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Testing and Evaluation of Particle Motion in a Multi-Pass Vibro-Fluidized Bed Tea Dryer

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ABSTRACT
Multi-pass vibro-fluidized bed dryer is a novel energy saving design concept which involved a drying chamber with three sloping decks fixed vertically in a zigzag path as a single unit and sloped in opposite directions to facilitate uniform particle motion. Each deck measured 3.6 m x 0.78 m and consisted of perforated sheets having 13 holes per square centimeter where each perforation diameter was 1.5 mm. The three decks unit was horizontally vibrated at 3 mm amplitude using an eccentric shaft driven by a 5 kW electric motor. A centrifugal fan (5 kW) with the capacity of 2.83 m3 /s was used for supplying air for fluidization. The scope of this study was limited to optimize the vibration frequency and slope of the deck to obtain the expected particle moving speed of 6 mm/s at different moisture contents (MC). Orthodox rolled tea dhools at three levels of moisture (10%, 30% and 55%) were used for testing at different vibration frequencies and slope of the deck at the fixed amplitude and air flow rate. Results revealed that the optimum bed slopes were determined as 3%, 4% and 5% for 10%, 30% and 55% MC (wet basis), respectively, at 38Hz (504 rpm).

Keywords: *Frequency, Multi-pass vibro-fluidized bed dryer, Moisture contents, Slope, Vibration*

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I. INTRODUCTION

Tea could be categorized as one of the safest and healthiest beverages in the world. Sri Lanka produces high quality black tea being the third biggest tea production country in the world with around 9% of the global share and the total annual production is about 338 million kg of made tea [1]. The total tea land extend is approximately 221,969 hectares [2]. By far tea is the most important export crop in Sri Lanka which acts as the backbone of Sri Lankan economy [3].

Energy is a critical input for tea manufacture. The process of tea manufacturing consists of different energy intensive unit operations viz. withering, processing (rolling/CTC cuts), fermentation, drying, sifting and packing.Among them drying process consumes a large share. Tea industry get thermal energy from biomass (fuel wood), liquid fuel, diesel and furnace fuel while more than 95% of the electrical energy requirement is supplied from the national grid.

Tea industry in Sri Lanka, accounts for 33% of the industrial firewood consumption and it is also the second largest consumer of oil [4].One kilogram of made tea requires 3.5-6 kWh of thermal and 0.21 - 0.5 kWh of electrical power [5].

The total specific thermal energy consumption is 6.84 kWh/kg of made tea in Sri Lanka. Thereby 3.73 kWh/kg of made tea accounts for drying process.In Sri Lanka total specific electrical energy consumption in tea manufacturing is 0.52 kWh/kg of made tea and drying process accounts only 0.02 kWh/kg [6].

Drying is one of the key factors determining the profitability and success of the tea manufacturing process. Therefore, improving the process and adaption of more efficient systems with innovative equipment in drying will help conserve energy.

1.1 Problem definition

Drying is the most energy consuming process in black tea production [7]. The cost of drying is as high as 30% of total processing cost in most factories. Therefore, drying must be carried out as economically as possible.

Endless chain pressure type (ECP) dryer, fluidized bed dryer (FBD) and vibro fluidized bed dryer (VFBD) are three common dryers those are used in the tea industry. These have both advantages and disadvantages as well.

In the ECP dryer, tea particles tend to form lumps and adhere to the bed when the moisture content of particles is higher than about 59%. This is subject to frequent breakdowns. High pressure drop, high temperature exhaust air and lower thermal efficiency are the disadvantages of the FBD compared to ECP dryer.

Both FBD and VFBD have disadvantage of heavy emission of dust and consume large amount of electrical energy for cyclone collectors. The ECP dryer is more thermally efficient than FBD and has low temperature exhaust air that can be considered as advantages [7]. The FBD has s advantages of high mass and heat transfer rates, ease of control and low maintenance cost. Higher drying rate, better solid circulation, reduced particle agglomeration and channelling are main advantages of the VFBD.

By incorporating the advantages and reducing the disadvantages of ECP dryer, FBD and VFBD, Multi-Pass Vibro-Fluidized Bed Tea Dryer is introduced. The new dryer will have a commercial potential due to its expected low electrical energy consumption, affordable cost, reduced foot print and low cost of installation than other three common dryers.

1.2 Objectives

1.2.1 Development objective

- Design and development of a multi–pass vibro-fluidized bed dryer for tea and desiccated coconut

1.2.2 Specific objectives

- To optimize the bed slope and vibration frequency to achieve the required particle travelling speed of around 6mm per second
- To study the effect of moisture content of dhools on particle motion
- To test the particle motion (resident time) on multi pass bed dryer.

II. LITERATURE SURVEY

2.1 Drying of Tea

The most important factor that determines the quality and the storage capacity of tea is moisture content. Proper drying of tea helps to keep the moisture content within the desired limits.. Further fermentation of tea dhools is holted due to arising temperatures during drying process. From the drying process moisture content of dhool should be reduced from about 70 % to 3 % (wb) before packing and storage [8]. When drying equipments are selected incorrectly it will affect badly to the quality factors of the tea due to not removing moisture content well[9].

2.1.1 Drying principle of tea

The major principle of tea drying is the transfer of heat and mass between hot air and drying leaves. The energy for moisture evaporation from tea is provided by hot air stream and it will carry out that evaporated moisture from tea leaves [10].

2.1.2 Effect of drying on made tea quality

Drying process should not have any adverse effects on made tea quality in the sense of chemical components. Therefore drying is not only a process of reducing the moisture to desired value. It should be able to stop the fermentation and deactivate the enzymes [3].The purposes of drying tea are to hold fermentation, remove moisture and produce good quality tea with good keeping quality [11].

As hot air acts as a medium to remove the moisture from wetted particles, high moisture tea dhools require more heat energy to remove their moisture. To get good quality with non- burned and non- harden dried tea, inlet temperature should be in between 83Ċ - 99Ċ. Exhaust air temperature should be changed according to the inlet air as 49Ċ to 57Ċ. The dryer efficiency is reduced when the exhaust air temperature is higher. At higher exposure of heat will causes the loss of tea quality by adding burnt taste and become hardening. Therefore air temperature is an important factor in drying [12].

Drying time is also more important to get stable drying. Long time period of drying causes reduction of tea quality while fast drying increases the bitter taste of tea. In most of commercial dryers 15 to 25 minutes drying time is practiced which is governed by type and leaf thickness of tea and heat quantity [12]. Tea drying technique and the final moisture content in the made tea are the factors of determining the keeping quality of final product tea.

2.1.3 Tea drying techniques

Drying is the major energy consumer in black tea manufacturing process [7]. There are several types of dryers that are commonly used in the tea industry. According to the chronological order of tea dryer ECP, FBD and VFBD were developed.

Table.1: Comparison of the performance parameters of dryers

Performance Parameters	**Dryer type**	
	ECP	**FBD**
Electrical Power (kW)	18	61
Electricity Consumption (kWh/kg)	0.061	0.123
Equivalent Thermal Energy (kWh/kg)	5.76	4.48

Specific Energy Consumption (kWh/kg)	5.82	4.60
Water Evaporation rate (kg/h)	380	700
Fly off (% of made tea)	3%	16%

The efficiency achieved in an ECP dryer is 36% whereas it is 54% in the FBD. However, many Orthodox tea producers still use ECP dryers, because it can be used to dry both CTC and Orthodox tea[6].

2.2 Fluidization principles
Fluidization is a process that solid particles act as a fluid and thoroughly contact with a gas[13]. It is new phenomenon of solid materials are in a gas or liquid media as a suspension [14].

2.2.1 Fluidized Bed Drying
Wet particles and fluidizable granular materials are dried mostly dried under FB dryers. FBD should be operated at gas a velocity which is higher than the minimum fluidizing velocity called as the superficial gas velocity. Minimum fluidizing velocity is a certain value which supports the whole bed.
Moisture content is a factor of affecting on minimum fluidizing velocity. Minimum fluidizing velocity at lower value of dry particles than high moisture content particles due to cohesive forces are dominant at high moisture levels.A perforated plate has the upwardly directed flow which has the exceeded 30 % of pressure drop across the distributer than the pressure drop across the bed [15].

2.2.2 Heat and mass transfer rates in Fluidized Bed
Operating conditions are highly affect to the heat transfer mode as particle size, air flow conditions, temperature, pressure, distributor type and fluidization regimes [15]. Rapid and vigorous mixing of particles take place just above the distributor in gas fluidized bed. Therefore heat transfer can be possible either by conduction, convection or radiation in gas fluidized bed. Easy exchange of heat and mass between solid and the fluid can occur due to rapid mixing [16]. Thus heat transfer coefficients are very high. It is essential to occur high rates of particle displacement to have high heat transfer coefficients.

2.2.3 Effect of gas velocity
Surface moisture removal is affected by gas velocity while the drying rate is dominantly increased by increasing gas velocities. At the end of the drying period the internal resistance to moisture removal can be prominent [15]. Cushioning effect of gas will prevent the damage of braking down the dried particles [16].

2.2.4 Vibro-Fluidization principles
Fluidization characters can be improved by incorporation with the vibration along with fluidization. Vibration helps to decrease the minimum fluidization velocity and it avoid the channeling and defluidization in fluidized bed [13].
According to the previous study that was done by using sawdust in a vibro fluidized bed dryer, air velocity for drying was able to reduce significantly with vibration effect. Defluidization was able to avoid combination with vibration on 66.7 % MC (wb) sawdust particles [17].

2.2.5 Behavior of vibro-fluidized dryer
Minimum fluidization velocity was depends on the vibration parameters and vibration amplitude [13].

III. RESEARCH METHODOLOGY

3.1 Overview
This research was conducted at the Pirekma Pvt. Ltd., Industrial Park, Galigamuwa using a -vibro fluidized bed dryer under development. Initial trials were done using saw dust and orthodox tea dhool obtained from Upland Tea Factory, Peradeniya was used for operational trials.

3.2 Design of the dryer
Dryer was designed by the Faculty of Agriculture, University of Peradeniya and fabricated by the technicians at the Pirekma Pvt. Ltd. The dryer consisted of a three-pass dryer deck, a vibratory drive and an air blower. The dryer deck consisted of three sloping decks sloped in opposite directions. Each deck measured 3.6 m x 0.78 m and consisted of perforated sheets having 13 holes per square centimetre where each perforation diameter 1.5 mm. Vibratory drive consisted of an eccentric shaft driven by an electric motor coupled with variable speed controller was used to provide different levels of horizontal vibration frequencies for the three decks and the vibration amplitude was fixed at 3 mm. A centrifugal fan driven by a 5 kW, 220V electric motor was used for supplying air.

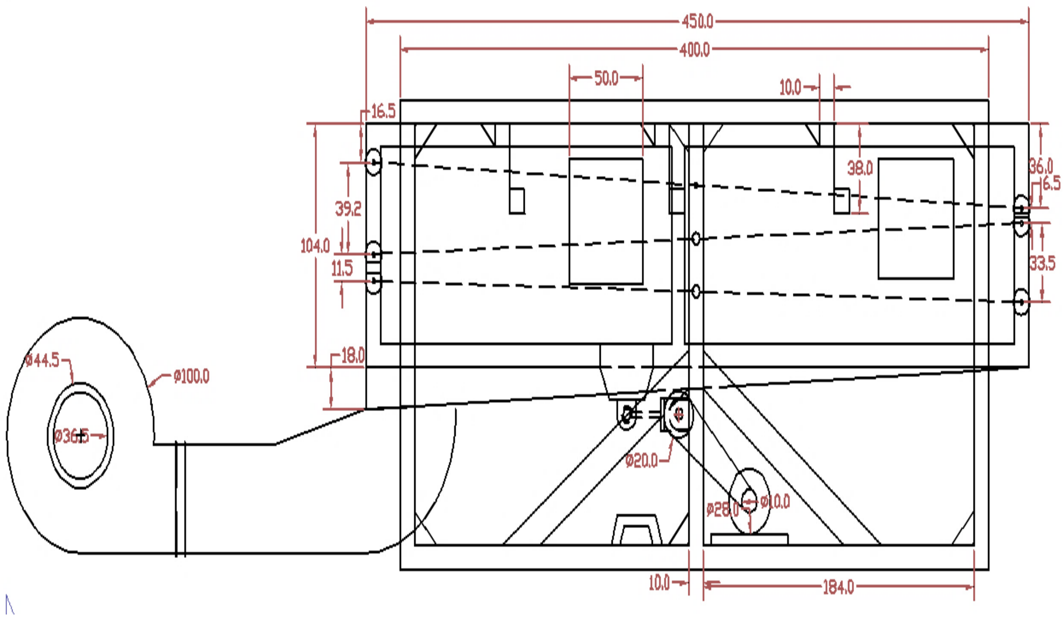

Figure1: Side view of the dryer

3.3 Experimental procedure

At the initial stages a single pass conveyance model was used for trials. Slope of the bed deck and vibration frequency were considered as independent variables in this study. Therefore by changing these two conditions, experiment was carried out. By adjusting screws, the slope of bed plate was changed while frequency of vibration was changed using a variable frequency inverter coupled to the drive motor.

Preliminary trials were carried out using saw dust at different levels of frequencies between 29 Hz to 35 Hz. Particles at three levels of moisture, 10 %, 30 % and 55 % (wet basis) were used for testing at different vibration frequencies and deck slopes at the fixed amplitude and air flow rate. Slope of the bed plate was changed between 2.9 % to 5.3 %. The particle motion was observed under different rates of air flows to identify the influence of the air flow rate on particle motion along the deck bed.

Refuse tea and orthodox rolled tea dhools were also experimented under single pass conveyance model. Predetermined three moisture contents represented the expected mean moisture contents in three decks. The frequency had to increase up to 40 Hz to get better results about behaviour of particle under several levels of frequencies while slope of the bed was changed in between 2.5 % to 5.3 %.

According to the findings from single bed deck experiments, the required slope and frequency levels were predicted to get required particle speed. Two decks were fixed and average particle motion was studied for both decks.

3.3.1 Density measurement of material

All samples were taken from the same well mixed materials. The density of the material had a great effect on the dryer output. Therefore, measurement of density was important. A box structure which was in 0.237 m^3 volume was used for density measurements using the weight of known volume. Bulk density was measured for three levels of moisture contents (10 %, 30 % and 55 % wet basis).

3.3.2 Determination of moisture content of materials

The standard oven dry method was used to measure the moisture content of particles. The calculation of moisture content was done by using the equation 1 [18].

Wet basis moisture content;

$$M.C.(wb) = \frac{M_1 - M_2}{M_1 - M_0} * 100\%$$

(Equation 1)

Where; M_0 = Weight of empty can (g)

M_1 = Weight of can with material before oven drying (g)

M_2 = Weight of can with material after oven drying (g)

Water was added to dry feed materials to get the several moisture levels at the experimental site and wetted samples were also tested using oven dry method to make validate the adjusted moisture levels.

3.3.3 Bed thickness determination

According to the required output from the dryer and moisture levels thickness of the bed was determined. At higher moisture levels the density of particles was higher than lower moisture levels. The expected dryer output was 200 kg/hr and based on the density values for each moisture levels the bed height was determined.

3.3.4 Determination of weir height

Materials were discharged over a weir at the outlet of the dryer. The weir height was observed as an important factor for the retention time and the continuous flow along the bed plate at initial trials. Therefore the weir height was adjusted according to the bed thickness.

3.3.5 Measurement of air flow and pressure drop

The model was tested with unheated ambient air supply. At initial stages the particle motion was observed with different air flow values. Air flow was controlled by using a damper system to supply different air flow rates. At later stage the constant air flow was maintained for the trials. Air flow was measured using a vane anemometer. The pressure drop across the fluidized bed was measured by using a U tube water manometer.

3.3.6 Measurement of particle speed

At initial trials particle speed was measured under different air flow rates by changing the frequency and bed slope for different levels of moisture contents. After several trials, air flow was kept constant and only the frequency and slope of bed were changed as independent variables. All the trials were conducted with three replicates to improve accuracy. Time taken to travel 1 m length in two sections at the middle of the bed was measured to get the average particle speed.

3.3.7 Measurement of particle size distribution of orthodox tea dhools

Particle size was determined by sieve analysis method at the Agricultural Engineering laboratory due to its simplicity, speed, and ease of interpretation. The samples were shaken in the auto sieve until the amount retained becomes more or less constant.

3.3.8 Measurement of rpm value of the motor

The Laser Photo Tachometer was used to get rpm value readings of the motor. The relationship between the frequency and the rpm value of the motor was developed.

IV. RESULTS AND DISCUSSION

4.1 Saw Dust Trials

A set of trials was conducted using saw dust to obtain preliminary data on the effect of air flow, moisture content and bed slope on the particle motion parameters.

4.2 Effect of air flow rate on resident time of the particles in the dryer deck

The variation of resident time of saw dust at different moisture contents with air flow rate is shown inFigure 2, Figure 3 and Figure 4 for three different bed slopes 2.9 % and 3.5 %.

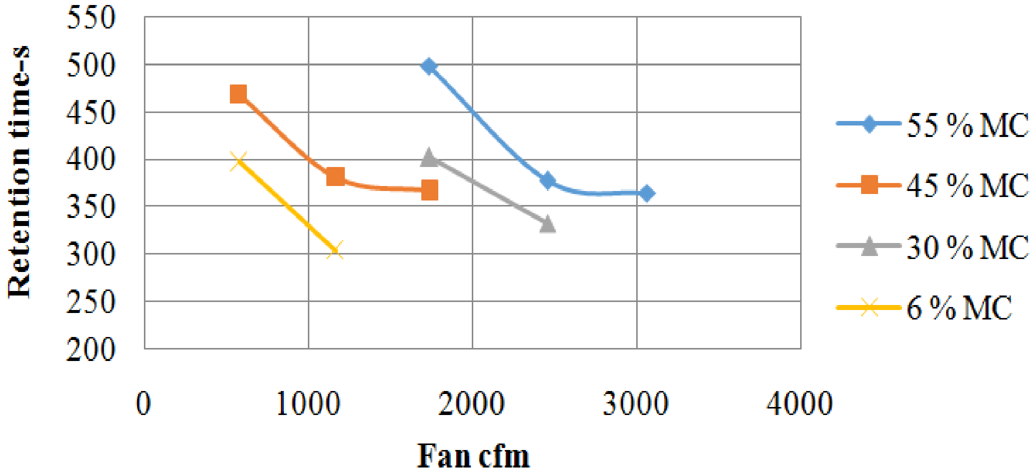

Figure 2: Variation of resident time with air flow rate at 2.9 % slope and 32.4 Hz frequency with saw dust at different moisture contents

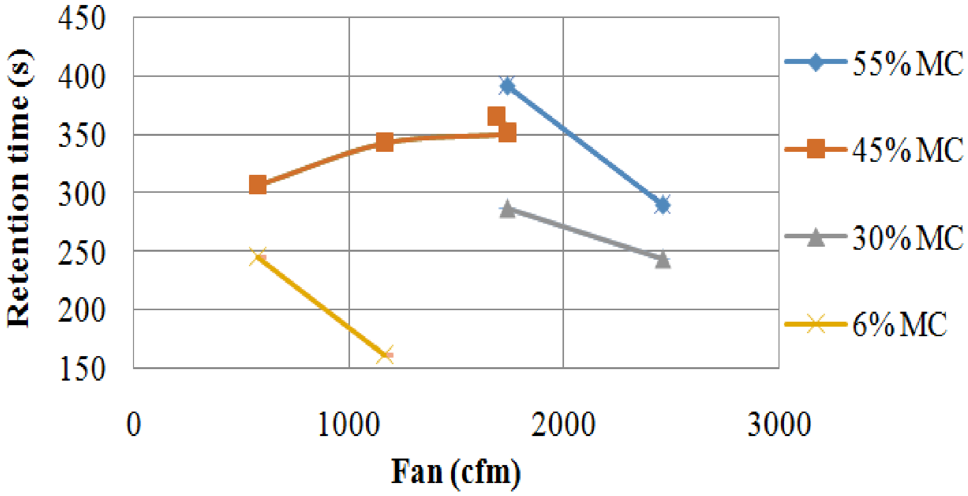

Figure 3: Variation of resident time with air flow rate at 3.5 % slope and 32.4 Hz frequency with saw dust at different moisture contents

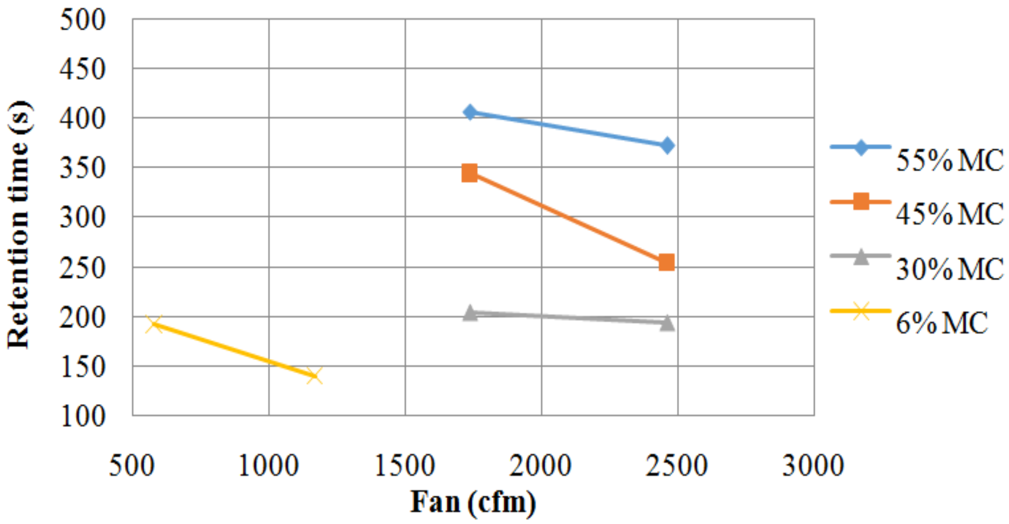

Figure 4: Variation of resident time with air flow rate at 4.3 % slope and 32.4 Hz frequency with saw dust at different moisture contents

It is clearly seen from the figures it that increasing air flow increased the particle velocity and reduced the resident time. This is a favourable result considering that the required particle motion can be enhanced by increasing the air flow through the bed.

The particle velocity increased with the increasing air flow in all the tests except when bed slope 45% MC (wb) at 3.5 % bed slope. This may be due to some problem with the bed thickness variation during the tested time.

This result of these trials can be used for future development of this dryer by changing the air flow rate for each bed deck, by adding separate air blowers to each deck. This result can be used for the air blow calculations in future development stages.These results also indicate that there is a relationship between moisture content and resident time of particles at given vibration frequency, slope and air flow. Higher moisture content increases the retention time. It provides an indication that at same vibration frequency and air flow rate, changing the slope of the can be used to change the retention time of different moisture samples.

4.3 Effect of moisture content on the particle speed

This dryer will be used to reduce the moisture content of tea to 3 % MC (wb). From the highest value of moisture, the tea should be dried down to this value along the three sloping decks. The effect of reduction of the moisture of tea results the density reduction of particles. Therefore their internal characters also vary with the drying process.

Trials using different moisture contents of saw dust at same slopes, air flow rates and frequencies, indicated that increasing the moisture content appeared to reduce the speed of the particles while increasing the retention time.

4.4 Effect of slope of bed on the particle speed

The results shown in the figure 2, figure 3 and figure 4 also indicate that the particles exposed to increasing slopes under in the same conditions of other factors, increased the particle speed along the deck. It was observed that good mixing of particles occurred at higher values of slopes than lower values. This observation was used when deciding on the slopes of the decks with tea dhools.

The use of high frequency levels (>40 Hz) during the trials indicated that even bed thickness could not be obtained due to imperfect flowing of particles along the bed with the air flow. At higher frequencies piling in the middle of the bed occurred resulting in a non-uniform bed. Therefore, frequencies higher than 40 Hz were not used.

4.5 Trials with of big bulk tea dhools

In this vibro-fluidized bed, the particle motion for tea dhools was tested under different conditions. The required value of air flow calculated as 6,000 cfm (2.83 m^3/s) and was fixed for each trial.

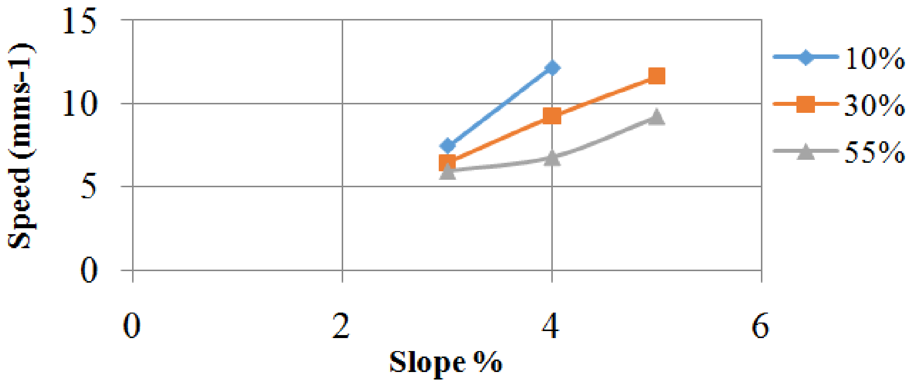

Figure 5: Effect of bed slope on particle speed at 38 Hz frequency for tea dhools

The vibration frequency of 32.5 Hz was required to start the movement of tea dhool particles at the slope of 3 % under the air flow rate of 6000 cfm. In the dryer, three beds act as one unit. That was the reason for measuring the particle motion starting at 33 Hz for each trial.

When the vibration frequency was increased, it had the effect of increasing the particle motion speed, but not in linearly. This may be due to the change in bonds within the particles with the increasing vibration frequency because vibration helps transition from the fixed bed to the fluidized bed [19].

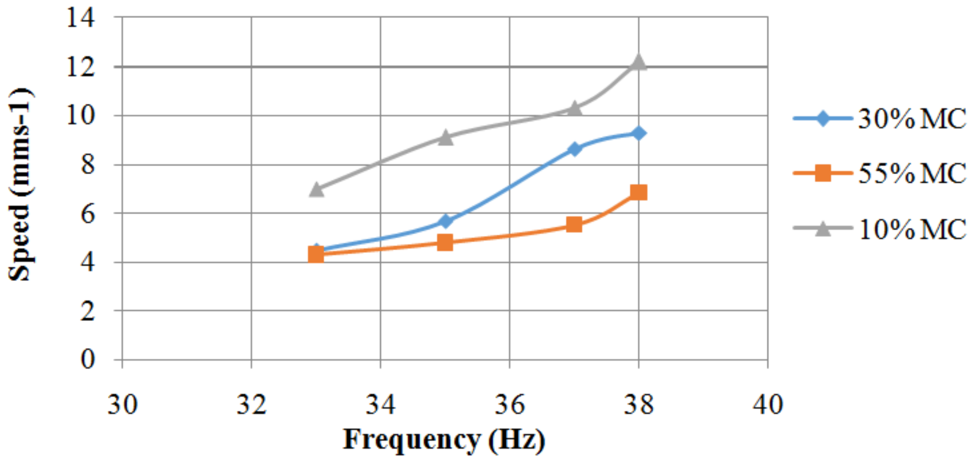

Figure 6: Effect of vibration frequency on particle at 4% bed slope for tea dhools

According to these results the vibration frequency of 38 Hz was identified as the frequency to get the required particle speed. At this frequency of 38 Hz the bed thickness was uniform.

From these results the required slope for different moisture contents can be identified. Though the actual bed condition at the developed stage, air flow and bed pressure will be different from experimental conditions, having the deck slopes at 3 % for 10 % MC (wb), 4 % for 30 % MC (wb) and 5 % for 55 % MC (wb) can be suggested.

V. CONCLUSIONS

Drying in black tea manufacturing process consumes both thermal and electrical energy. The cost component for energy in drying is relatively high due to inefficient drying equipment. Multi-pass vibro-fluidized bed dryer was a novel design concept of conserving energy in drying process in tea industry. Moisture content influences the particle motion speed on the bed. Decrease of moisture of tea dhools increases the particle speed at a given bed slope and frequency. A frequency of 38 Hz (504 rpm) at 6000 cfm (2.83 m^3/s) air flow rate was found to produce the expected particle speed for all three moisture levels and the bed slopes of 3 % for 10 % MC (wb) and 4 % for 30 % MC (wb) and 5% for 55 % MC (wb) at 38Hz (504 rpm).

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