the water vapors presents. This process is called as removal of latent heat of vaporization. This loss of heat energy to evaporate water reduces the boiler efficiency.

A multiple stage fluidized bed dryer is one of the bagasse dryer to accelerate the evaporation of moisture content at faster rate. The hot air passing through the bagasse removes the surface water content. The fluidized bed dryer consists of two or three stages of drying process containing rectangular and circular shaped distributor pipe connected with the wall of the vertical dryer through extended pipes at four sides contains many number of nozzles.. The counter current flow of bagasse and hot air induces the removal of moisture content over the surface of the bagasse. The latent heat of evaporation is accelerated in faster rate with the help of separate mechanical device which agitate the bagasse between the holding tray and the distributor.

Key words: Fluidized bed dryer, drying, bagasse, mechanical device, calorific value.

INTRODUCTION

Drying occurs by effecting vaporization of the liquid by supplying heat to the wet feedstock. Heat is supplied into the dryer by hot air, the heat transfer takes place between bagasse and hot air in convection mode. Over 85 percent of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. Over 99 percent of the applications involves the removal of water vapour. The vapor present in the bagasse travels towards the top boundary layer of the material before it is transported away by the carrier gas. The Moisture content of bagasse from the mill wet after leaching out of sugar juice is in the ranges of 48 -52%.

The byproduct of bagasse obtained from the sugar cane is as in the form of pith can be achieved by crushing many number of stages. The varying percentage of moisture is depends upon the number of stages of crushing and quality of milling process. Wet bagasse feeding directly into the boiler needs more quantity of excess air and it leads to heat losses through flue gas. Also the excess amount of air reduces the combustion efficiency in the boiler by vaporizing the moisture. The amount of heat required to vaporize per kg of water content from the wet bagasse is 418 kj (or) 100 kcal.

The moisture reduced bagasse has higher heating values and also has the ability of good combustion performance with minimum amount of bagasse in the case of cogeneration power plant. The higher calorific value of the moisture reduced bagasse increases 2%, and by evaporating the moisture content by 1% from the mill wet bagasse. The 1% drop of moisture content will increase the temperature of 11.5°C in the boiler

The square type bagasse dryer was constructed with deflectors and their actuating mechanism was constructed vertically by prof. E.W. Kerr in 1910 due to not able to meet to supply the excess air to the boiler furnace. After introducing the dryer the fact that the efficiency of the boiler was improved as in the form of better combustion, increased in the amount of steam production and considerable quantity of bagasse saved. The requirement of electricity needed for processing the plant can also produced satisfactorily. It overcomes the energy demand caused due to burning the mill wet bagasse directly into the boiler. After then no significant research paper was published about the drying methods, because of the easy availability and low cost of fossil fuel.

In this type of dryer bagasse is directly allowed to flow downward by the gravitational force by falling over the deflectors one by one. The deflectors are actuated by the mechanism such that the bagasse passed towards downward through it and counter currently the hot flue gas allowed to pass towards upward in the opposite direction into the square type vertical dryer. Finally the moisture reduced bagasse collected at the bottom of the dryer. Boulet[9] in his article shows properly designed bagasse dryer with flue gas as drying medium considerably save the fuels and every 3 to 4 months once can pay for itself. Bailliet [20] has recommended the bagasse drying and preheating of the air in the air preheater can both improve improvement of boiler efficiency. Young [21] proposed a rotary dryer for the mill wet bagasse. The rotary dryer consists of a rotating drum for better mixing with the flue gas for the removal of moisture content in the bagasse. Arrascaeta and Frideman [2] analysed the advantages of drying of bagasse upto 1984 by using fluidized-pneumatic transport dryer. They separated the bagasse by fractions during the process. Hogot[8], drying of bagasse generally not to be below 30% of moisture content to avoid increase of higher boiler temperature and it could leads to melting of ash and the clinker formation over the surface of the boiler tubes. Correia (1983) described the use of a pneumatic transport dryer. This dryer was developed in the santo Antonio factory, in Alagoas, Brazil. He reported that the increase of steam production is 16% by drying the bagasse from 52% to 40%. Salermo and Santana (1986) worked with a dryer composed of a fluidized bed, a pneumatic duct and a cyclone separator. The use of cyclone separator is to separate the solid and gaseous phases. This system worked Cardenas. (1994) described a pneumatic dryer in an industrial size. They studied the energetic and energetic efficiencies of a boiler-dryer system. They concluded that the use of a dryer improve the boiler efficiency.

Excess air level requirement and the percentage (%) moisture content.

Excess air level	% of moisture content
1.4 to 1.6 times	52- 58
1.2 to 1.4 times	48 – 52
1.0 to 1.2 times	35 – 40

Efficiency of Boiler and the percentage (%) moisture content.

Efficiency of Boiler	% of moisture content
0.8 to 0.85	52- 58
0.86 to 0.89	48 – 52
0.90 to 0.93	35 – 40

REASON FOR BAGASSE DRYING

Enhancing the NCV of bagasse:

Drying of bagasse can improve the Net Calorific Value. The heat capacity of bagasse can be expressed in terms of calorific values. Calorific value means the amount of heat generated per unit weight of bagasse burning (KJ/Kg). The calorific value can be classified into two namely: Gross Calorific Value (GCV) and Net Calorific Value (NCV). When burning any type of fuel the total amount of heat generated is known as Gross Calorific Value. If any moisture present in the fuel, certain amount of heat can be utilized to evaporate the moisture content and it is known as latent heat of vaporization. The latent heat cannot be recovered during the combustion process and this heat is lost along with the flue gases from the boiler furnace. The remaining heat energy available due to the burning fuel in the boiler is termed as Net Calorific Value. From the GCV of the fuel the moisture presents in the wet bagasse absorbs certain amount of heat energy to vaporize the water content. The heat energy utilized to vaporize the water content is only the waste of energy and the improvement of thermal efficiency of the boiler is only based on the percentage of moisture level. The percentage of moisture level in the bagasse cannot be reduced just below 35% to avoid the raise of temperature of the boiler will go up, this results the formation of clinker due to melting of ash over the surface of the boiler tubes. The clinker formation would reduce the heat transfer rate and it would be cleaned periodically by allowing a jet of water stream between certain uniform intervals of time into the boiler.

Excessive reduction of moisture level (below 35%) causes the flying of bits and cannot be catch hold of fire due to induced drafting this maintains negative pressure in the convection zone in the boiler. The escaped unburnt fuel causes severe dust pollution in the atmosphere.

Reducing moisture to the certain percentage level using fluidized bed dryer will improve the Net Calorific Value and it saves the bagasse for achieving the same level of thermal efficiency of the boiler.

Model Plant Layout of Bagasse Dryer:

The plant consists of the following major equipments

1. Forced Draft Centrifugal blower.
2. Electric heater with Glass wool insulation.
3. Fluidized bed dryer with perfect insulation.
4. Cyclone separator.
5. Induced Draft Centrifugal blower.

1. Forced Draft Centrifugal blower

Fig-1 Centrifugal blower with manometer measurement set up

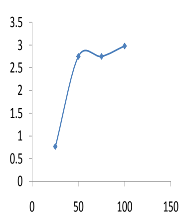
Readings and Calculations

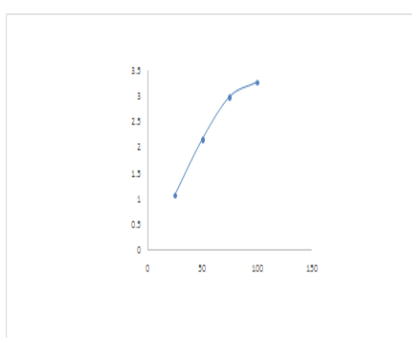
Valve open Position	Manometer Readings (m)		
	At Inlet	At Outlet	At Orifice
Full opening	0.015	0.018	0.085
¾ opening	0.013	0.014	0.085
½ opening	0.013	0.008	0.071
¼ opening	0.001	0.002	0.000

Table- 1 Manometer readings at Inlet, Outlet and at Orifice of the blower

S. No.	PROPERTIES OF AIR	UNIT	100% opening	75% opening	50% opening	25% opening
1.	Mass flow rate at Inlet	Kg/sec	3.0	2.7	2.7	0.8
2.	Mass flow rate at outlet	Kg/sec	3.3	2.8	2.2	1.0
3.	Mass flow rate at orifice	Kg/sec	7.0	7.0	6.4	0.0
4.	Pressure rise at inlet and outlet	KN/m^2	100.162, 100.216	100.156, 100.168	100.156, 100.096	100.012, 100.024
5.	Pressure rise of air at orifice	KN/m^2	101.021	101.021	100.853	100.021
6.	Velocity of air flow at outlet	m/sec	0.58	0.51	0.38	0.19

Table- 2 Properties of air flow at Inlet, Outlet and at Orifice of the blower





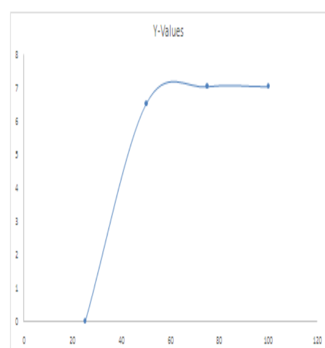
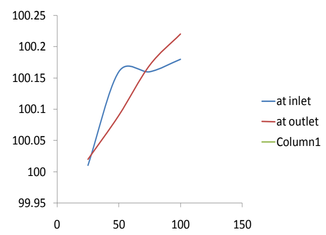


Fig I, 2&3 - Mass flow rate of air at the blower inlet, outlet and orifice



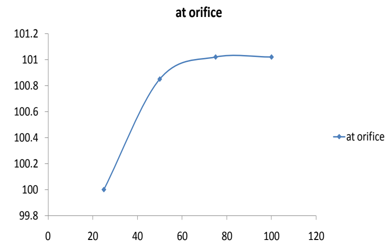


Fig 4 &5 - pressure rise of air at the blower inlet, outlet and orifice (KN/M^2)

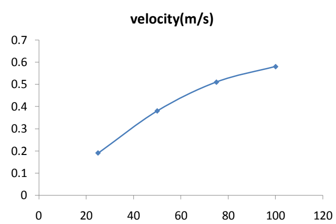


Fig 6 – velocity of air flow through outlet of the blower (m/s)

2.0 Electric Heater with Glass Wool Insulation

Type of heater	- Spring coil type
Maximum temperature (° C)	- 300° C
Minimum temperature (°C)	- 150° C
Power rating (W)	- 3000 W
Voltage (V)	- 230 V
Response time (sec)	- 15 sec

Table -3. Specifications of Electric heater with Glass wool insulation

X-axis = Time in sec Y- axis = Temp. in °C

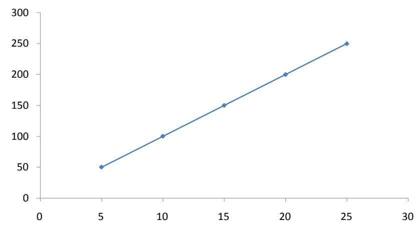


Fig -7 Heating response by the electric heater

3.0 Design, Construction, and working principle of dryer and its components:

1. Hopper
2. Flat tray
3. Dryer unit with rotating mixer rod with bevel gear attachment
4. Hot air distributors
5. Design of nozzle

Components Design and working principle:

3.1 Hopper

Length of the top portion (L) = 1 m

Length of the bottom portion (l = 0.5 m

Height of hopper (H) = 0.25 m

Corner radius of hopper(R) = 0.075 m

$$\text{Area of hopper (A)} = \left(\frac{L+l}{2}\right) \times H$$

$$= (2.5/2)\times 0.25$$

$$= 0.3125\ m^2$$

Fig -7 Trapezoidal shape hopper (placed at the top and bottom of the dryer)

Working principle:

Hopper is trapezoidal shaped sheet metal fabrication placed at the top and bottom of the vertical body of the dryer unit. At The top input feeding of bagasse takes place and at the bottom the moisture reduced bagasse collected from the hopper.

3.2 Flat tray

Length of the tray = 1 m

Breadth of the tray =1m

Thickness of the tray = 0.0025m

Corner radius = 0.075 m

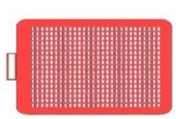


FIG.2 SLOTTED TRAY

Working principle:

There are two flat plates have the same dimensions, one is slotted with multiple slots placed just below the rectangular hot gas distributor, and the other has no slots over the surface of the solid flat plate is placed just below the circular distributor. The thickness of plate is 2.5 mm. The slotted flat plate is allowing the hot gas flow through it from its bottom side, which extracts the moisture from the bagasse. Also it helps the downfall of bagasse to be hold for a short period of time for better drying. The second solid surface flat plate is placed just below the circular distributor pipe and it holds the bagasse till the required moisture level achieved.

3.3 Vertical fluidized bed dryer with bevel gear attachment

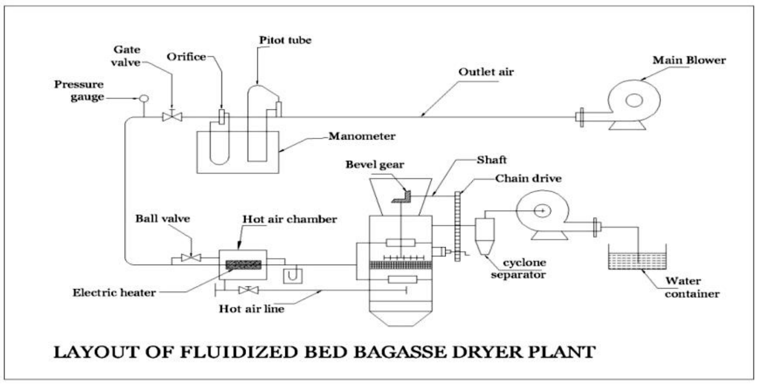


FIG.1 LAYOUT OF FLUIFIZED BED BAGASSE DRYER

Length of the fluidized bed dryer = 1m

Breadth of the fluidized bed dryer = 1m

Height of the fluidized bed dryer =2m

Corner radius = 0.050m

Construction and Working principle

Construction

The vertical body of the dryer is designed and fabricated to the above dimensions. The dryer has the arrangement of mechanical rotating mixer, it is a long steel rod of 15mm square; it is mounted vertically into the dryer in between the first distributor and the slotted tray through the top opening of the dryer. The bottom end of the rod is centrally welded with a horizontal rod and this horizontal rod has welded with smaller sized iron pieces from the centre of the rod with uniform distances on both sides.

The top end of the rod is mounted with bevel gear attachment such that it makes to rotate the square rod with respect to the vertical axis. One bevel gear is attached with one end of the horizontally mounted shaft and the other end of the shaft is connected with chain and sprocket drive. The smaller sized driven sprocket is mounted with the horizontal shaft and the bigger size sprocket is acted as driver and it is attached with the body of the dryer with the manually rotating shaft. Both the sprockets are linked by using chain drive.

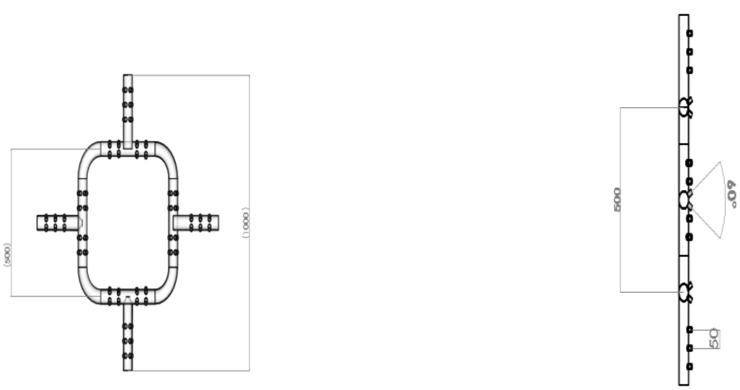
Working principle

The manual rotation given to the driver sprocket shaft causes the rotation of the driven sprocket through the chain drive. This makes the vertically mounted mechanical mixer rod can rotate inside dryer through the bevel gear set up. Hence the driven sprocket causes to rotate the bevel gear on the same horizontal axis through the shaft mounted. The change of direction of the rotation takes place by 90° vertically downward by the matted bevel gear. Since the change of direction of rotation causes the square rod to rotate in the vertical axis.

The main advantage of using this simple mechanism is to speed up the vaporization of water through the intimate contact between the mill wet bagasse and the high temperature hot air. This is achieved by the agitation made over the wet bagasse with the help of the rotational mixer rod. The mixer rod also induces the downward movement of the bagasse into the dryer to the next distributor for further evaporation of retained moisture, eventually the moisture reduced bagasse will be collected at the bottom of the vertical dryer. There will be no electric power needed to drive this mechanism also it is not necessary to rotate the mixer rod continuously. The slow speed movement of the bagasse into the dryer by gravitational force, the agitation speed of the mixer rod and the temperature of the hot air will ensure the evaporation rate of moisture and the quantity of bagasse to be dried.

3.4. Hot Air Distributor Pipes

i. Rectangular Distributor Pipe:



Outer diameter of the pipe = 0.050m

Inner diameter of the pipe = 0.045m

Thickness of the pipe = 5 mm

Length of Distributor Pipe = 0.5 m

Breadth of Distributor Pipe = 0.5m

Corner radius = 0.050m

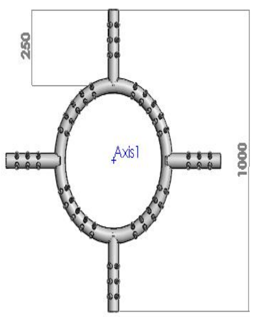
Length of pie connected with dryer = 0.25 m

Total Length of pipe required = (4 ×0.5 + 4×0.25)

$$L = 3m$$

The top hot air distributor pipe is placed inside of the dryer from 0.5m below the top of the dryer. Extended pipes from distributor at four sides are welded with the dryer. The net hot air coming from the heater through the pipe is split into two: one part of hot air is allowed to flow into the top distributor and the other part is to allowed to flow through the lower part of the distributor. The shape of the distributor pipe is rectangle with the extended pipes on four sides firmly welded with the dryer wall. It has curved radius at the corner joints, and carries nozzles to deliver the high velocity jet of hot air into the dryer.

ii. Circular Distributor Pipe:



Radius of circular pipe = 0.25 m

Circumference length = $2\pi r$

$2\times\pi\times0.25$ = 1.5 m

Length of pipe connected (4× 0.5) = 2m

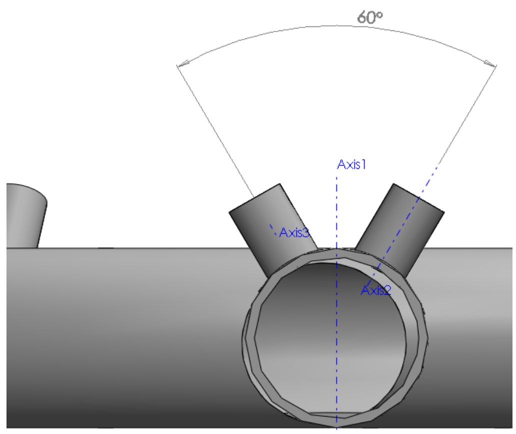
Total length of pipe required (1.5 m+2m) = 3.5 m

Construction and working principle:

It is placed at the lower part of the inside dryer from 0.5m below the first distributor. Extended pipes are welded with the dryer inside wall similar to the upper distributor. The part of hot air coming into the distributor is circulated and coming out with high velocity through nozzles which are fitted along the circumference of the circular distributor.

The main advantages of changing the shape of the distributor pipes are ensuring the better mixing of the bagasse when it comes towards downward into the dryer during drying process, also it makes the hot air to move freely through the voids. The turbulent intensity created by the hot air from the nozzles increases the drying rate and reduces the retention time.

3.5. Design of Nozzle



Length of the nozzle = 0.020 m

Outer diameter of nozzle (D) =0.014 m

Inner diameter of nozzle (d) =0.010m

Area of nozzle ($\frac{\pi}{4} \times (D^2 - d^2)$) = 75.3982 mm^2

Successive distance between two nozzles = 0.05m

Total length of nozzle pipe required =1.5 m

Thickness of nozzle = 0.0004 m

Total number of nozzle =120

Angle between the two adjacent nozzles =60 degree

S. No.	PROPERTIES OF AIR	UNIT	100% opening	75% opening	50% opening	25% opening
1.	Velocity of hot air flow through single nozzle	m/sec	33.33	26.67	20.00	10.00
2.	Mass flow rate of hot air flow through single nozzle	Kg/sec	0.0122	0.0098	0.0073	0.0036
3.	Volume flow rate through single nozzle	m^3/sec	0.010	0.008	0.006	0.003
4.	Total volume flow rate through **120** nozzles	m^3/sec	1.08	0.96	0.72	0.36

Table -4 Properties of hot air flow through nozzle

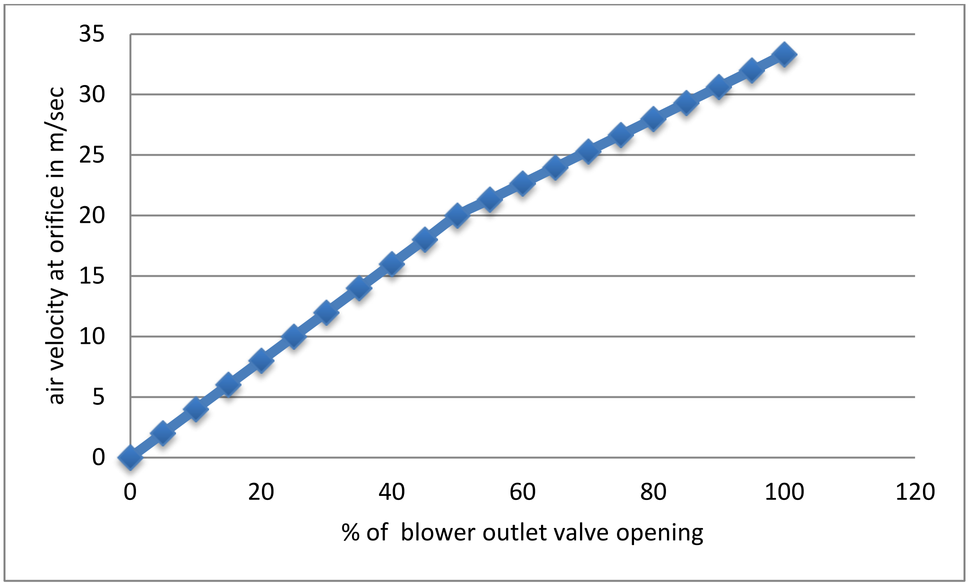


Fig -8 Velocity of hot air flow through orifice

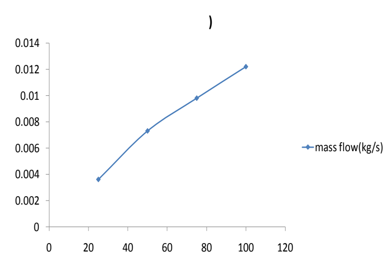


Fig -9 mass flow rate of hot air flow through single nozzle

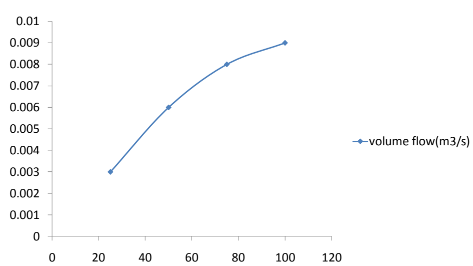


Fig – 10 Volume flow rate through single nozzle

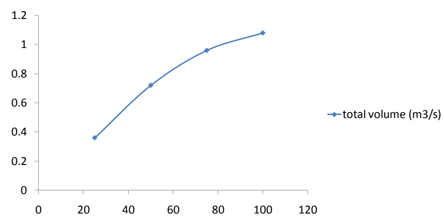


Fig -11 Total volume of hot air flow through 120 nozzles

Working Principle:

Fixed number nozzles are mounted over the surface of the distributor pipes and it discharges the hot air with high velocity of jet into the dryer. The mode of heat transfer on the surface of the hot distributor pipes and nozzles with the wet bagasse is conduction, and the mode of heat transfer through which the hot air and the wet bagasse is as convection heat transfer.

4. Drying of bagasse

The drying process of bagasse takes place inside the medulla of the dryer through which the downward flow of mill wet bagasse and the upward flow of hot air intimately contact with each other. Hence the drying process is nothing but the simultaneous removal of certain mass of moisture content by the hot air at one particular flow direction. The hot air will penetrate the wet material by diffusion and evaporate the water particles.

Since the pith is smaller sized solid particles and it does not have any specific moisture transport mechanism from the surfaces. The moisture transport takes place directly from the surfaces of the pith material by allowing hot gases to flow through it, this in turn to remove greater mass of moisture by observing larger amount of heat energy.

When hot flue gases used for drying process filters the highly polluted macro to micro level of particles and the dilution of concentrated toxic gases. Hence the fluidized bed dryer acted as a filtering element to prevent the atmosphere to pollute. Also any unburnt combustion products available is again taken to the boiler in that way of further combustion of the same products increase the thermal efficiency.

The drying time or the retention time required for the moisture removal rate is mainly based on the geometry of the fluidized bed dryer, dry bulb temperature hot air and heat and mass transfer through molecular diffusion. Conducting experiments by setting various flow and temperature combinations of both solids and fluids will determine the period of fastest drying time. The process of the removal of the moisture content by circulating hot gases over the solid surfaces and finding the fastest rate of drying time is also known as constant rate of drying time. This time period will remove certain percentage of moisture constantly for any particular setting values.

The geometry of the dryer is rectangular in construction with curved and radial shape with some radii (0.05m) at the corners for ensuring smooth flow of bagasse inside, and there are five thermocouples installed to measure the temperature at various places. One is installed in the heating coil with temperature controller and indicator to set and read the temperature of the heating coil. One of the thermocouple installed at the exit pipe from the heater, two of the thermocouples installed inside the dryer nearer to both the distributors and finally the fifth thermocouple is installed at the top of the dryer to measure the wet exit gas outlet temperature from the dryer.

Constant Rate of Drying Time

Initial moisture content =50%

X – Axis : .001 = 45% ; Y –Axis : 1 = 3.45 mts.(time)

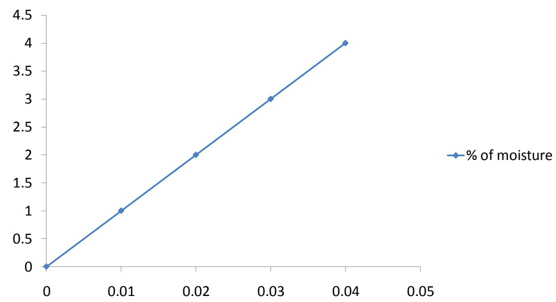


Fig -12 Drying time Vs % of moisture reduction

From the fig -12 constant rate of drying time can be found. It means the moisture reduced bagasse is available at the bottom of the dryer and it may not be drying further. The Constant rate of drying time will be varied due to the factors such as: temperature of the hot gas, turbulence intensity created by the velocity of flow of the gas through nozzle and the retention time of the bagasse into the dryer.

5. Principles of Heat Transfer Analysis

First Law of Thermodynamics is used for analyzing thermal systems based on steady flow energy balance equation by considering the conservation of energy between the system and its surroundings to determine the heat and mass transfer.

S. No.	Time min.	2	4	6	8	10	12	14	16
	Temp. Indicator (T2)°C	Temperature Indicator reading of Air-Vapor mixture (T3) °C							
1.	150	110	112	114	114	116	118	118	120
2.	175	135	136	137	138	139	143	146	150
3.	200	153	156	161	163	167	169	172	175

Table - 6: Temperature of Air-Vapor mixture at 2 mints period of time (T3)

S. No.	Temperature (T3) °C	Total weight of Sample (gm)	% by wt. of bagasse	% of moisture
1	110	45.6	90	41.2
2.	112	44.6	88	39.2
3.	114	43.8	88	37.6
4.	114	43.8	88	37.6
5.	116	43.1	86.1	36.2
6.	118	42.3	84	34.6
7.	118	42.3	84	34.6
8.	120	41.6	82	33.2

Table-7 : Sample weight with respect to temperature and % of moisture

S. No.	Time min.	2	4	6	8	10	12	14	16
	Temp. Indicator (T2) °C	Temperature Indicator reading of Air-Vapor mixture (T4) °C							
1.	150	110	110	114	116	120	122	125	125
2.	175	145	148	152	155	158	162	164	165
3.	200	168	170	173	175	178	180	181	182

Table - 8: Temperature of Air-Vapor mixture at 2 mints period of interval of time (T4)

S. No.	Temperature (T3) °C	Total weight of Sample (gm)	% by wt. of bagasse	% of moisture
1	135	37.03	74.00	24.06
2.	136	36.76	73.52	23.52
3.	137	36.49	72.98	22.98
4.	138	36.23	72.46	22.46
5.	139	35.47	70.90	20.90
6.	143	34.96	69.92	19.92
7.	146	34.24	68.48	18.48
8.	150	33.33	66.66	16.60

Table-9 : Sample weight with respect to temperature and % of moisture

(Assume 50°C = 10°C)

S. No.	Time min.	2	4	6	8	10	12	14	16
	Temp. Indicator (T2) °C	**Temperature Indicator reading of Air-Vapor mixture wet basis [Wet Bulb Temp.] (T5) °C**							
1.	150 (30)	23	22.6	22.0	21.4	21.2	20.4	20.0	19.5
2.	175 (35)	29.2	28.8	28.2	27.4	26.8	26.0	25.8	25.0
3.	200 (40)	33.6	33.0	32.2	31.6	30.8	30.0	29.6	29.0

Table - 10: Temperature of Air-Vapor mixture at 2 mints period of interval of time (T5)

(Assume 50°C = 10°C)

S. No.	Time min.	2	4	6	8	10	12	14	16
	Temp. Indicator (T2) °C	**Relative Humidity of Air-Vapor mixture (%)**							
1.	150 (30)	56	51	50	45.5	45.2	45	45	44.9
2.	175 (35)	64	60	57.5	53	49	48	47	45
3.	200 (40)	48	47	46	46	45.5	45	44.9	44.5

Table - 11: Relative Humidity of Air-Vapor mixture (%)

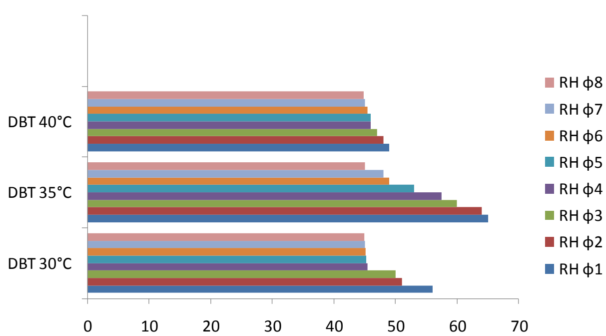


Fig : Dry Bulb Temp. (DBT) Vs Relative Humidity (RH)

S. No.	Temperature (T3) °C	% of moisture	weight of Carbon(gm)	weight of Oxygen (g/mole)	Calorific value of Bagasse(KJ /KG)
1	110	41.2	31.75	52.9	11981
2.	112	39.2	32.83	50.5	12770
3.	114	37.6	33.69	43.92	14210
4.	114	37.6	33.69	43.92	14210
5.	116	36.2	34.45	44.84	14310
6.	118	34.6	35.32	45.88	14461
7.	118	34.6	35.32	45.88	14461
8.	120	33.2	36.07	46.78	14572

Table-12 : Calorific Value of bagasse using Dulong's Formul

S. No.	Temperature (T4) °C	% of moisture	weight of Carbon(gm)	weight of Oxygen (g/mole)	Calorific value of Bagasse(KJ /KG)
1	135	24.06	40.98	32.42	18170
2.	136	23.52	41.29	31.72	18928
3.	137	22.98	41.59	31.07	19143
4.	138	22.46	41.87	30.45	19351
5.	139	20.90	42.71	28.58	20173
6.	143	19.92	43.24	27.40	20351
7.	146	18.48	44.02	25.67	20940
8.	150	16.60	45.03	23.42	21267

Table -13: Calorific Value of bagasse using Dulong's Formula

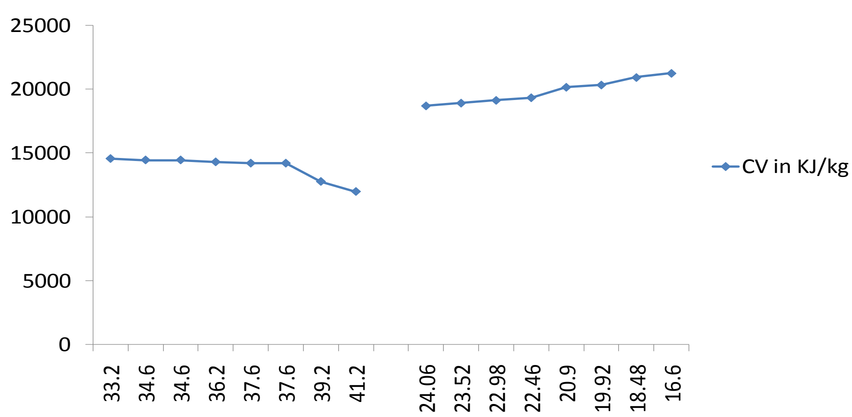


Table : % of moisture in bagasse at T3(°C) and T4(°C) **Vs** Calorific value(KJ/KG)

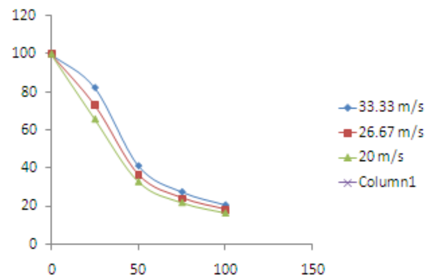


Fig -13 Drying time Vs Enthalpy of hot gases at 150°C at different velocities