PERFORMANCE STUDY OF FLUIDIZED BED BAGASSE DRYER WITH NOVAL ATTACHMENT OF DISTRIBUTORS AND ORIFICES

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Abstract

Sugar cane bagasse can be used as fuel in boilers to produce steam and electricity in co-generation power plant. After many stages of milling process of sugar cane, the byproduct named as bagasse is available in different ranges of size of particles called as pith with higher percentage moisture content. The size of the bagasse particles varies from 2mm to 6mm after the depithing process, and this would be used as fuel in the co-generation power plant boilers of sugar cane processing industries. Due to high ranges of moisture content from 48% to 55%, the pith needs more than the normal percentage of excess amount of oxygen for complete combustion in the boiler. Few percentages of heat energy produced and have to be utilized by the wet bagasse to vaporize the surface moisture as well as the inner moisture content by the diffusion process. The loss of heat energy utilized to evaporate the moisture content reduces the boiler efficiency.

Two hot air flow distributors of different shape placed in the fluidized bed dryer increased the rate of evaporation of moisture content by uniformly distributed hot air. On the surface of the two distributors were perfectly drilled and welded by two rows of orifices with certain included angle for the hot air flow. The hot air flow from the orifices makes countercurrent flow effect against the bagasse feeding from the hopper from the top of the fluidized bed dryer. Thus, the countercurrent flow effect makes a better mixing of solid – gaseous particles where the removal of moisture content of the bagasse. A slow speed rotating stirrer with bevel gear attachment and chain and sprocket driven mechanism into the fluidized bed dryer called mechanical agitator to agitate by spreading the bagasse across the surface area covered on the perforated plate to improve the evaporation rate of the moisture. The performance of the fluidization behavior of the dryer had been evaluated interms of moisture content reduction. The effect of temperature and the high velocity jet of hot air flow for the given time also considered for evaluating the performance of the fluidized bed dryer.

Key words: Bagasse, Fluidized bed dryer, Mechanical agitator, Distributors and Orifices.

INTRODUCTION

Sugar cane bagasse is an important renewable energy source for integrated cogeneration power plant. It can burn with coal and produces less Co2 emission to the atmosphere and it causes less environmental impact [1-2]. The mill-wet bagasse has high moisture content ranges from 48% to 55% on wet basis, and when it burns produces less LCV due to significant amount of thermal energy spent by the boiler furnace to evaporate the moisture content. In most of the countries for drying the biomass different types of dryers are being used. A new innovative design of fluidized bed dryer with mechanical agitator [4], distributors with orifices and perforated slotted holes containing tray was introduced here to ensure to supply uniform rate of flow of hot air inside the dryer to remove the moisture content. (Yuping Liu et.al). The size of the bagasse particles ranges from 1mm to 5mm [6] is to be liable to free flow without forming agglomeration due to high moisture content[7]. The Dulong's formula is used to estimate the higher heating value of Organic fuels. The moisture content decreased by 1% in the bagasse by using any one method of drying would be increased the boiler efficiency by 0.5% described the use of a pneumatic transport dryer (Design of Bagasse Dryer to Recover Energy, Correia (1983). He reported in increase in steam production of 16% by drying the bagasse from 52% to 40%. This dryer was developed in the santo Antonio factory, in Alagoas, Brazil. Study of granular material flow for the same size, the same moisture content and the density through screw conveyor dryer was studied and excellent result in mixing was observed, but the power required to run was considerably high for continuous drying process [8]. The better mixing of biomass particles in fluidized bed dryer using mechanical stirrer needs only less power and it could be conserve the power requirement [9]. The moisture reduced bagasse fuel burnout completely in the atmosphere of enriched excess amount of oxygen above the stoichiometric level in the combustion chamber of boiler and it improves the combustion quality, reduces the green house effect and it results the increase of the boiler efficiency[10]. The absence of inert particles in the fluidized bed dryer would result to reduce the process time for adding, mixing and separating with the biomass [11]. 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 [12].

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1. Materials and Methods

1.1 Bagasse collection from jaggery plant

Sugar cane bagasse required for the experiment conducted were collected from a Jaggery plant where produces jaggery in large amount using sugarcane. The cleaned sugarcane cut into small pieces and were ed into the crusher. The juice collected from the sugarcane crushing would be processed to make jaggery and the solid waste remained are called as bagasse. Bagasse is an organic substance to be used as fuel in the boiler furnace in the cogeneration power plant for producing power and steam. The wet bagasse containing upto 55% of moisture content, the thermal energy produced by the wet bagasse burnout was only less in the boiler due to the part of heat energy spent for the evaporation of moisture in the boiler. The percentages of moisture reduction in the bagasse were investigated and the performance of the fluidized bed dryer was evaluated by conducting through series of experiments.

1.2 Experimental setup

The noval fluidized bed dryer used in the experimental setup as shown in the **Fig. 1** has two hot air distributors placed one below the other with uniform distance between them. The top one distributor is rectangular and the bottom is circular in configuration with number of orifices. The distributors have four extended pipes on its four sides were welded and fabricated on the wall surface of the fluidized bed dryer. The three extended pipes were perfectly sealed with the sides of each wall of the dryer by welding and the fourth extended pipe was connected with the hot air inlet as shown in **Fig. 2.** The distributors and the extended pipes were drilled by two rows of holes of the same diameter andl were fitted and welded with the same diameter of the orifices on it for the hot air flow. The position of the orifices on the distributors were in inverted position with an included angle of 60̊, therefore the hot air came out through the orifices were towards downward in direction. After discharged into the dryer the movement of the hot air flow takes place towards upward direction along the vertical height of the dryer. The wet bagasse feed from the hopper from the top of the dryer making a perfect contact of solid and gaseous particles due to countercurrent flow of both solid and gaseous materials. Thus the effect of countercurrent flow, causes a better mixing of hot air and the solid wet particles. A movable steel plate called as tray through a small gap made one side of the wall on the dryer helps to move and separates the two stages of drying process. The plate was moved outward from the dryer with the help of a handle provided by pulling and allowed the bagasse to subject for the second stage drying process. The perforated slotted holes on the tray cover the area around 80% of the material removed. A mechanical agitator inside the dryer keeps rotating over the wet bagasse available on the perforated slotted plate during the first stage of drying process and then allowed to move to the second stage drying process.

The spouted bottom part of the dryer has an additional hot air pipeline with an attachment of hand-operated ball valve from the air-heating chamber to supply high temperature hot air directly in the spouted area of the dryer. It would be help to further reduction of moisture content from the dried bagasse has came out after the two stages of drying process in the dryer. At the bottom of the dryer can be closed by using a steel plate during the time of experiments were conducted. There were four numbers of thermocouples (T1, T2, T3 and T4) and Relative humidity sensors called as hygrometer (R1, R2, R3 and R4) were placed in the dryer with uniform distances in between them. The values measured by the thermocouples and the Relative humidity sensors were shown as output by the indicators during the drying process.

A centrifugal air blower supply air continuously with a measured quantity of constant flow rate and increased in pressure. An electric heater, which was mounted over the discharge pipeline from the centrifugal blower, used to heat the air, which flows through the pipeline, and the air collected in a heating chamber as shown in **fig .2.** The air-heating chamber was perfectly insulated to prevent the heat transfer takes place to the atmospheric air. Three thermocouples (T5, T6, and T7) were used to measure the air inlet temperature to the heater, air temperature in the air-heating chamber and the temperature of the air at the distributors before the inlet to the fluidized bed dryer. A digital temperature controller with an establishment of automatic ON-OFF controller is used to set and alter the air temperature in the region of heating zone. A U- tube manometer was installed before the dryer entrance to measure the pressure of the flow of hot air interms of height differences h1 and h2 measured using scale. There was another U- tube manometer it has been installed at the exit of the fluidized bed dryer to measure outlet air pressure. An insulating cover made at the outside of the dryer helps to prevent the heat losses due to the atmospheric air contact.

2. 0 CONSTRUCTION OF THE FLUIDIZED BED DRYER

2.1 Fluidized bed Dryer Consist of the following components

1. Hopper.
2. Hot air distributors (Rectangle and circular) with orifices.
3. Flat plate or tray with Perforated slotted holes.
4. Chain drives mechanism with an agitating mechanical stirrer.
5. Hot air pipeline at the spouted bottom of the dryer.

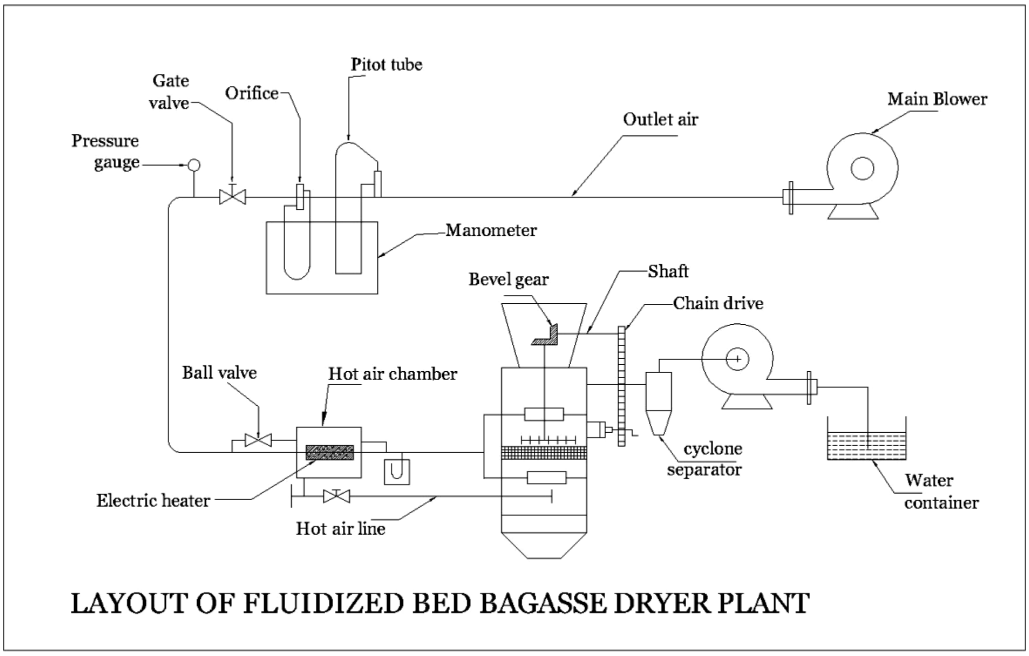

FIG.1 LAYOUT OF FLUIFIZED BED BAGASSE DRYER

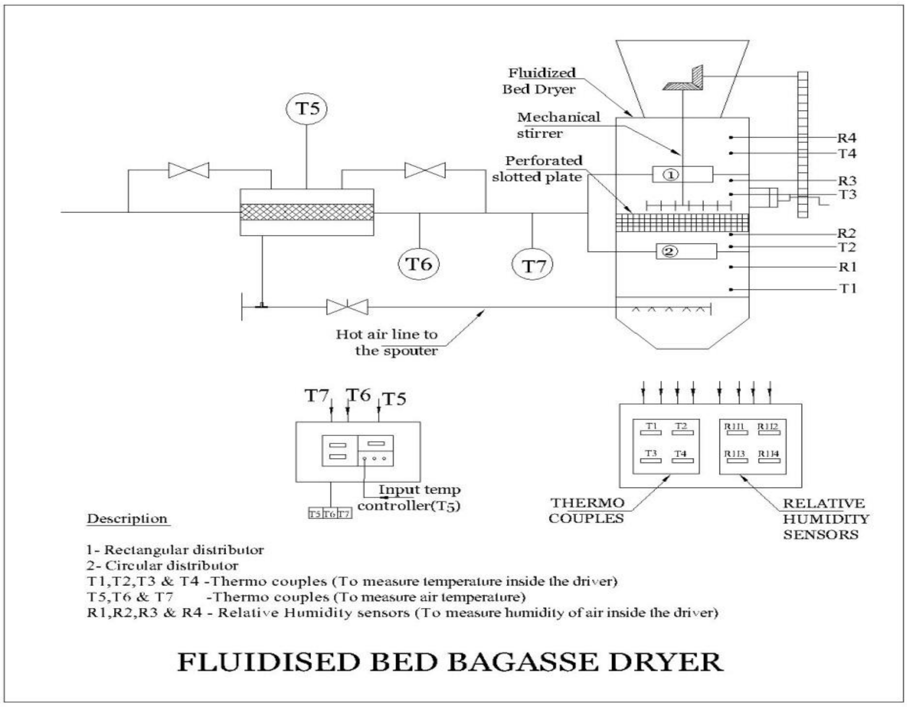

FIG.2 CONSTRUCTION OF FLUIFIZED BED BAGASSE DRYER

(a) (b) (c)

PHOTOGRAPHIC VIEW

a. A model of Fluidized Bed Dryer plant.
b. Mechanical strrier, Rectangular Distributor with orifices and Perforated slotted Tray. (Top View).
c. Mechanical strrier, Rectangular and Circular Distributors with orifices(Top View).

3.0 EXPERIMENTAL PROCEDURE

The centrifugal blower was started with the full opening of gate valve at the delivery side hence the maximum quantity of air was passed across the heating zone. Therefore, the air temperature rose in the heater region and reached to the predetermined value of the temperature controller. The hot air came out from the heater region allowed to flow into the dryer to raise its temperature and it was continued for some time until to attain the temperature of the controller for attaining steady state condition. A weighing scale with an accuracy of 0.2mg used to measure the weight of the dried bagasse sample. A bag containing dried bagasse from the jaggery unit was weighed initially in the weighing machine and the weight of the bagasse has been noted. Then the weighed dry bagasse-containing bag was immersed into the water to make it into wet bagasse. The weight added by the water in the wet bagasse to be kept not less than 50% of the actual weight dried bagasse. This work could be done with the help of weighing machine. The 50% moisture content of the wet bagasse were loaded into the dryer through hopper from the top and settled over the perforated plate. The rotating mechanical agitator spreads the bagasse particles to the inside surface area of the dryer. This would create pores space between the wet solid particles, and the hot air flow through the spaces removed the moisture content due to the countercurrent flow effect. This process would continued for some period of time called as first stage drying then the perforated plate is pulled out and the partly reduced moisture content bagasse had been again allowed to flow to the second stage drying for further reduction of moisture content. The time taken for the whole drying process into the dryer called as retention time. The moisture reduced bagasse taken out through the spouted bottom of the dryer and was weighed using weighing scale to measure the weight loss of the bagasse. The same experiments were repeated with different weight and different percentage of moisture content of wet bagasse particles. The hot air temperature also could be changed by setting with various temperature level in the controller at the heating zone.

$$M_{loss} = M_n - M_m = m_a \sum_{i=n}^{n} S_i \quad \text{[g-water]} \qquad (1)$$

$$Y_d = \frac{dw}{dt} = \frac{\sum_{i=m}^{n} S_i}{t_n - t_m} = \frac{m_a (S_m + S_{m+1} \ldots S_i)}{(t_n - t_m)} \quad \text{(gm-water/min)} \qquad (2)$$

$$S = 0.622 \left[(P_s / (P - P_s) \right] \quad \text{(gm – water / kg-air)} \qquad (3)$$

Where, From the eqn. (1), M_{loss} is the determination of loss of moisture, and M_n and M_m are the mass of wet bagasse measured before and after drying at different periods of time. m_a is the mass of the air. S_i is the specific humidity of wet air. Rate of drying of the bagasse Yd, is determined using the Eqn. (2)

Where $\mathbf{m_a}$ is the mass of air and **S** is the specific humidity of moist air and the specific humidity is calculated from the above eqn. No. 3

3.1 Rate of water evaporation by per unit area and unit time in a dryer

The evaporation rate of water is defined as the ratio of mass of water vapour evaporated from the initial moisture to the final of moisture in a given unit rate of time and the unit area of the dryer [15]. It can be calculated as follows:

$$\mathbf{m_{evp}} = \frac{\mathbf{m}_{wi} - \mathbf{m}_{wf}}{\mathbf{td \cdot A}} \tag{4}$$

$\mathbf{m_{evp}}$ **– mass of evaporation of water** , $\mathbf{m}_{wi}$ and $\mathbf{m}_{wf}$ – Initial and final mass of water vapour.

Table I

Ref [15] Percentage of individual elements distribution

With and without water content in the bagasse

Components	C	H	O	N	S	Ash
Weight in kg (without water)	49	6.5	23.5	0.11	0.055	0.735
Weight in kg (with water)	27	8.5	63.5	0.11	0.055	0.735

TABLE II

Ref [16] Enthalpies of Combustion Gases (J/gmol)

K	N_2	O_2	Air	H_2	CO	CO_2	H_2O
273	0	0	0	0	0	0	0
291	524	527	523	516	525	655	603

298	728	732	726	718	728	912	837
300	786	790	784	763	786	986	905
400	3,695	3,752	3,696	3,655	3,699	4,903	4,284
500	6,644	6,811	6,660	6,589	6,652	9,204	7,752
600	9,627	9,970	9,673	9,518	9,665	13,807	11,326
700	12,652	13,225	12,736	12,459	12,748	18,656	15,016

Table III

Bagasse drying Factors in Fluidized Bed Dryer

Factors	**Fluidized Bed Dryer**
Type of the techniques used	**Mechanical Agitator**
Dryer Initial moisture content (wt.% wb)	50
Bagasse mass (Kg)	12
Air flow (Nm^3 /h)	2.26
Air velocity (m/ s)	0.32
volume of bagasse in the bed ($\times 10^{-3}$ m^3)	0.031
Bed height (cm)	3.5
Final moisture content of bagasse (wt.% wb) [to stop flying inside the boiler due to drafting]	30
Rotational speed of the Agitator (Manual rotation)	5 rpm

3.2 Determination of heat lost due to Vaporization of water

The Heat of Vaporization of water at 20^0 C = 2440 KJ/kg.

Consider mass of bagasse "W" in kg.
Consider mass of Hydrogen "H" in kg.
Consider heat lost = 2440 (W+9H) KJ/kg.
The mass of bagasse for the heat transfer analysis (W) = 1 kg,
Mass of Hydrogen present in 1 kg of bagasse(H) = 0.085 kg
Heat lost due to vaporization of water = 2440 + (1+9(.085)) =4306.6 KJ/kg

3.3 Determination of Higher Heating Value of bagasse:

The reduction of moisture content from 50% to 35%, will increases the higher heating value of the bagasse due to the value of major elements increases in percentage by weight.

The **Dulong** formula used to estimate the higher heating value of Organic fuels.

KJ/Kg = 337 C + 1419 (H – (1/8 O)) + 93 S

The major elements of the dry bagasse at 35% moisture content in percentage by weight

C - 49, H - 6.5, O – 42.7, S - 0.1, N - 0.2

Using the **Dulong** formula, the HCV of bagasse = **18,186.34 KJ/Kg**

The major elements of the wet bagasse at 50% moisture content in percentage by weight

C – 27, H – 8.5, O – 63.5, S – 0.055

Using the **Dulong** formula, the HCV of bagasse = **9955.5 KJ/Kg**

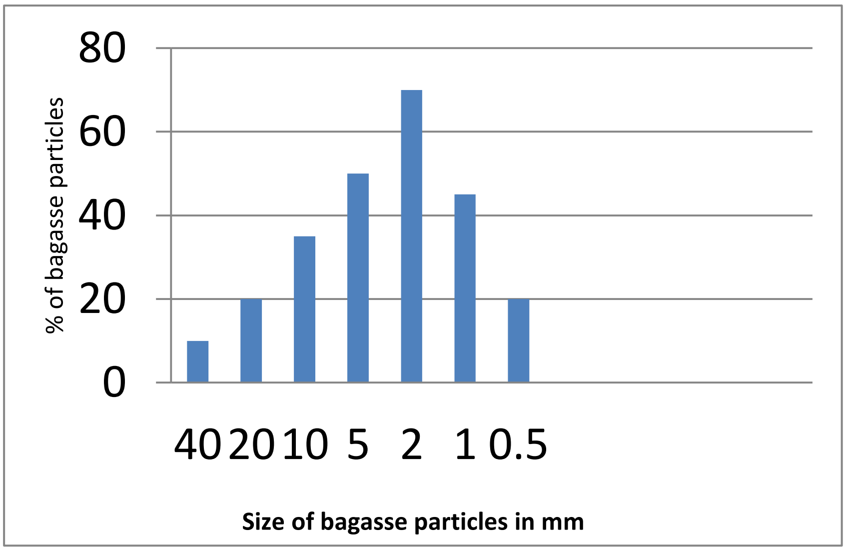

Fig.3. Size of bagasse particles after sieving in percentage

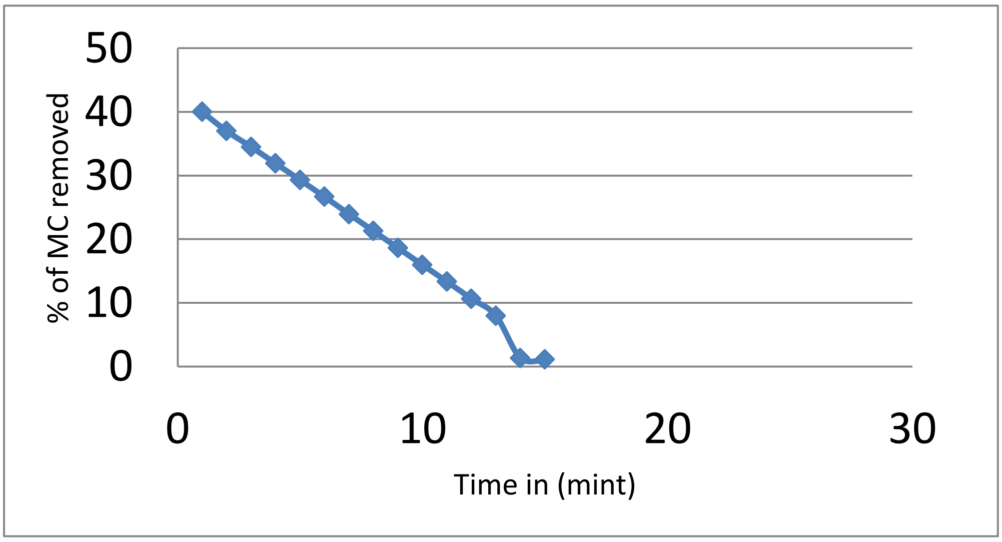

Fig.3. Drying of wet bagasse at the hot air temperature 150̊ C

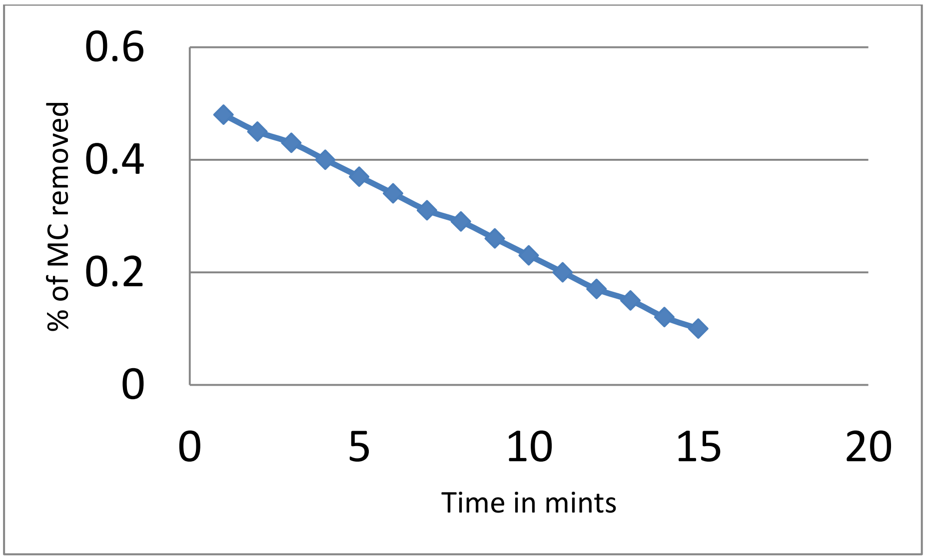

Fig.4. Drying of wet bagasse at the hot air temperature 175̊ C

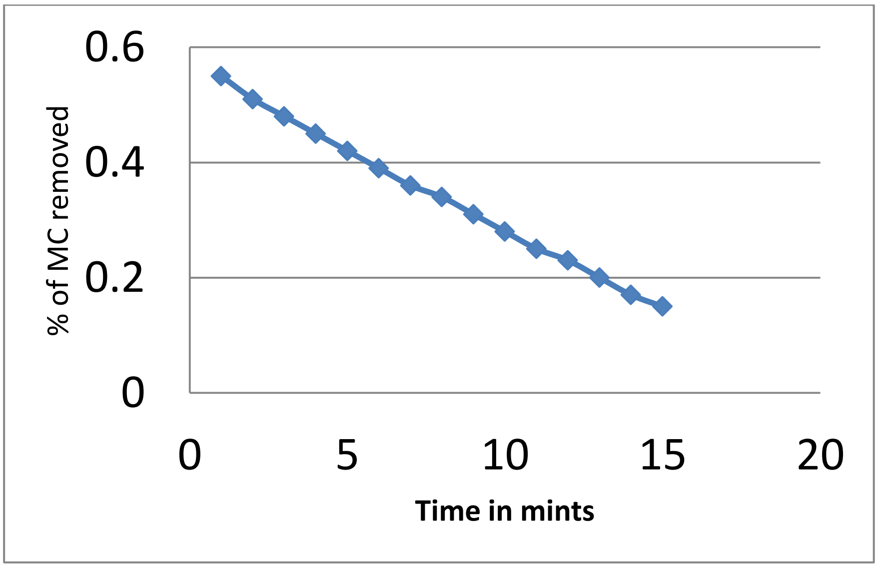

Fig.5. Drying of wet bagasse at the hot air temperature 200̊ C

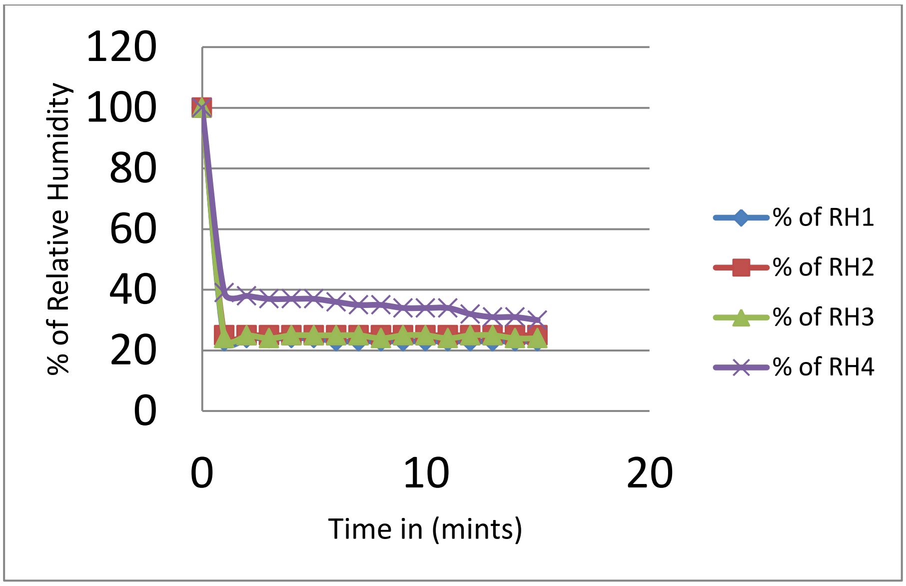

Fig.6. percentage of Relative Humidity of air at 150 ̊ C in the dryer

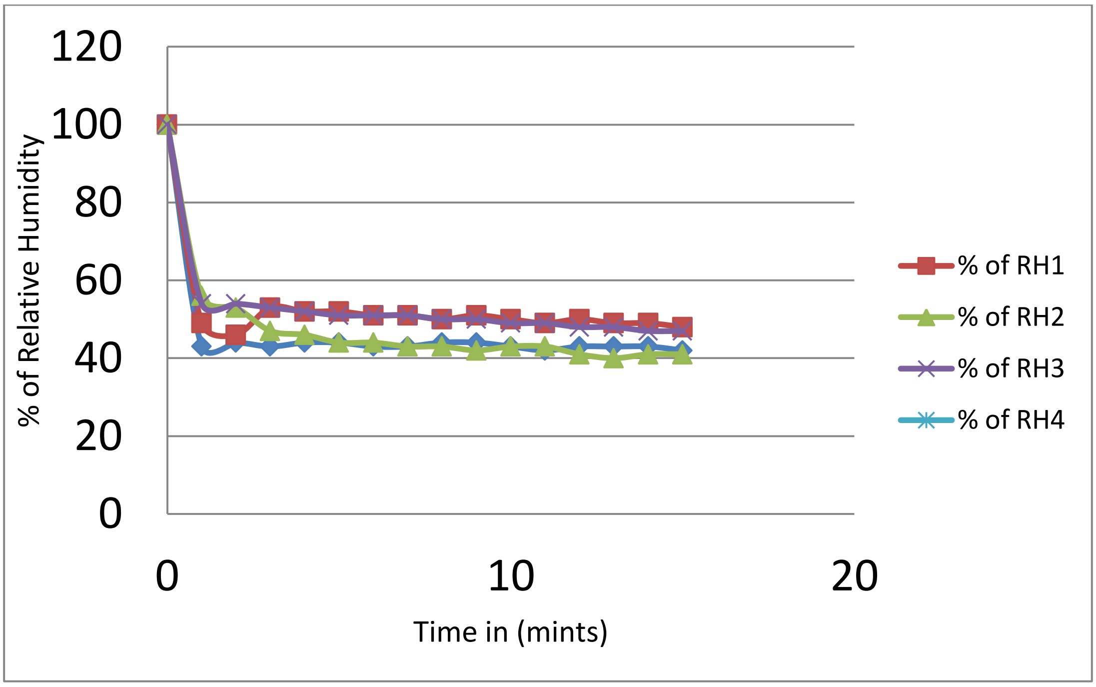

Fig.7. percentage of Relative Humidity of air at 175 ̊ C in the dryer

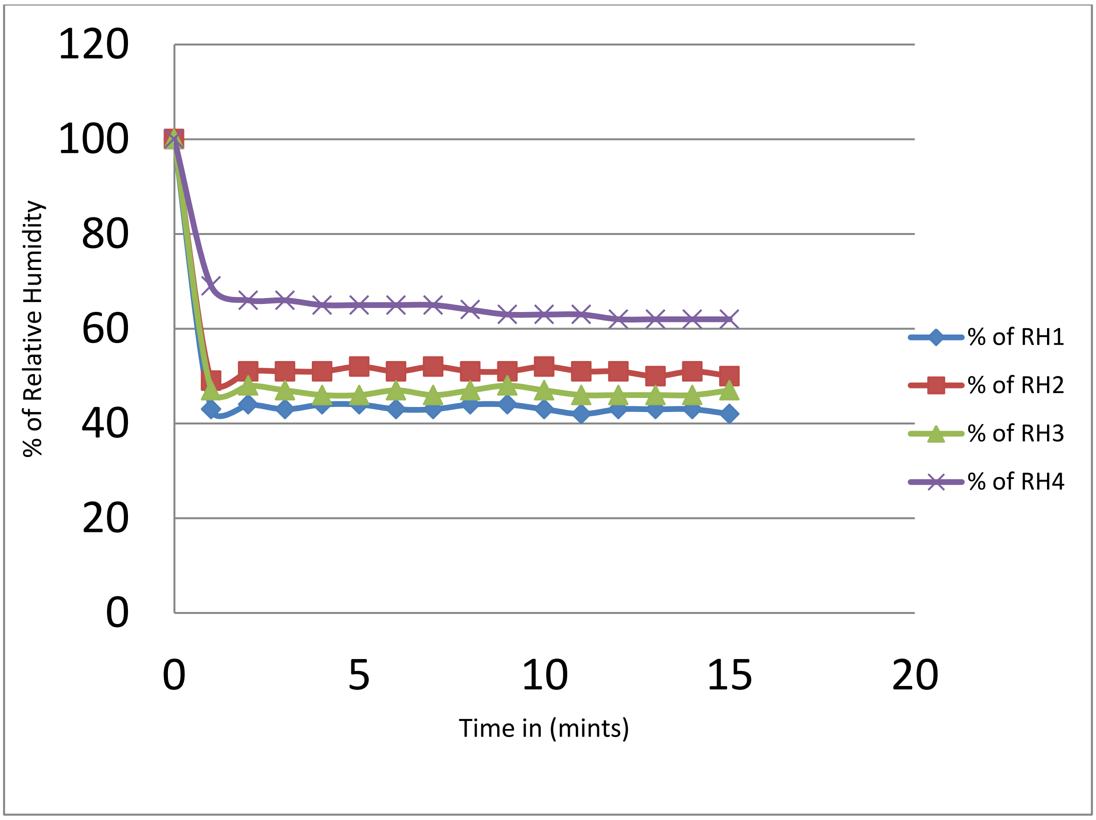

Fig.8. percentage of Relative Humidity of air at 200 ̊ C in the dryer

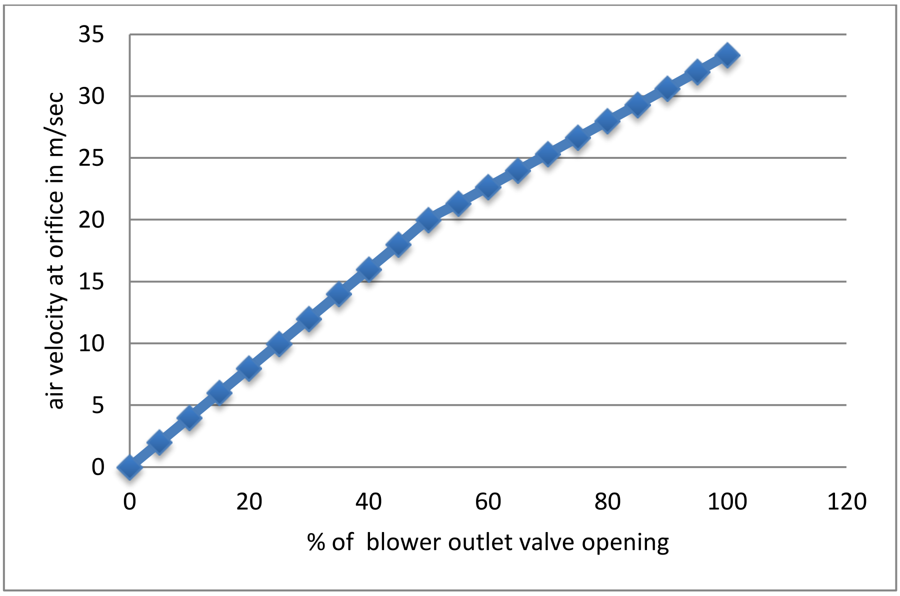

Fig. 9. Velocity of hot air flow through orifice

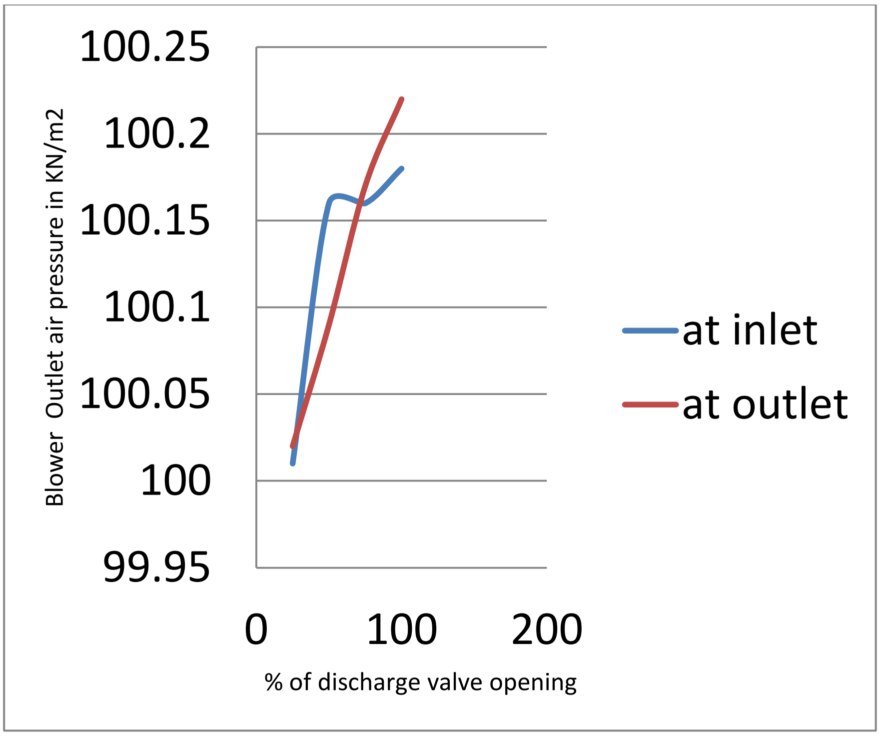

Fig -10 The air pressure at the outlet of blower and % of valve opening

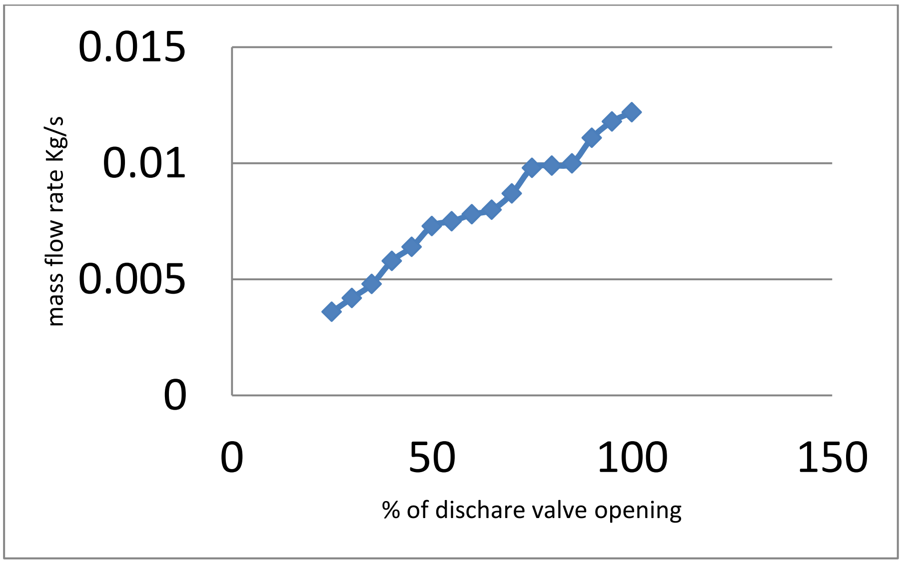

Fig -11 mass flow rate of hot air flow through single nozzle

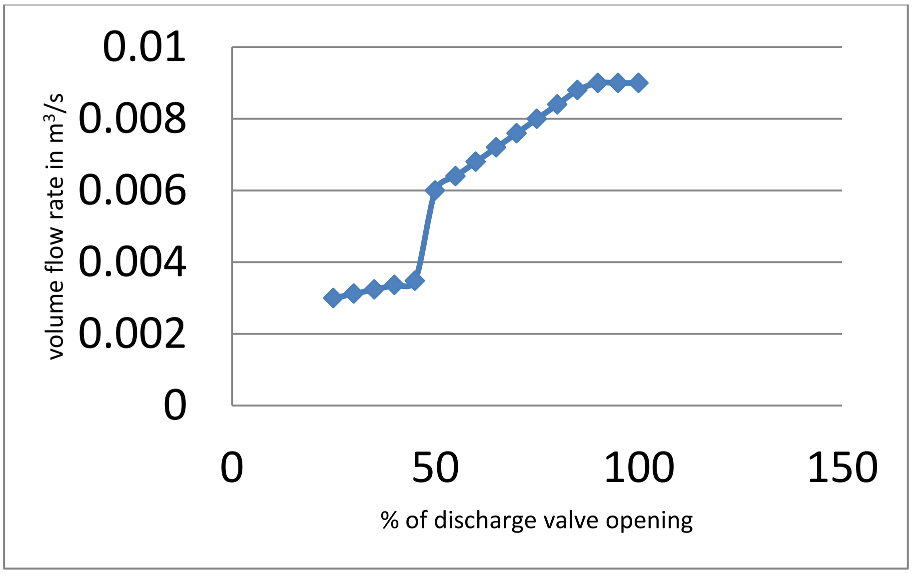

Fig – 12 Volume flow rate through single orifice

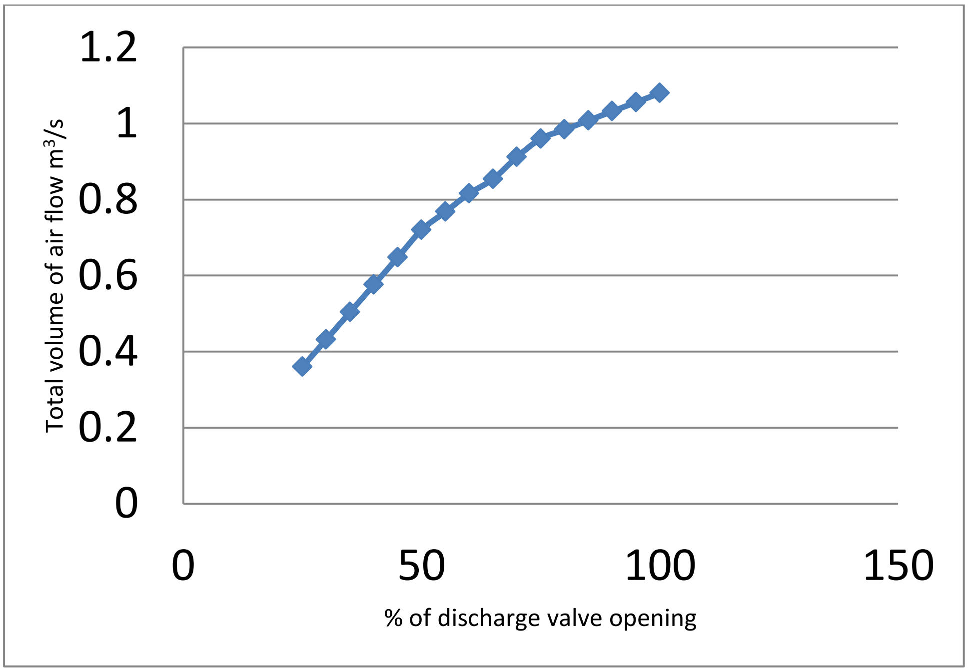

Fig -13 Total volume of hot air flow through 120 orifices

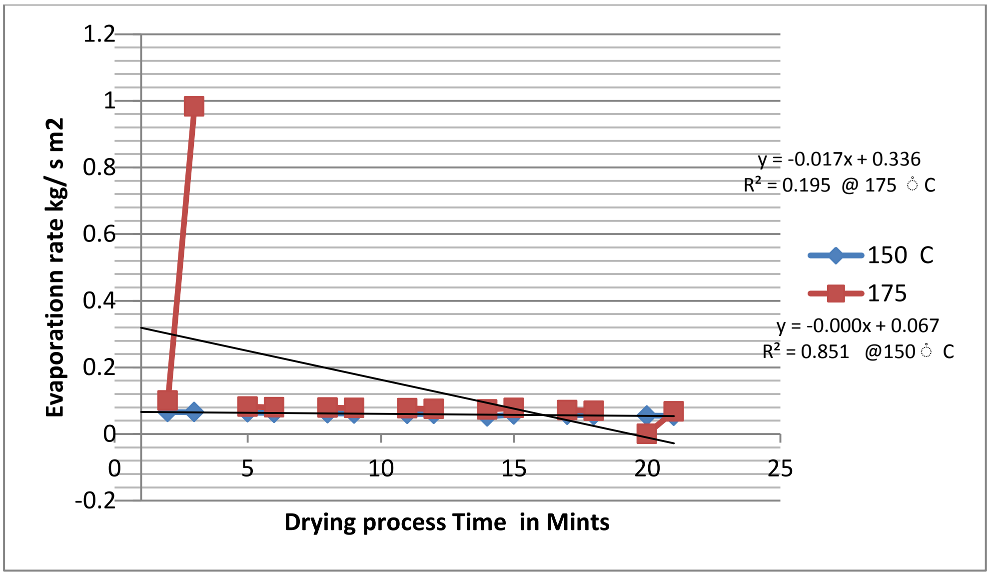

Fig 14- Evaporation Rate Level

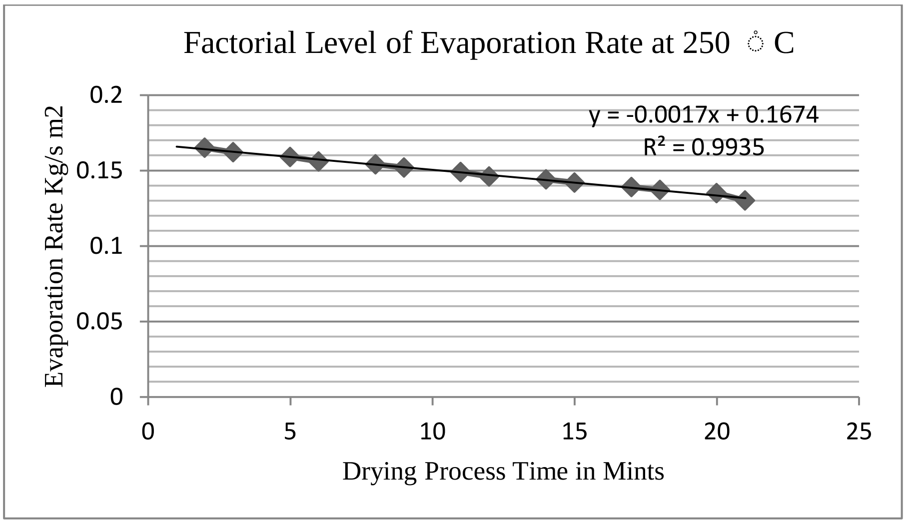

Fig 15- Evaporation Rate Level

4.0 Result and Discussion

The fluidized bed dryer was newly designed, fabricated one by innovative thinking by referring various journals and thesis published. The dryer was subjected to different weight with different moisture contents of bagasse and the performance of the dryer was studied for the given conditions. The performance of the dryer in the way of moisture removal rate, relative humidity of air coming out from the dryer after the drying process, velocity of hot airflow into the orifices and the total discharge of airflow through the orifices mounted in the two distributors for the given period were noted. The input and the output values from the indicators displayed during the drying process were noted and graphs were plotted for the respective properties were noted during experiments were conducted. The same experiments were repeated for three times for getting and ensuring the same results that could be obtained in all the experiments conducted. The results were plotted and graphs were plotted for all the results. In addition, the results were evaluated with the help of graph.

5.0 Drying kinetics of hot air flow in the fluidized bed dryer

The centrifugal blower discharged the constant mass flow rate of air at the outlet with increased pressure and velocity. The mass flow rate of air entered into the hot region over the surface of an electric heater was controlled by ¼th, ½ th, ¾ th and fully opening and closing by manually operated gate valve. Since the electric heater placed on the outside surface of the airflow pipe, the heat absorbed by the air through the inner pipe flow was limited because of the limited length of the heated surface of the electric heater. Unless when the gate valve was not fully opened the quantity of flow rate of air was insufficient into the dryer through distributors and orifices. If the velocity of the hot air flow into the dryer existed only at low velocity (m/s) through the airflow chamber to the dryer when the valve not opened fully. In addition, it would affect the process of drying significantly with less performance of the dryer. If the velocity of hot air flow allowed to the dryer to the maximum (m/s) by fully opened position of the gate valve would have increased the performance of the dryer. The fully opened position of the valve would admit more quantity of hot air with high velocities through the orifices into the dryer, and the rate of drying increased slightly when compared with the low velocity flow of hot air.

A newly designed and fabricated cylindrical hot air chamber with baffle plates made up of steel material was welded around the inner circumference of the cylindrical wall of the hot air chamber with uniform distances between them. There are two separate air lines were connected with the hot air chamber, the one end of the hot air chamber was connected with cold air inlet from the blower, and the other end of the hot air chamber was connected with the main stream of outlet hot air flow. This set up was mounted over the electric heater, and the baffle plates would create disturbances in the flow of air across inside the chamber would have created the turbulent effect. Further, due to the turbulent effect the flow of air absorbed the heat energy existed over the surface of the electric heater and the temperature increased in the air was measured by the thermocouple inserted.
The hot air supplied into the dryer would have increased the temperature gradually and to be maintained until reaches to the set value in the temperature indicator. The newly designed fluidized bed dryer was perfectly insulated at the outside to prevent the contact of the low temperature atmospheric air with the outside wall surface of the dryer. The fluidized bed dryer would be allowed to reach the temperature equivalent to the set value as shown by the inlet temperature indicator. Bagasse with high initial moisture content was supplied through hopper from the top of the dryer. The drying processes of bagasse have been takes place by the hot air flow through the orifices to remove the surface moisture content. The fluidized bed wall temperature, the distributors' wall surface temperature and the heat hold by the perforated slotted plate would make to faster the process of moisture removal rate. The hand driven mechanical agitator spreads the bagasse over the entire surface area of the perforated slotted plate and provides enough footprint for the hot air flow. The same process was replicated by three times using the same weight of the samples each time, and the process of drying would have done by handling different weight ratios of the bagasse material. The RH (hygrometer) probes and the RH meter and the thermocouples with the temperature indicator mounted in the fluidized bed dryer displayed the respective values during the process of

drying.. The ASTM D4442-07 standard was followed to find the final moisture content of the dried samples using hot air oven method.

The inlet temperature increases, the molecules movement increases faster and therefore more collsion of molecules takes place frequently. The molecules also carry more kinetic energy. Thus, the collisions proportion can overcome the activation energy for the reaction increases with temperature.

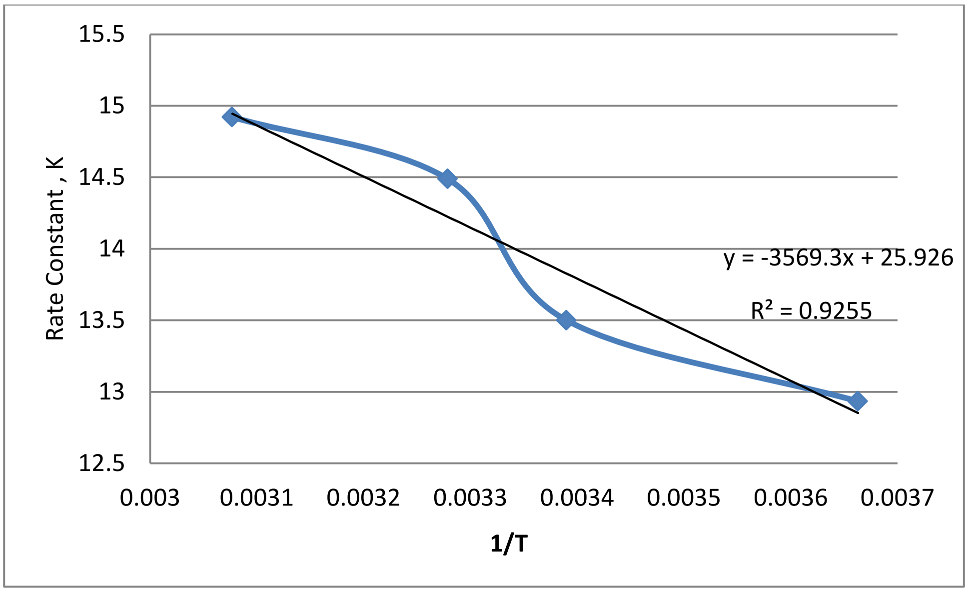

Fig 16 - Activation Energy for the bagasse drying process

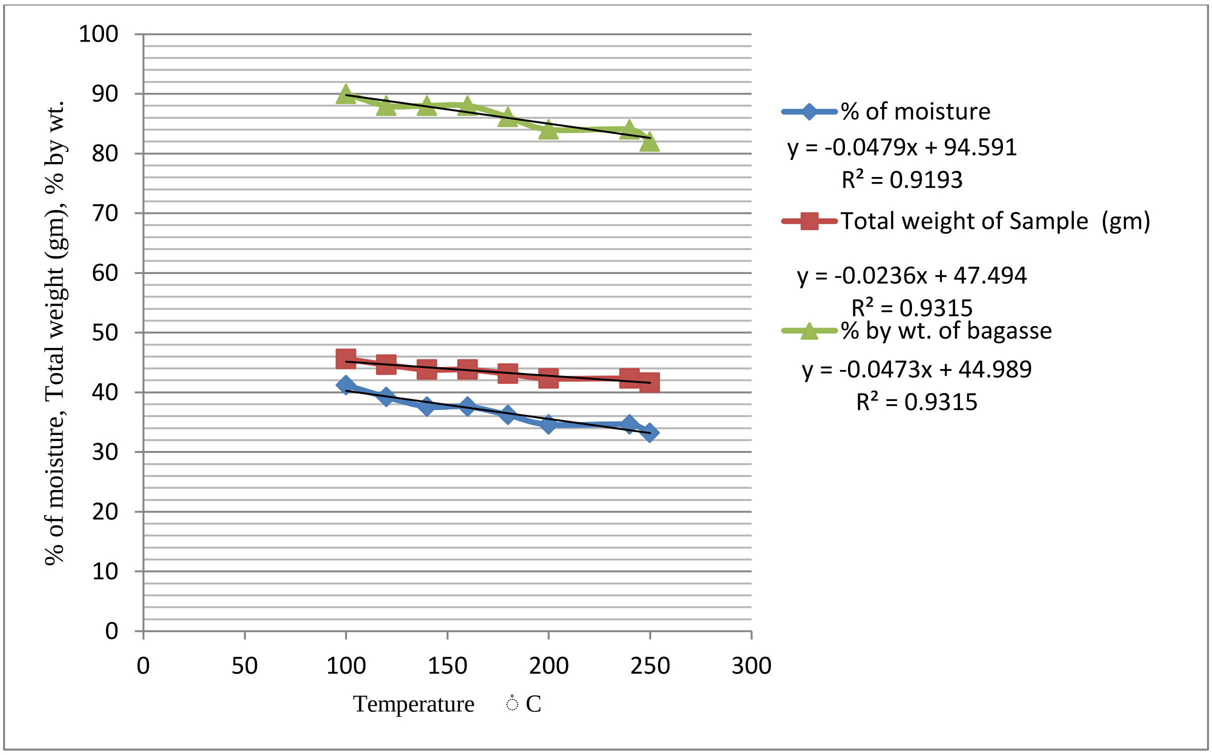

Fig 17 - Properties of bagasse sample for the input temperature ranges

CONCLUSION

This is a new innovative fluidized bed dryer it contains two hot air flow distributors and one additional distributor. The circular and rectangular distributors with the orifices makes hot air flow into the dryer ensures uniform quantity and maintains uniform temperature. The additional hot air line in the spouted part of the dryer makes to either increase or decrease the moisture content based on the bagasse calorific value tested using calorimeter. The mechanical stirrer mechanism and the perforated plate in between the distributors the reaction of the heat mass transfer in the dryer. It is possible to allow the maximum temperature and the discharge of air with the close monitoring and controlling devices. If the plant would be made into automation the productivity will increase more and minimize the manpower requirement, and it needs only less maintenance, less power consumption. The rate of power generation also improved similarly, the consumption of the bagasse fuel needed to burn into the boiler to produce the required quantity of steam. Future scope of the work is to connect data acquisition system with the dryer. When it would be connected, the flow process could have been controlled easily and plotting graph becomes to easy with the help of softwere installed. The another future scope is the replacement of manually operated mechanically agitated strrier into motorized stirrer will improve the drying process faste in manner.

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