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Bagasse Dryer

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Abstract
Bagasse is a cellulose fiber that is obtained as a residue from sugar cane after the juice is extracted in sugar mill. In earlier times, it was considered as a waste in sugar industry and was usually burnt for disposing. Later, due to the fuel crisis in 1970 and consequent increase in fuel prices, the concept of bagasse being regarded as a solid waste was changed into a useful biomass fuel for combustion in boilers. Also, there is an increasing demand for bagasse as raw material for paper, furniture and other industries. A typical 2500 TCD capacity sugar mill produces 750 tons of bagasse per day (30%). The moisture content (MC) of bagasse obtained from exit of sugar mill varies from 45 — 55 %. The bagasse which is used as fuel for boilers is normally combusted without drying due to the need for installing separate auxiliary equipment. The GCV of bagasse ranges from around 9600 kJ/kg for 50 % MC to 14500 kJ/kg for 25 % MC. Due to the presence of inherent & surface moisture, it is obvious that the calorific value of bagasse gets lowered and leads to high specific fuel consumption. As a rule of thumb, for every 20° C reduction in back end temperature there is 1% increase in boiler efficiency and for 10% reduction in excess air 0.4% increase in boiler efficiency were observed. Similarly, for every 1% reduction in bagasse MC, 0.8 % increase in boiler efficiency can be achieved. This necessitates the need for drying bagasse before being fed into the boiler. Despite many efforts put in by researchers for drying bagasse, the drying solutions were not successful due to its complex drying characteristics. On analyzing the different drier models, the major findings were that the flue gas obtained from boiler cannot be used for bagasse drying (by direct contact method), flash drier though technically possible is not energy efficient due to high energy consumption, rotary and fluid bed driers possess the disadvantage of inability to handle bagasse due to its abysmally low particle density. As a solution for drying bagasse, without negotiating the performance and energy involved, a percolating type batch drier has been designed. The objective of the project is to design, fabricate and analyze the drier performance experimentally and obtain the technical feasibility of the drying system for implementation in sugar mills. It has been observed that the moisture content of bagasse has been reduced by 15% in 2 hours' time period with the new developed drier.

Keywords: Gross Calorific Value, Dry Bulb Temperature Moisture Content, Specific Moisture Evaporation Rate

Introduction
The Indian sugar industry is the second largest agro-processing industry in the country after cotton textiles. With an estimated production of 18.6 MMT in sugar year or SY2006 (sugar year is from October to September). India is the second largest sugar producer in the world (after Brazil), accounting for around 10-12% of world's sugar production. With 566 operating sugar mills in different parts of the country, Indian sugar industry has been a focal point for socio-economic development in the rural areas.
The Government of India initially permitted small-sized new units of 1250 ton crushing per day (TCD) capacity only and later on increased the minimum economic size of plant to 2500 TCD and has recently increased this to 5000 TCD. Such policies of the government led to the sugar industry growing horizontally with an all-India per unit average capacity of 2690 TCD.
Bagasse is the fibrous waste that remains after recovery of sugar juice via crushing and extraction. The bagasse percentage in cane can vary from 23% to 37%. The advent of cogeneration technology and the recent fuel crisis has led to the.perception of bagasse usage more as a valuable fuel than a disposable waste. The value of bagasse as a fuel depends largely on its gross calorific value (GCV), which in turn is affected by its composition, especially with respect to water content and to the calorific value of the sugarcane crop, which depends mainly on its sucrose content.
The GCV of bagasse ranges from around 9600 kJ/kg for 50 % moisture content (MC) to 14500 kJ/kg for 25 % MC. The bagasse is burnt in boilers that are normally designed to use both bagasse and/or coal.
Drying is a complex operation involving transient transfer of heat and mass along with several rate processes, such as physical or chemical transformations, which, in turn, may cause changes in product quality as well as the mechanisms of heat and mass transfer, thus making it a fascinating and challenging area for research and development.
The objective of this project is to design, fabricate and evaluate the performance of a prototype bagasse drier. The prototype has been installed at Cheyyar Cooperative Sugar Mills Ltd., Tamil Nadu, India.

To Be Considered For Drier Selection
The important factors that are to be considered prior to selection of drier are:

Properties of the material being handled
a. Physical characteristics when wet
b. Physical characteristics when dry

c. Corrosiveness
d. Toxicity
e. Flammability
f. Particle size
g. Abrasiveness

i. Drying characteristics of the material
a. Type of moisture (bound, unbound, or both)
b. Initial moisture content
c. Final moisture content (maximum)
d. Permissible drying temperature
e. Probable drying time for different driers

ii. Flow of material to and from the drier
a. Quantity to be handled per hour
b. Continuous or batch operation
c. Process prior to drying
d. Process subsequent to drying

iii. Product qualities
a. Shrinkage
b. Contamination
c. Uniformity of final moisture content
d. Decomposition of product
e. Over drying
f State of subdivision
g. Product temperature
h. Bulk density

v. Recovery problems
a. Dust recovery
b. Solvent recovery

vi. Facilities available at site of proposed installation
a. Space
b. Temperature, humidity, and cleanliness of air
c. Available fuels
d. Available electric power
e. Permissible noise, vibration, dust
f. Source of wet feed
g. Exhaust-gas outlets

LITERATURE REVIEW

Sugar cane stalls are chopped, crushed and rolled to extract the sugar juice. The remaining particles of fibrous material (bagasse) vary in shap, size and physical composition, both within and between mills (McGaw and Pilgrim,1991). The physical components are the hard rind, the cellulosic fibers and the pith. These components are not evenly distributed through the cane. When all the sugar has been extracted from the cane, the green bagasse, containing 45 to 55 % water, is discharged from the sugar mill (Lynch and Goss, 1932). The bagasse was usually treated as a refuse. But due to increasing energy crisis, it was regarded as a potential biomass fuel. Since then, the concept of cogeneration became popular in sugar industries.

Traditionally, the wet bagasse is fed to the boiler directly without drying. Most of the sugar industries do not practice bagasse drying due to its technical difficulty and therefore regard as not so economical option. But, the moisture present in bagasse would increase the delay for combustion and reduced energy output. This is also similar to report produced by downing et al.

The efficiency of a bagasse fired boiler varies as a function of the moisture in bagasse, as well as other factors. This can be significant around the relevant moisture levels. Out of 20% condensation loss in the boiler efficiency, 14% of the loss is due to the moisture in bagasse, which is around 50%. Reducing the bagasse moisture would help to increase the calorific value of bagasse, resulting in an increase in the quality of bagasse saved (Narendranath and Prasada Rao, 2002).

Bone dried bagasse presents a gross calorific value of 19268 kJ/kg. because of the moisture, the net calorific value at 50% (wet basis) is only about 7563 kJ/kg. in addition to increasing the net calorific value the reduction of bagasse moisture also reduces the volume of the flue gases (Juan H. Sosa-Arnao, 2004). Furthermore, the specific heat of water vapour is almost twice the other gases, and hence the reduction of water vapour in the combustion gases will result in higher combustion temperature, thus improving boiler efficiency. The reduced volume of water vapour will also result in a reduced load on the induced draft fans (Upadhiaya, 1991).

Boulet (1975) stated that drying could reduce both air pollution and air demand in the furnace. Nebra (1985) concluded that pneumatic drying is a good alternative even when using exit gases from preheating is the substantial increase in “burn ability” of the bagasse. for mills unable to attain bagasse Moisture below 50% and producing a substantial bagasse quantity, bagasse drying is definitely recommendable.

Paiva souza et al. (1998) showed that the drier could save more energy than the preheater. Arrascaeta e friedman (1984) and kinshita (1991) also stated that bagasse drying in an integrated system allows obtaining a lower temperature of the exit gas. According to Edwards (1981), the use of a bagasse Drier could reduce exit gas temperature from s range of 200 to 390 to about 140 deg C and increase efficiency from 54% to 69%.

Although, it is obvious that decreasing the moisture content in bagasse would improve the calorific value, the drying of bagasse is difficult due to involvement of both heat and mass transfer phenomenon. The drier design is specific; hence no design procedure of a particular drier is applicable for other conditions. Hence, some small- scale tests are needed to determine the materials drying characteristics in order to predict the way in which the raw material, here bagasse, would behave in the actual unit (Mujumdar, 1995).

A part from traditional driers, special driers designed for bagasse are also available. One typical example is the patented modification of rotary drier, which contains two concentric drums where the drying takes place in stages.

Furies (1976) first reported the operation of an industrial bagasse drier of rotary drum type using boiler stack gases. Since then, bagasse driers mainly of the rotary drum and flash types have been installed in America, brazil, Philippines, Australia, china, Cuba and India. Arrascaeta and Friedman (1987) compiled data of 14 such driers installed up to 1987 with details of feed capacity, input and output moisture and the temperature of the flue gas used. Reports of bagasse drying with varying degree of success followed (Maranhao, Dixon &Jorgensen, 1988, Wang et al, 1990, Kinoshita, 1991). A drying process was patented in 1981; it involves flue gas drying of bagasse after its separation into coarse and fine particles.

Drier Performance

The performance of a drier can be expressed with the efficiency parameter called specific moisture evaporation rate (SMER). It is defined as the amount of moisture evaporated (in kg) for unit energy consumption (in kWh). Its unit is kg/kWh.
SMER = amount of water evaporated kg energy used kWh

A. Bagasse & bagasse drying

Sugarcane is a large grass with a stalk that grows 2-5 m tall. Only the stalk contains sufficient sucrose to be processed into sugar. All other parts of the sugar cane including leaves, roots, etc. are termed 'trash', which should be eliminated through the harvesting process. Once inside the mill, juice is extracted in the plant milling section by passing the chopped and crushed cane through a series of mills. The cane remaining after milling is called bagasse.

B. Bagasse generation

Bagasse is an important by-product of sugar. It is rich in cellulose fibre. Usually, it is a biomass-type fuel of varying composition, consistency and heating value. These characteristics depend on the climate, type of soil where the cane is grown, cane type, harvesting method, amount of cane washing, and efficiency of the milling plant. The bagasse percentage in cane can vary from 23% to 37%.
It can be used as a major substitute for raw material in the paper and pulp industry, replacing wood and bamboo thus reducing deforestation. Costly imports of pulp and waste paper can be avoided thus conserving the outflow of foreign exchange. Bagasse has also been suggested as a base material for cattle feed after mixing with molasses in varying proportions. The other important product, which can be manufactured from bagasse, is fin-fural, which is a very versatile chemical with good potential for commercial usage.
Presently, almost all the sugar mills utilize this bagasse as an in-house fuel in boilers for steam generation. Numbers of mills are planning to utilize the bagasse efficiently in high pressure boilers for cogenerating electricity for export to the grid/neighboring units.

C. Properties of bagasse

i. Physical properties

1. White & light green.
2. It is odourless.
3. The typical specific weight is 250 kg/m3.
4. Composition: 45% moisture, 50% cellulose (27.9% hemi cellulose, 9.8% lignin & 11.3% cell contents) & 6% others.
5. Energy content: - 19400 kJ/kg dry and ash free.

ii. Chemical properties

The percentage distribution by dry wt. of major elements composing the bagasse is present in the below table.

Components	C	H	O	N	S	ASH
% By Weight (Dry Basis)	49	6.5	42.7	0.2	0.1	1.5

E. Calorific Value

The raw bagasse obtained at the exit of sugar mill contains approximately 50% moisture. The Gross Calorific Value (GCV) of dry ash free bagasse is 19400 kJ/ kg while bagasse with 50% moisture content has GCV of 9600 kJ/kg & Net Calorific Value (NCV) of 7600 kJ/kg.
Gross calorific value of bagasse is calculated from the formula:

GCV = [19605 — 19605 (M) — 19605 (A) — 3114 (B)] kJ/kg

And the LCV of bagasse is given by,

LCV = [(18309 — 2076 (M) — 19706 (A) — 3114 (B)] kJ/kg

Where, M, A and B represent the moisture, ash and brix percentage in bagasse respectively.model which would dry the bagasse effectively considering the basic qualities a drier has to satisfy viz., handling, capacity, drier type (continuous or batch) etc. Three concepts have been identified accordingly,
1. Pneumatic / Flash drying
2. Cyclone as bagasse drier
3. Bubbling

Moist Air

Bubbling Bed Bagasse Drier While the preceding techniques are classified under continuous type of drier, this technique is classified under batch drying. This is a modified form of withering process in tea production, wherein, wet tea leafs are withered (`withering' is different from 'drying' where a calculative amount of moisture is removed from tea leaf without affecting the leaf quality) by passing ambient air. The drying system consists of a trough whose bed is made of a perforated plate. Wet bagasse is loaded above the bed/plate. Air is blown into the bottom of the trough by an FD fan of axial type configuration. The air passes through the bed of wet bagasse particles which absorbs the surface moisture while passing through the bed packed with wet bagasse. Figure 4.3 shows the drying system.

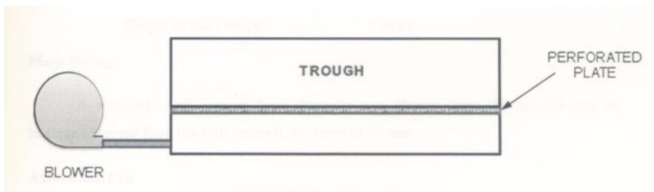

Figure 4.3 Bubbling bed bagasse drier

Selection of Appropriate Concept for Bagasse Drying

To start with the experimental analysis, it is necessary to select any one concept from the 3 viable options that were discussed earlier. Accordingly, the third concept namely 'Bubbling Bed Bagasse Drier' was selected due to following reasons:

i. It utilizes only ambient air for drying, which promotes in identifying the suitability and capacity of drying with ambient air.
ii. In order to determine the drying characteristics of bagasse, samples of various MC has to be experimented. Since the particle density is a critical factor for both flash drier and cyclone drier, these methods cannot handle bagasse particles with wide variation in the design parameter (particle density), which is not a critical factor in bubbling bed bagasse drier.

TECHNICAL SPECIFICATION & FABRICATION OF BAGASSE DRIER

i. Drier Sizing

Sugar Mills generates 750 tons of bagasse in a day during sugar season (30% of crushing capacity). Since, it is an experimental analysis of drier performance; the drier was designed as a prototype to handle 20% (150 kg) of the plant's bagasse output. Accordingly the drier trough was sized as below:

Length of the Trough = 3.05 m
Width of the Trough = 1.22 m
Height of the Trough = 0.91 m

ii. Mesh Sizing

A standard mesh size of 3mm diameter was chosen since the particle size of bagasse obtained from the mill varies from 6 mm to 20 mm.

iii. Axial Flow Fan

The amount of air required to reduce the moisture content of bagasse at an initial moisture content of 50% by 10% requires 10500 CMH approximately. Also, since the bagasse has higher pith content and bulk density, an axial flow fan was chosen for supply of more volume air at low discharge pressure. The detailed configuration of axial flow fan employed with the drier is given below:

Flow capacity = 10695 CMH
Pressure Head = 20 mm WC
Operating Temperature = 40 °C
Motor Rating = 1.5 kW

The dimensional specification with axial flow fan location in the drier is given in figure 4.4, 4.5, 4.6.

All dimensions are in 'in' Figure 4.4 Specification of Bubbling Bed Bagasse Drier Fabrication — Bill of Materials

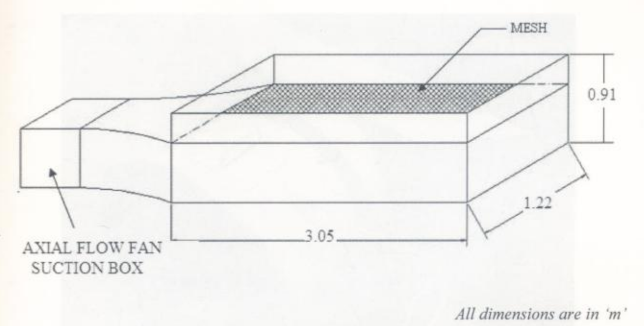

Figure 4.4 Specification of Bubbling Bed Bagasse Drier

Fabrication – Bill of Materials

Fabrication – Photographs

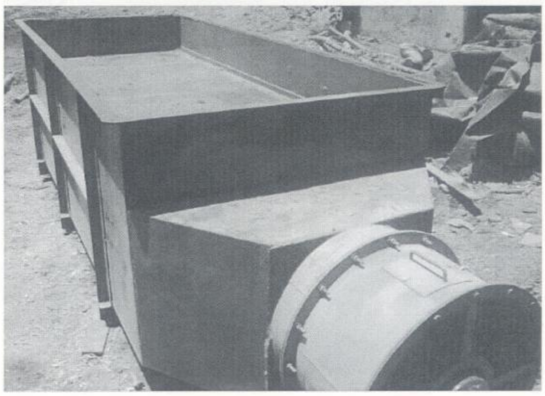

Figure 4.5 Photograph of fabricated drier (View 1)

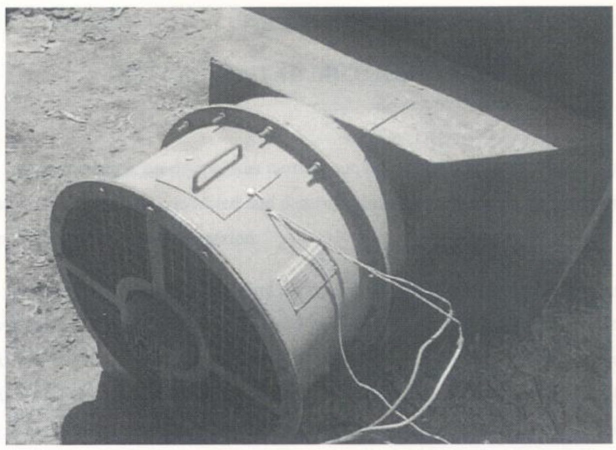

Figure 4.6 Photograph of fabricated drier (View 2)

Experimental Methodology

Experimentation on drying was carried out for 3 days. Since the drier is of batch type, the drying process is conducted and described in sessions. Here, 4 such sessions were performed during the 3 day trial period.

The trials were conducted during off season i.e., the plant was not in operation due to unavailability of cane. The bagasse used in the experimentation had various moisture levels depending on the area at which it was taken from yard.

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Moisture level up to a maximum of 74% was available at the yard. Although the obtained bagasse (with such MC) is not similar to bagasse that is obtained directly from mill (with 50% MC) to be used for experimentation, it is still worth for determining the drying characteristics. The step by step procedure followed during the course of experimentation is given below:

1. A calculated quantity (by weight) of bagasse was collected and loaded in the trough.
2. Proper mixing (homogenization) and leveling of bed was performed.
3. Ambient air was supplied by switching ON the fan.
4. The psychometric conditions of air at inlet, above the bed and away from drier were noted at regular intervals. The observations were recorded at 3 different points at inlet and at 8 different points above the bed.
5. Velocity of air at drier inlet was also noted at regular intervals.
6. The weight of bagasse after drying was measured to calculate the amount of moisture removed.

Experimental Observations

The observations recorded during 4 trial sessions are shown in Table 5.1

Table 5.1 Experimental Observations

S No.	Description	Unit	Trial 1	Trial 2	Trial 3	Trial 4
1. 1	Weather		35 ^{0}C & 55 % RH	35 ^{0}C & 47 % RH	35 ^{0}C & 45 % RH	35 ^{0}C & 59 % RH
2. 2	Amount of bagasse loaded	KG	158	150	52	90
3. 3	Specific Loading	Kg/Ft^2	3.95	3.75	1.3	2.25
4. 4	Bed Height	CM	16	15	7	11
5. 5	Initial MC of bagasse	%	71	74.5	33.3	64
6. 6	Weight of bone dry bagasse	Kg	45.82	38.25	34.67	32.4
7. 7	Weight of bagasse after drying	Kg	123.6	120	40	47.5
8. 8	Amount of moisture removed	Kg	26.4	30	12	42.5
9. 9	Initial moisture content to initial weight ratio	-	0.004	0.005	0.006	0.007
10. 9	Moisture Removal Rate	Kg of water / h	15.81	16.39	20.69	20.43
11. 10	Energy Consumed during drying	kWh	2.672	2.928	0.899	3.12
12. 11	Specific Energy Consumption	kWh/ kg of wet bagasse	0.0169	0.0195	0.0173	0.0347
13. 12	Specific Moisture Evaporation Rate kg of water	Kg of water / kWh	9.88	10.25	13.35	13.62

From the experimental observations made, it is mandatory to identify a common variable to compare the performance of the drier during various trials. As the trials were conducted with various loading and bagasse with different initial moisture content, the basic drier performance parameters cannot be used in comparison between the results. Hence, a new term named 'initial moisture to initial weight ratio' (IM/W) is introduced to compare the drier performance operating with different conditions. The comparison is subject to the following assumptions:

i. The relative humidity and dry bulb temperature of the ambient air are same for all the experimental trials
ii. The period of experimentation in each trial is for 1 hour. Accordingly, the moisture removal rate is also expressed in 'per hour' basis.

Description	Unit	Trial 1	Trial 2	Trial 3	Trial 4
Initial MC of bagasse	-	0.71	0.745	0.333	0.64
Amount of bagasse loaded	KG	158	150	52	90
Amount of bagasse loaded	-	0.004	0.005	0.006	0.007

The variation of performance parameters in each trial was compared. The list of performance parameters considered is:

- Temperature drop across the bed • Weight loss during drying
- Initial and Final moisture content
- Power Consumed
- Specific Moisture Evaporation Rate

A. Variation of Temperature Drop

The variation of temperature drop across the bed observed during the trials is shown in figure 7.1.

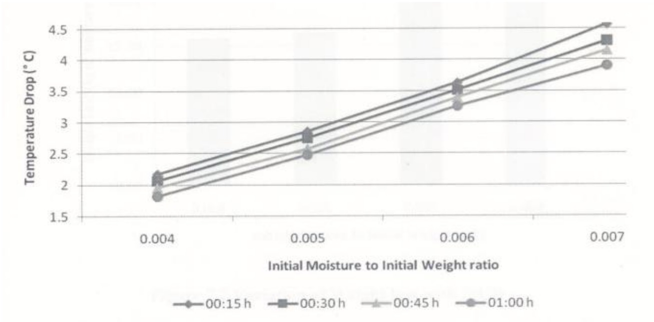

Figure 7.1 Variation of Temperature Drop with IM/W

The following inferences were obtained from the graph shown above,

- As the initial moisture content increases, the temperature drop across the bed also increases.
- The drop in temperature of air decreases as the drying time increases. This could be attributed to reduction of evaporative cooling of medium due to progressive reduction in moisture content in the bed.
- The rate of temperature drop increases with increase in IM/W ratio. This is due to higher moisture content in the bed which is the source for potential difference in evaporative mass transfer.
- Thus the trial with IM/W = 0.004 has lower temperature drop compared to trial with IM/W = 0.007.

B.Variation of Weight Loss

The variation of weight loss during drying in each trial are shown in figure 7.2

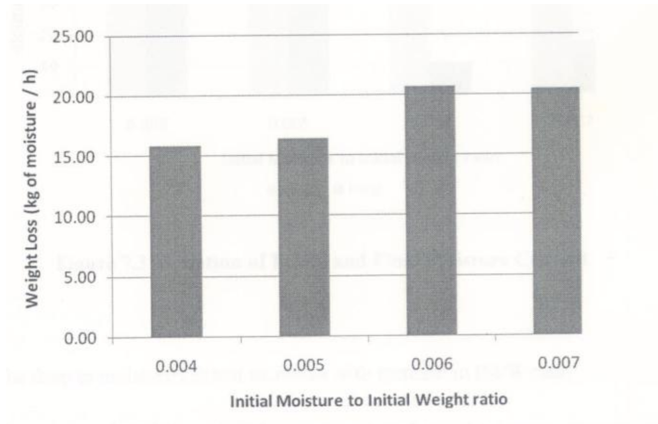

Figure 7.2 Variation of Weight loss with IM/W

- The weight loss after drying was found to increase with increase in IM/W ratio.
- The trial with IM/W = 0.004 was observed to have the lowest weight loss after drying.
- The trial with IM/W = 0.006 was found to have the highest weight loss. For a constant volume of air supplied, the amount of air available for moisture removal is higher for higher IM/W. Since the trial with IM/W = 0.006 had the lowest loading of 52 kg, an increased weight loss was observed.

Simulation Results

By using the equations as mentioned in chapter 6, the moisture removal rate obtainable for the following conditions were generated in graphs.

1) When bed voidage = 0.5 and temperature drop = 4 °C
2) When bed voidage = 0.66 and temperature drop = 4 °C
3) When bed voidage = 0.75 and temperature drop = 4 °C
4) When bed voidage = 0.5 and temperature drop = 5 °C
5) When bed voidage = 0.66 and temperature drop = 5 °C
6) When bed voidage = 0.75 and temperature drop = 5 °C

The velocity of the drying medium was assumed to be constant and taken as 1 m/s. The inlet DBT is taken along the abscissa and the moisture removal rate along the ordinate. Curves are generated for different RH values at inlet varying from 40% to 55% with a step value of 5%. In the fig.7.3 to 7.8 shown it.

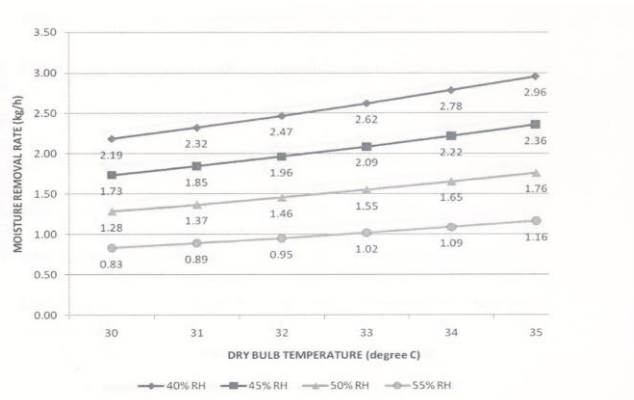

Figure 7.3 MRR Variation when bed voidage = 0.5 and temperature drop = 4 °C

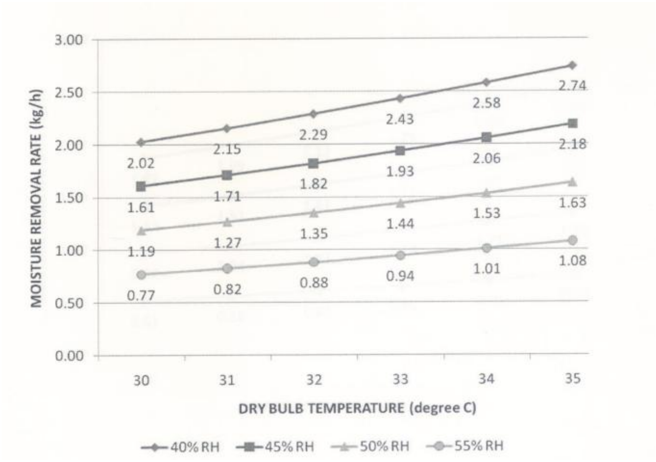

Figure 7.4 MRR Variation when bed voidage = 0.66 and temperature drop = 4 °C

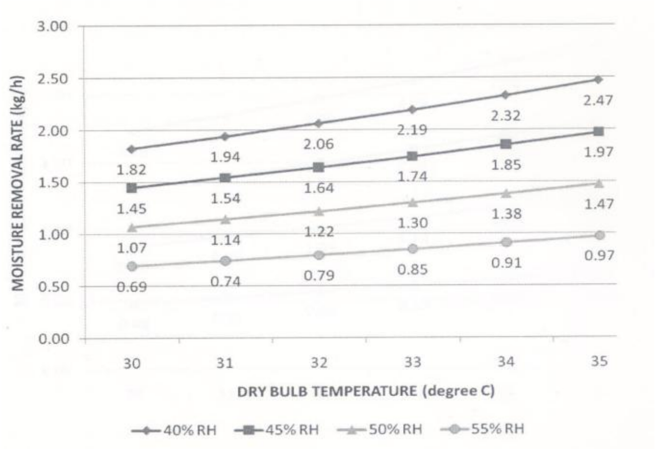

Figure 7.5 MRR Variation when bed voidage = 0.75 and temperature drop = 4 °C

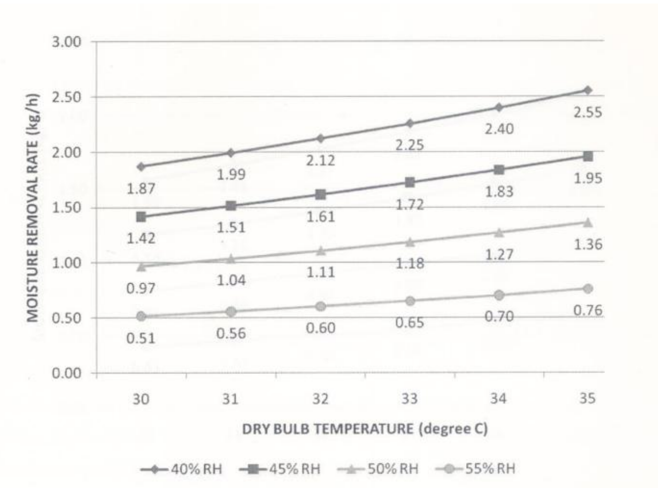

Figure 7.6 MRR Variation when bed voidage = 0.5 and temperature drop = 5 °C

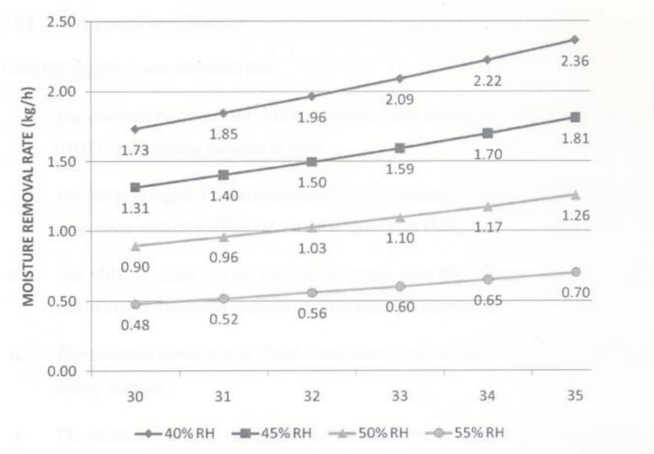

Figure 7.7 MRR Variation when bed voidage = 0.66 and temperature drop = 5 °C

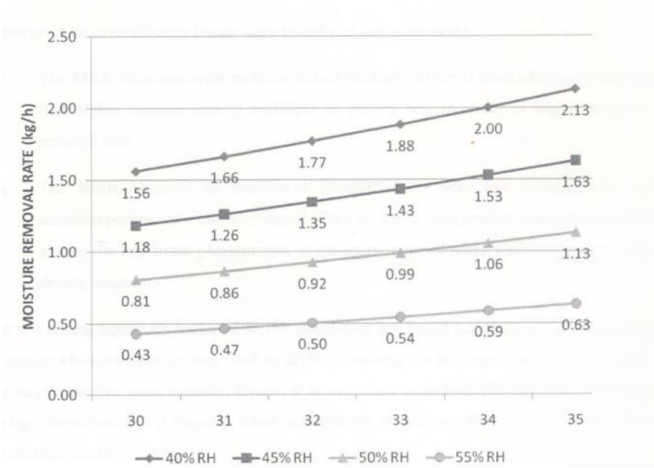

Figure 7.8 MRR Variation when bed voidage = 0.75 and temperature drop = 5 °C

Conclusion

1) The moisture removal rate (MRR) increases with increase in dry bulb temperature (DBT) of the drying medium at inlet.
2) The MRR is higher for the medium of lower inlet relative humidity (RH) compared to medium of higher RH at inlet for the same inlet DBT.
3) The MRR is higher for the medium of higher inlet DBT for the same RH. This is due to higher saturation capacity of air at higher temperatures.
4) The moisture removal rate (MRR) increases with increase in flow velocity of the drying medium.
5) The moisture removal rate decreases with increase in temperature drop across the bed. This could be attributed to supply of lower volume of air than the required volume for drying.

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