FLUIDIZED BED DRYER WITH THE NOVAL ATTACHMENTS FOR THE STUDY OF ITS PERFORMANCES

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ABSTRACT

Sugar cane bagasse is one of the biomass has high initial moisture content, the drying could be done using different type of dryers. To minimize the space occupied for the equipments used for the drying process a little known behavior of fluidized bed dryer was suggested. The influence of the high initial moisture content of the wet bagasse reduces the performance of fluidization. A solid circulation of bagasse particles has achieved with two dissimilar distributors and number of orifices associated with a mechanical stirrer to spread out and improve the fluidization. The removal of high moisture content by the performance of fluidization from the wet bagasse was to be done by the three input temperatures. At the increased input temperature, the drying rate achieved as high due to the faster heat and mass transfer rate. The dried bagasse particles have directly used as fuel and it does not require the process of separation of inert particles used as in binary mixture fluidization bed.

Key Words: Bagasse, moisture content, fluidization bed drying, hot air circulation, and stirrer.

LITERATURE SURVEY

The cost of fossil fuel in the beginning of nineteenth century between 1910 and 1970 was very low. Due to the low cost of fossil fuel the biomass were not utilized as the fuel, and it was considered only as waste material. Therefore the researchers were not shown much interest to do research work on biomass drying and were only very less number of papers published by the researchers. Professor Kerr in 1910 had studied first about the drying of the sugarcane bagasse using the exit flue gas. He designed and constructed a dryer made up of steel material with the dimensions of 1.2m x 1.8m cross-section and 6.0m high. The countercurrent effect with the deflectors in the dryer had promoted a better gas – solid contact. Kinoshita (1991) installed four dryers using boiler flue gases to dry bagasse and these dryers were installed in Hawdi. Three of the four installations were rotary type dryers and the other one was a flash type dryer. 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 production of steam had been increased by 16% by drying and reducing the moisture content of bagasse from 52% to 40%. Massarani and Valenca (1981 and 1983) have constructed a pilot moving bed dryer of dimensions mentioned as 0.40 x 0.50 x 2 m for studying purpose of the dryer. Nebra and Macedo (1989) developed flash type dryer could work with 25 ton bagasse/hr. Salermo and Santana (1986) worked with a dryer composed of a fluidized bed, a pneumatic duct and a cyclone. It is important that they used th e cyclone separator to separate the phases different phases. This system worked with 10 ton/hr of 47% moisture content (w.b) bagasse. Final moisture content was 35% (w.b) and inlet gas temperature 250 ̊C. The researchers from school of Mechanical Engineering and school of Chemical Engineering from state University of Campinas (UNICAMP) have been working with drying of agricultural residues like sugarcane bagasse in cyclone (Silva and Nebra, 1997, Correa et al., 2004). He observed that major part of moisture reduction occurred in the acceleration zone. A review of drying in cyclone that includes the works of this group is presented at Nebra et al. (2000). Alarcon and justiz (1993) also worked with pneumatic dryer, the dryer reduced the moisture content from 50% to 30% (w.b) and the particles were separated as pith (smaller size) and bigger sized particles. The biggest particle size of bagasse were used as raw material for pulb and paper industries, the pith were used as biomass fuel to the power plant boiler to produce steam and power generation.

1. Materials and Methodology

1.1 Bagasse collection from jaggery plant

Sugar cane bagasse was collected from a Jaggery unit. The cleaned sugarcane cut into small pieces and were fed into the crusher. The juice has collected from the sugarcane by crushing then 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 moisture content has upto 55%. Burning of the wet bagasse in the boiler produces only less heat energy. This is due to some part of heat energy would be spent for the evaporation of moisture, and the remaining part of the heat energy only utilized for steam production. The percentage of moisture reduction in the bagasse could increase the amount of heat of energy. A fluidized bed dryer used to conduct experiments on drying of bagasse, and the performance of the dryer was evaluated by percentage of moisture reduction. The mass of bagasse and the change of flow process parameters are mainly considered in the experiments.

1.2 Experimental setup

The set up of fluidized bed dryer as shown in **Fig. 1.** The overall size of the dryer is 2m x 1m x 1m and it is made up of 2mm thick steel plate. There is a hopper placed at the top of the dryer to feed the bagasse into the dryer. Inside the dryer has two hot air distributors with nozzles which would supply hot air uniformly to remove moisture content from the wet bagasse. There is a perforated slotted flat plate placed in between the two distributors. It allows free flow of moist air to come up to the top of the dryer. A rotating mechanical stirrer with chain and sprocket drive mechanism and bevel gear set up helps the spreading of bagasse over the perforated plate. There is a additional hot air supply pipe provided at the bottom spouted part of the dryer. This could supply hot air directly into the dryer from the hot air chamber.

The position of nozzles in the distributors is in inverted position with an included angle of 60 ̊. It provides the hot air flow through the nozzles into the dryer towards in downward direction. The design of the dryer consisted that the exit moist air is made to come out near the top of the dryer. Thermocouples four numbers T1, T2, T3 and T4 and the relative humidity sensors also called as hygrometer four numbers RH1, RH2, RH3 and RH4 placed into the dryer. The arrangement of the thermocouples and the RH sensors are as shown **in Fig.2**.

The air-heating chamber has provided with three thermocouples T5, T6, and T7 and an electric heater. The air-heating chamber consists of a cylinder with baffle plates arrangements inside. It would create a turbulent effect on the air inside the chamber. The air chamber is fabricated by steel material and is insulated perfectly with an insulating material to prevent heat loss to the atmosphere. A digital temperature controller programmed with an automatic ON-OFF facility is used to set and alter the air temperature in the heating chamber. A U- tube manometer attached at the place of hot air inlet to the distributor. It is used to calculate the air pressure in terms of height differences h1 and h2 measured on the scale. One more U- tube manometer has installed at the hot air exit from the fluidized bed dryer to measure the outlet air pressure.

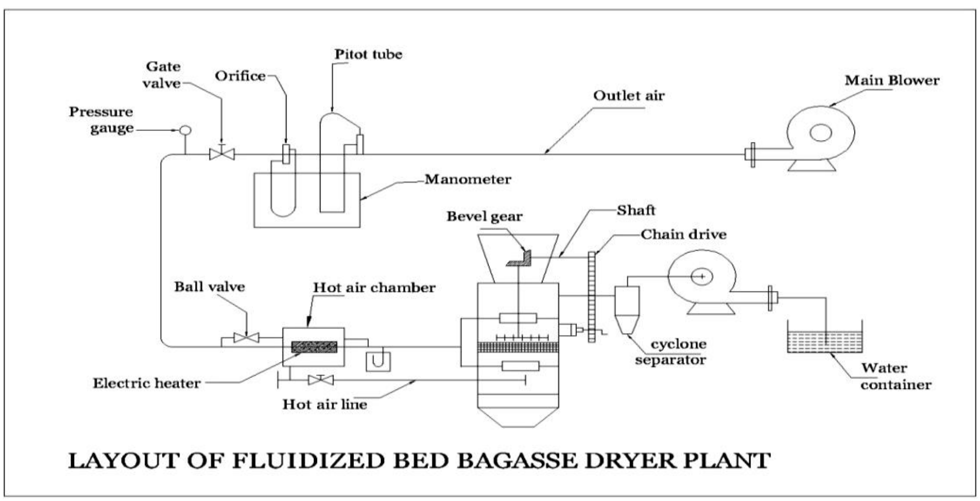

FIG.1 LAYOUT OF FLUIFIZED BED BAGASSE DRYER

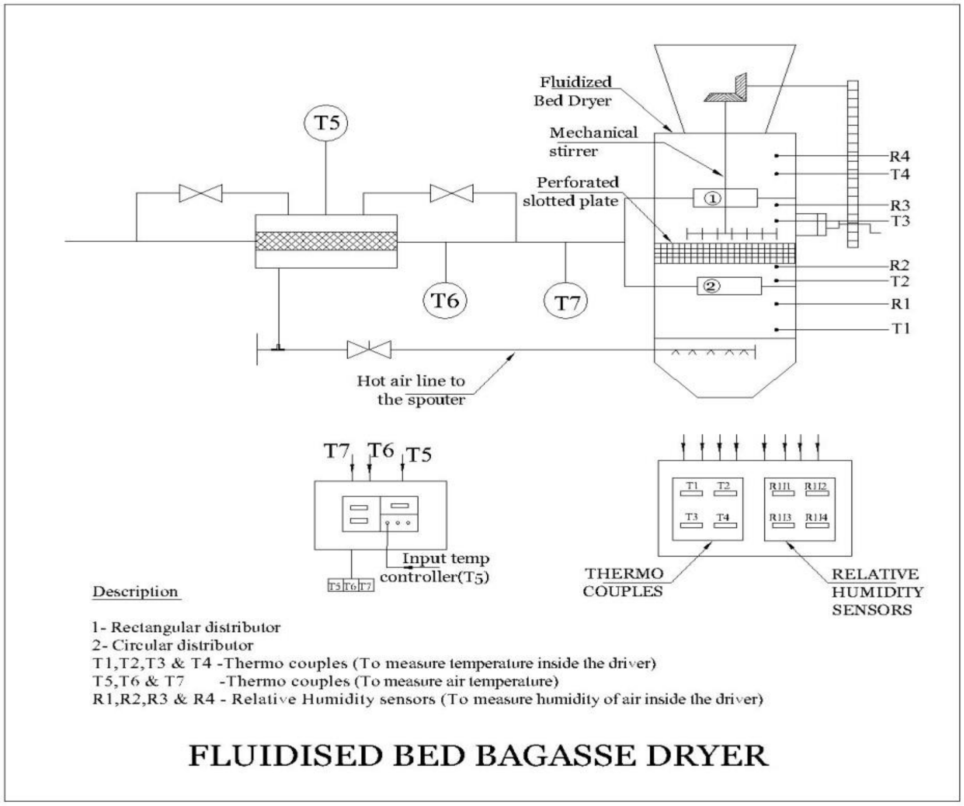

FIG.2 CONSTRUCTION OF FLUIFIZED BED BAGASSE DRYER

2.0 WORKING OF THE FLUIDIZED BED DRYER PLANT

2.1. Segregation of Sugarcane Baggase

Sugarcane bagasse obtained in sugar industry after leaching out of the juice content is available with different sizes. The big size bagasse particles were segregated from the smaller size particles, and these smaller particles called as pith were used as the fuel in the boiler. The big sized particles are separated by sieving using steel-wired mesh. The approximate size of the particles and its mass percentage after the sieving process are plotted in **FIG.3.** The chopped baggase has feed into the fluidized bed dryer for drying. Research work has been carried out for drying batch-sized bagasse such as 6kg, 10kg and 14kg.

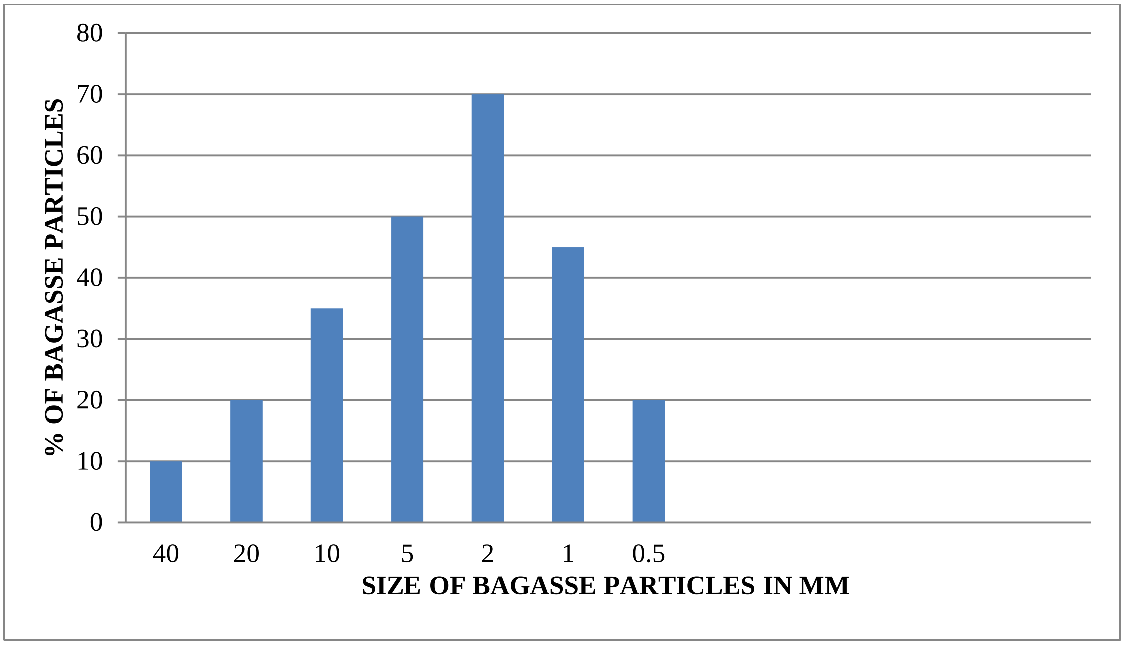

Fig.3. Size Of Bagasse Particles After Sieving In Percentage

2 .2. Hot air production Process

A constant discharge centrifugal blower provided with a gate valve at the delivery side to supply air to the heating chamber. The quantity of airflow to the heating chamber has controlled by manually opening and closing of the gate valve. A certain quantity of fresh air is tapped after the gate valve and it was directed to the heating chamber directly. A manually controlled ball valve attached with a reduced size of a pipe, which carried the tapped air to the heating chamber. The electric heater used to heat the air in the region of heating chamber.

2.3. Moisture removal in the FBD

Initially the hot air is allowed into the dryer through the distributors and nozzle s and it was circulated for some time. This would help the dryer to get worm up. The temperature of the dryer measured after some period of heating known as preheating of the dryer. A temperature indicator used to fix and display the measured the inlet air temperature. The preheating process of the dryer would continue until it reaches the steady state temperature. A known weight of bagasse with moisture has put into the dryer over the perforated plate. The mechanical stirrer made to rotate manually by the driving mechanism. Due to the stirring effect, the bagasse causes to spread over the entire surface inside the dryer. The hot air entering into the dryer through the distributors and nozzles remove the moisture content over the surface of the bagasse. The time for moisture removal is to takes place for 15 minutes for conducting an experiment. During the period, the thermocouple installed into the dryer measure the temperature inside of the dryer. In addition, the RH sensor measures the humidity of the air evaporated from the surface over the bagasse. The temperature indicator and the RH meter would help to display the respective values. The same method has to be considered for further experiments by considering different mass and the different percentage of moisture content of the bagasse. The air velocity and the air inlet temperature are the parameters mainly considered for conducting experiments.

(a) (b) (c)

Fig -4 PHOTOGRAPHIC VIEW OF FBD

a. Fluidized bed dryer associated with accessories, and attachments.
b. Mechanical stirrer, Rectangular Distributor, nozzles and Perforated slotted Tray. (Interior of the dryer)
c. Rotating stirrer with bevel gear driving mechanism, distributors (rectangular and circular), and nozzles.

3.0 Methodology

3.1 Determination of loss of moisture (M_{loss}), Rate of drying (Y_d) and the specific humidity (S_i)

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

$$Yd = \frac{dw}{dt} = \frac{\sum_{i=m}^{n} si}{t_n - t_m} = \frac{m_a(S_m + s_{m+1} + \cdots + S_i)}{t_n - t_m} [\text{g} - \text{Water/min}] \quad (2)$$

$$Si = 0.622 \left[(Ps / (P - Ps)) \right] \quad (\text{gm} - \text{water / kg-air}) \quad (3)$$

3.2 The saturation pressure of water vapor from the Wagner–Pruss equation

$$ln\left(\frac{p_s}{22.064e6}\right) = \frac{647.096}{T_k}(-7.85951783v + 1.84408259v^{1.5} - 11.7866497v^3 + 22.6807411v^{3.5} - 15.9618719v^4 + 1.80122502v^{7.5}) \quad (4)$$

Where, $$v = \frac{T}{647.096} \quad (5)$$

Where, From the eqn. (1), **M loss** is the determination of loss of moisture, and **Mn** and **Mm** are the mass of wet bagasse before and after drying for the given period of time. **ma** is the mass of the air. **Si** is the specific humidity of wet air.

Rate of drying of the bagasse **Yd**, is determined using the Eqn. (2)
Si is calculated from the eqn. No. (3). Where Ps is the saturation pressure and P is total pressure.

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 to the given time and the unit area of the dryer [15].
It can be calculated as follows:

$$m_{evp} = \frac{m_{wi} - m_{wf}}{td \, . \, A} \qquad (6)$$

m_{evp} – mass of evaporation of water , m_{wi} and m_{wf} – Initial and final mass of water vapour.

3.3 Analysis of energy utilization in the dryer

Air flow velocity $v = \frac{\sqrt{2x\, gx\, (h1-h2)}}{}$ m/s (7)

Mass flow rate of hot air $\dot{m} = \rho x A x v$ kg/s (8)

Volume of air flow into the dryer $\dot{V} = Axv$ m^3/s (9)

Heat energy utilized for the evaporation of moisture $Q_u = \dot{m}\ X\, C_p X (h_{di} - h_{do})$ (10)

Where, Q_u is the heat energy utilized in Kj/kg , $\dot{m}$ is the mass flow rate of hot dry air in kg/s

and h_{di}, h_{do} are the enthalpy of hot air inlet and the moist air outlet and C_p is specific heat capacity of hot air.

Enthalpy of moist air $h_{do} = C_p\ x\ (T - T_\infty) + h_{fg}$ in Kj/kg (11)

where, C_p is specific heat capacity of hot air; T is the temperature of the moist air ; T_∞ is ambient temperature and h_{fg} is the enthalpy of vaporization of water in Kj/kg .

Specific heat capacities of Inlet and outlet air calculated using Equation

$C_p = 1.004 + 1.88$ x w Kj/kg (12)

where, **w** is air moisture ratio and C_p is specific heat capacity of air, specific heat capacity of water 1.004 Kj/kgk.

$$\dot{m}_v = \frac{w_t - w_{(t+\Delta t)}}{\Delta t} \quad (13)$$

where, $\dot{m}_v$ is drying rate; Δt is drying time interval; w(t) is initial weight of the wet bagasse and w(t+Δt) is weight of wet bagasse after drying.

4.0. Result and discussion

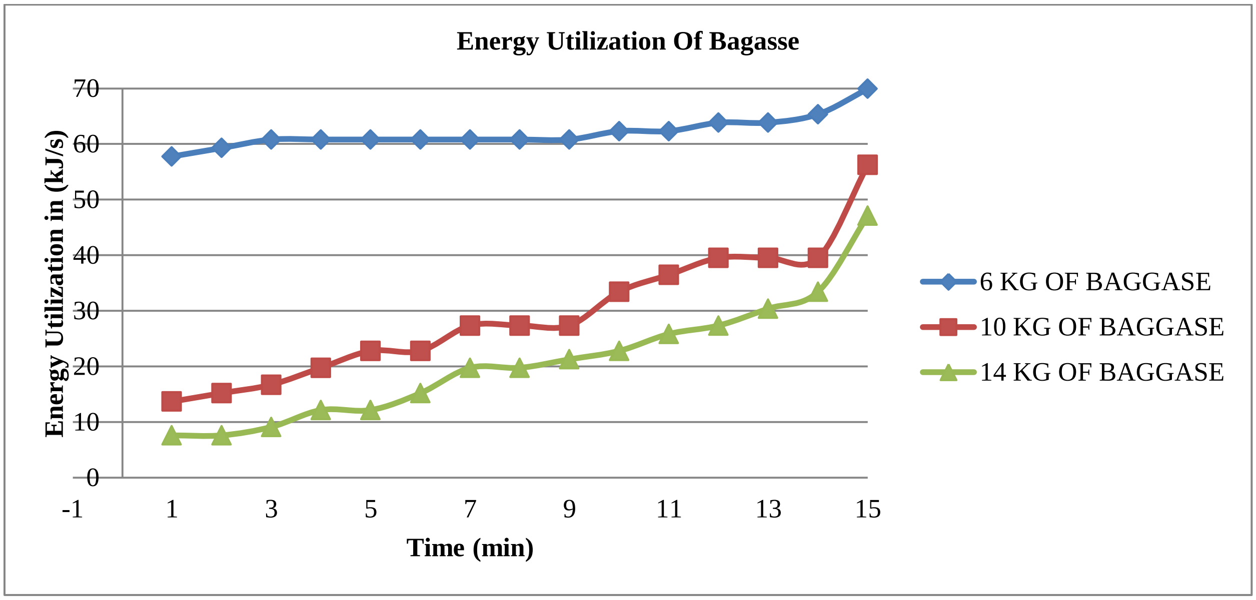

Fig 5. Heat Energy Utilized At 150^{0}c Of Air Inlet Temperature

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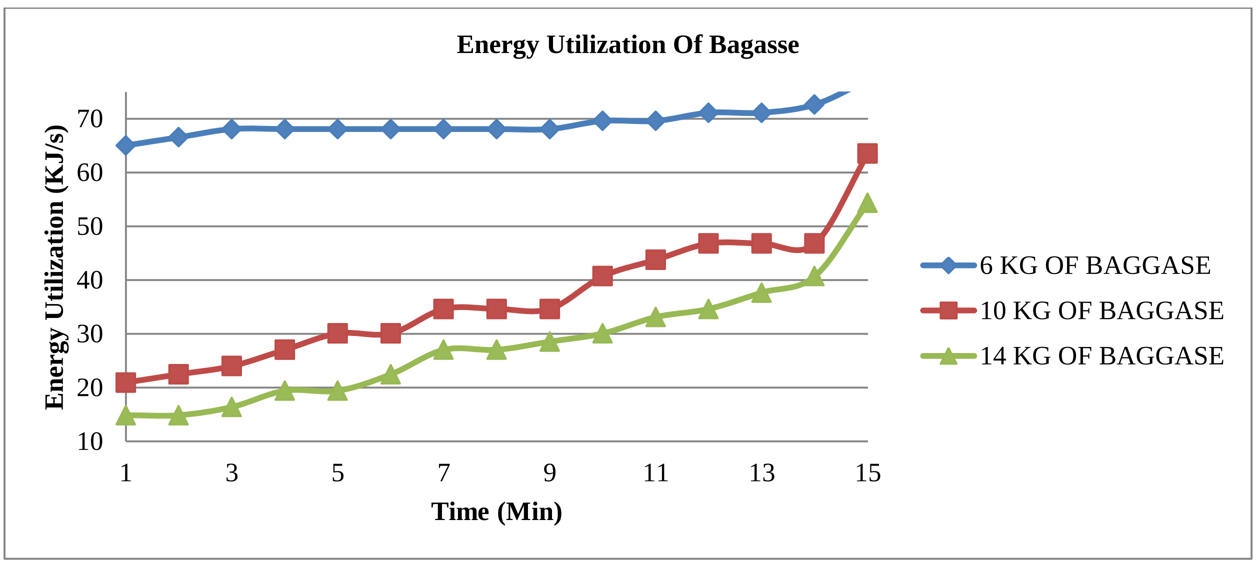

Fig 6. Heat Energy Utilized At 175^{0}c Of Air Inlet Temperature

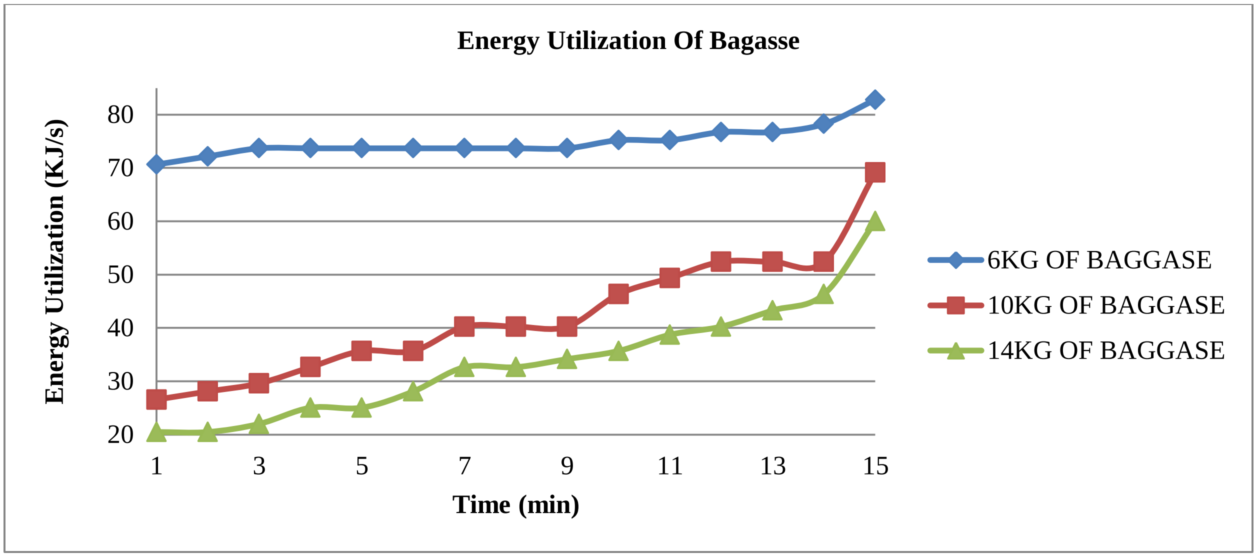

Fig.7 Heat Energy Utilized At 200^{0}c Of Air Inlet Temperature

In order to remove the moisture content from the wet bagasse the experiments were conducted using the fluidized bed dryer. The weight of bagasse considered for the experiments were 6kg, 10kg, and 14kg respectively by keeping the hot air inlet temperature at 150 ^{0}C. **FIG -5** shown the graph plotted with 6 kg , 10kg and 14kg mass of bagasse. The surface moisture evaporated at 10kg, 14 kg were less initially by utilizing the low heat energy, and it will increases gradually during the drying period

The same experiments were repeated at 175 ^{0}C to remove the moisture content from wet bagasse with 50 -55% using the fluidized bed dryer at 6 kg , 10kg and 14kg mass of bagasse. There would be no significant differences found by the drying processes at 150 ^{0}C and 175 ^{0}C. This has been shown from the graph plotted **Fig. 6**.

At 200 ^{0}C the experiments were also conducted to remove the of moisture content from the wet bagasse with 50 -55% using the fluidized bed dryer at 6 kg , 10kg and 14kg mass of bagasse . This has been shown from the graph plotted **Fig. 7**. From the experiments conducted it could be known that the higher moisture content of the bagasse with the significant mass utilizes more heat energy to remove the moisture at faster rate for the given period.

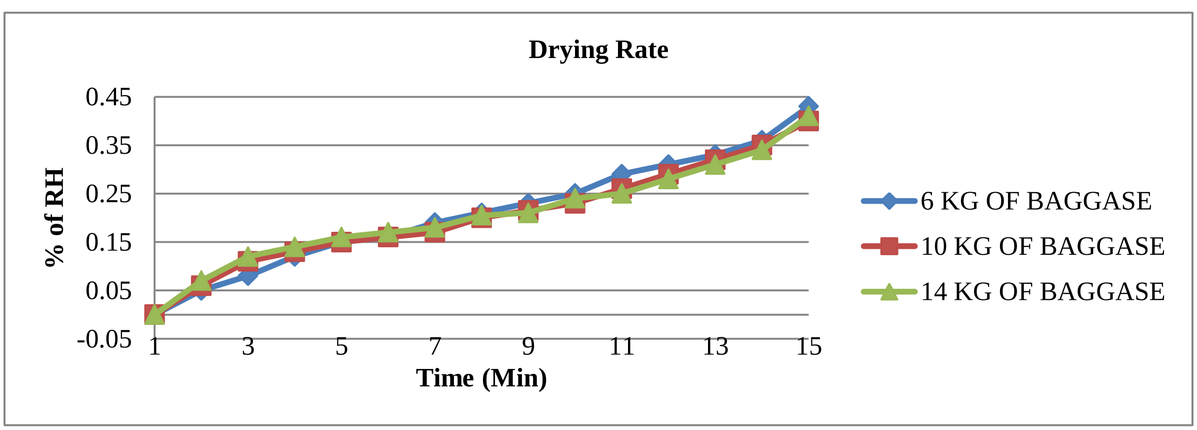

Fig. 8. Drying Rate Of Bagasse At 150^{0}c

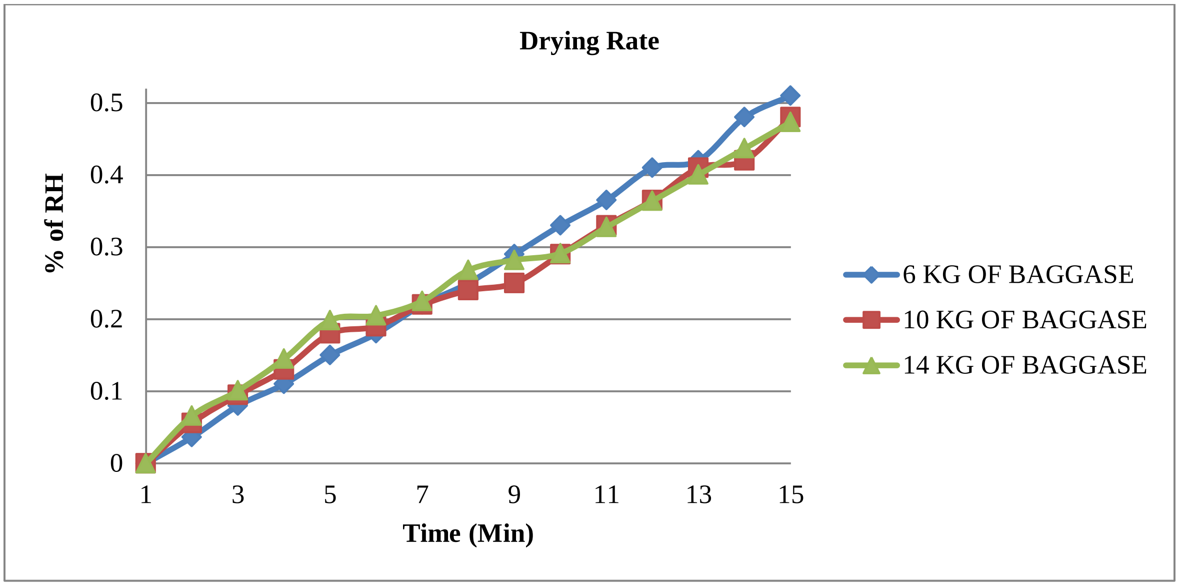

Fig. 9. Drying Rate Of Bagasse At 175^{0}c

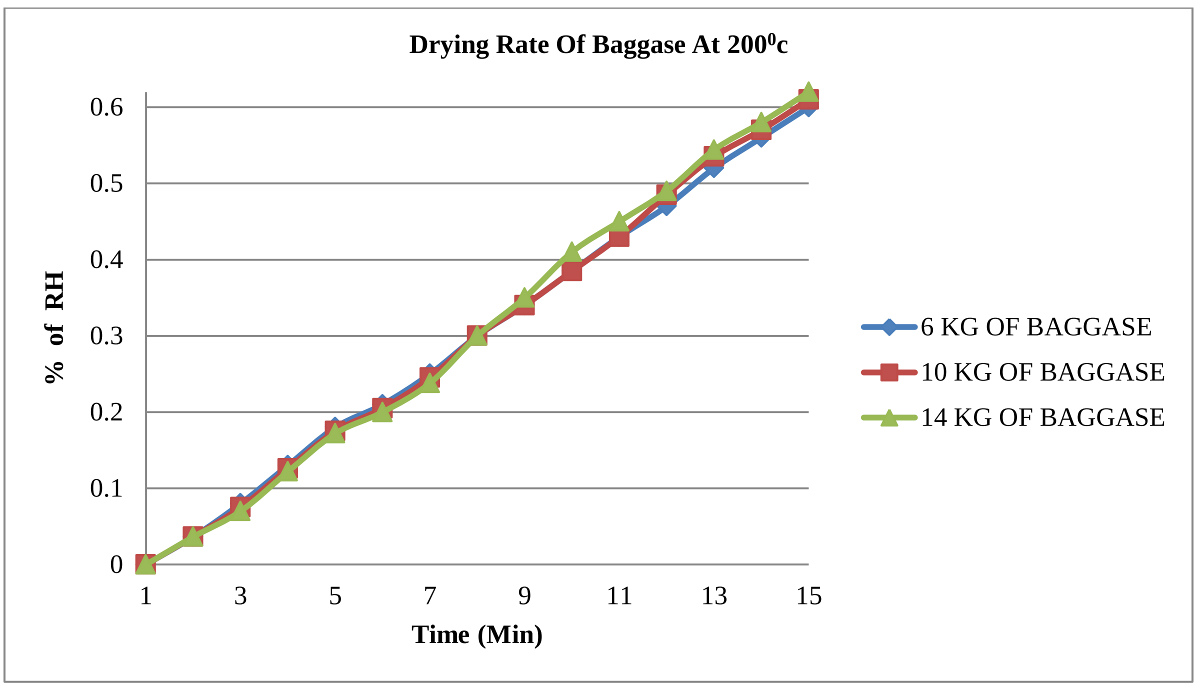

Fig. 10. Drying Rate Of Bagasse At 200^{0}c

4.1. Fluidization behavior of bagasse in the fluidized bed dryer

The fluidization behavior of bagasse at different temperatures and airflow velocity were investigated by considering three aspects with respect to time. The fluidization behavior of the bagasse was mainly affected by the moisture content [7, 9]. The changes in the saturation pressure in the fluidized bed dryer occurred due to the rate of change of the evaporation of the moisture [23]. The drying rate was initially high due to high surface moisture content, and slowly decreased the evaporation rate. The mechanical stirrer influenced the drying rate by spreading the wet bagasse over the surface area of the perforated plate.

The inlet-preheated air temperatures as mentioned above (**150^{0}C, 175^{0}C and** 200^0**C)** were mainly considered. In addition, the percentage of relative humidity and the height of the bagasse over the plate also the important factors for the evaporation of moisture. The variation in the percentage of relative humidity is the indication of the change of vapor pressure across the bed. The percentage of moisture decreased below 35 - 40% the cohesive forces between the particles would becomes too negligible. The effect of fluidization behavior of the bagasse could be easier due to less attractive forces. The complete dried bagasse when it used in the boiler started to fly without burning due to induced drafting effect. It reduces the fuel economy in the boiler as well as causes particulate pollution effect in the outside atmosphere. It would be must to maintain certain percentage of moisture to avoid complete drying and to prevent the above effects. The complete drying causes the moisture to come over the surface by the diffusion process.

The height of the bagasse kept in the dryer also considered for the performance of the dryer for batch flow type. The height to depth ratio of the bagasse particles determines the rate of drying for the given period. The H/D is less than 1 then the drying medium causes to increase the drying rate.

The Relative humidity sensors and the RH meter fitted in the dryer indicates the change of percentage of relative humidity values . The percentage of RH values for the weight of the bagasse at 6kg, 10kg and 14kg are plotted in the graph as shown in Fig.8, Fig.9 and Fig.10**.**

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

The gate valve mounted at the discharge pipe controlled the mass flow rate of air entered into the heating chamber. An electric heater heats the air available to flow through the discharge pipe, as well as in the cylindrical chamber. The heated air with high velocity passed into the dryer through the nozzles will increases the rate of drying. The hand driven mechanical agitator spreads the bagasse over the entire surface area of the perforated slotted plate. The ASTM D4442-07 standard of method D has followed [16] to find the final moisture content of the dried samples using hot air oven method.. The kinetic energy increased depending upon of the molecular movements, the temperature of the air inlet, mass flow rate and the size of the nozzle.

The drying kinetics in the fluidized bed dryer has shown for the different airflow velocities [17]. The airflow velocity at 2 m/s has shown the increased drying rate. The blower discharge valve1 at 1/4th, 1/2th, 3/4th opening did not produce high velocity. The airflow velocity at 2 m/s would be sufficient to retain the stable fluidization, and the increased heat transfer rate in the fluidized bed. The temperature of the preheated wall surface of the dryer maintained until it would equivalent to the temperature of the hot air inlet.

The increased temperature inside the dryer caused to increases the molecular movements in faster rate, causes collision between the particles. The kinetic energy carries more molecules and the proportion of the collision of more molecules causes more activation energy. The activation energy reaction will increases due to the temperature of the dryer increases [18].

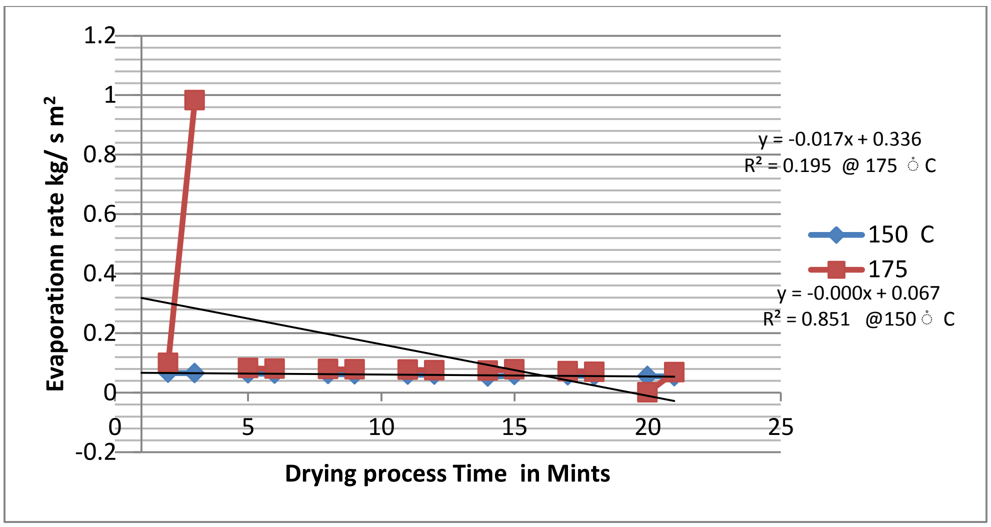

Fig 14- Evaporation Rate Level

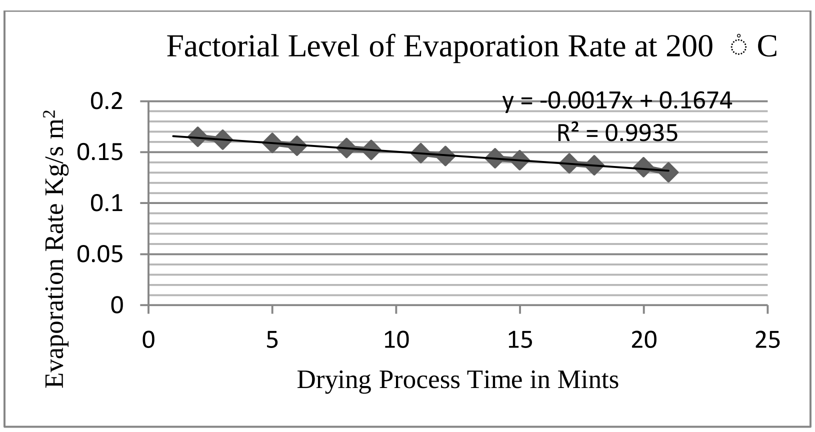

Fig 15- Evaporation Rate Level

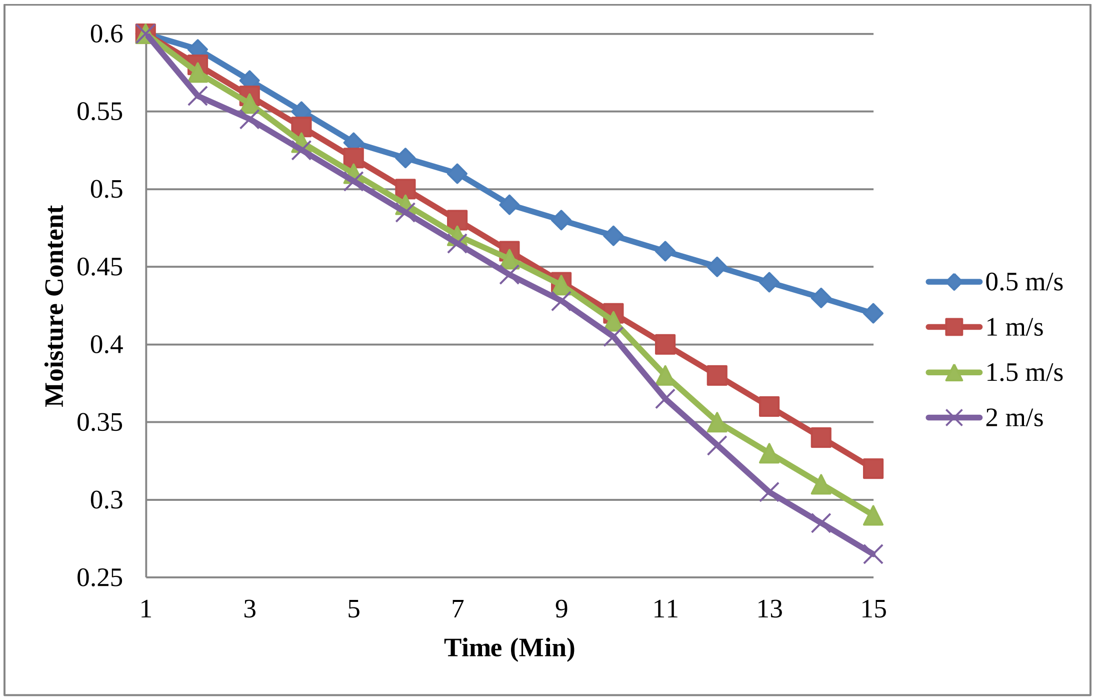

Fig. 16. Drying Kinetics At Different Velocities

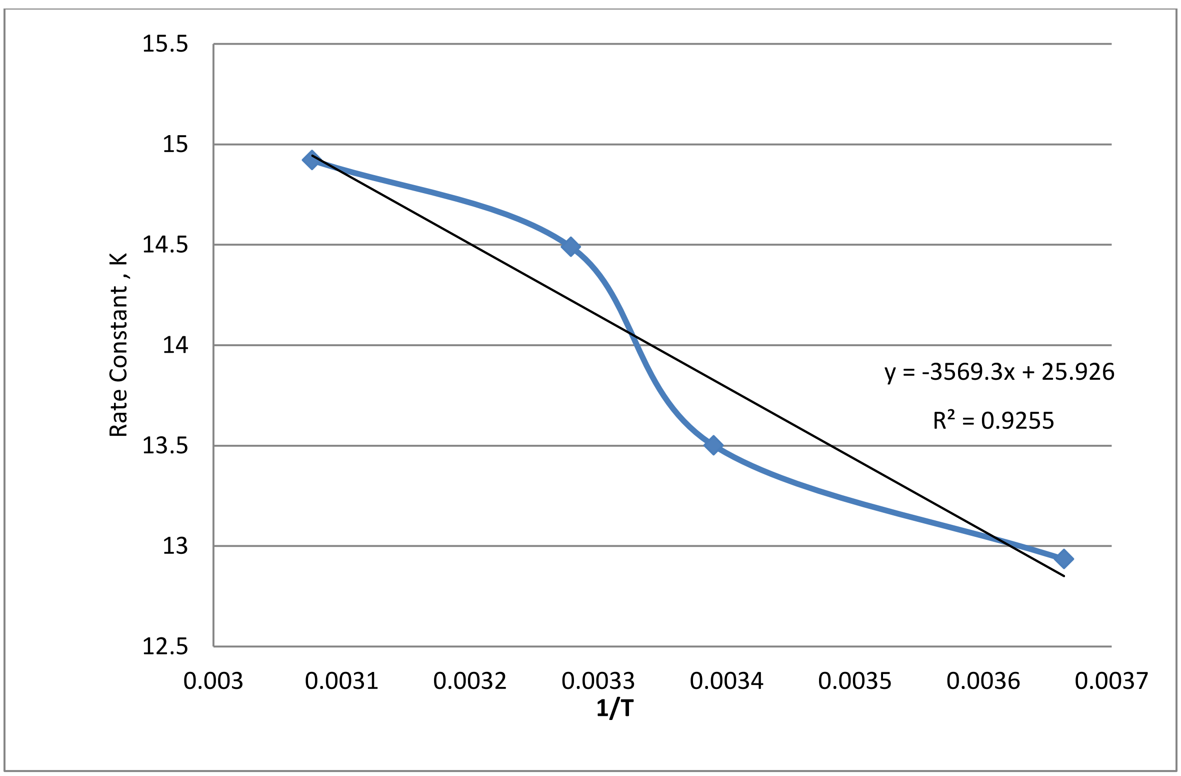

Fig 17 - Activation Energy for the bagasse drying process

CONCLUSION

The nozzles and distributors placed in the fluidized bed dryer were merely at the mid part of the dryer has the prime importance to reduce the moisture content effectively. The additional hot air line introduced in the spouted bottom of the dryer from the hot air chamber makes to increase the performance of the dryer. The controlling and monitoring devices help to control and monitored the temperature, mass flow rate and the velocity of air. Therefore, it would be possible to set the hot air temperature as similar as to the flue gas temperature to achieve the required drying rate. The drying is achieved as in terms of the percentage of moisture content reduction with the faster and accurate manner. The Future scope of the work in the dryer has had the opportunity to connect with a data acquisition system with the drying parameter probes. The rate of drying will also be faster by the replacement of manually operated mechanically agitated stirrer into a motorized one will improve the drying process. Also by the introduction of one or more distributors and the number of nozzles by constructing, a new modified dryer will increases the drying capacity. Due to these changes, the range of power production may cause to increase to the actual requirement for the smooth running of the plant.

Abbreviations:

Wb	Wet basis
Mn and Mm	Mass of wet bagasse before and after drying
Ma	Mass of air in Kg
Si	Specific humidity
Yd	Rate of drying
Ps	Saturation pressure in KN/m^2
P	Total pressure in KN/m^2
Mevp	Mass of evaporation of water in kg
M_{wi} and M_{wf}	Initial and final mass of water vapor
t_d	Drying time in min
A	Area of cross section m^2
v	Air flow velocity in m/s
Q_u	Heat energy utilized in KJ/Kg
Hdi	Enthalpy of hot air inlet in KJ/Kg
Hdo	Enthalpy of moist air outlet in KJ/Kg

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