Experimental Analysis of Heat Pump Assisted Circular Dryer

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Abstract - *Drying is the removal of moisture from the product. Drying has lot of advantages such as preserving, packaging, transporting etc. Many types of dryers are in the market, among which heat pump assisted dryer has lot of advantages. It consume less energy, produce good quality product. Drying rate is the term that determine the effectiveness of a dryer. It has lot of influencing factors such as drying temperature, velocity of flow, presence of recirculation of air, geometry of chamber etc. In this work checking the influence of drying temperature, velocity of flow and effect of swirl motion at inlet. Here green peas is used as product for drying. Its drying temperature varied from 50℃ ,55℃and 60℃ . Velocity change and swirl motion at inlet is created by providing a forced drat with varying speed at inlet. By comparing the effect of swirl motion at inlet the drying rate is increased by 10.20%.By comparing the effect of different velocity it is concluded that drying rate is increased to 10-30%.*

***Key Words*: Drying rate, Drying time, Heat pump, Relative humidity**

1. INTRODUCTION

Drying is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid. This process is often used as a final production step before selling or packaging products. To be considered "dried", the final product must be solid, in the form of a continuous sheet (e.g., paper), long pieces (e.g., wood), particles (e.g., cereal grains or corn flakes) or powder (e.g., sand, salt, washing powder, milk powder). Drying of selected food products is essential to reduce the weight for easy transportation and to enhance the shelf life of the product without quality losses over an extended period of time. Drying involves the simultaneous application of heat and removal of moisture from foods. When a solid body containing moisture is subjected to thermal drying, two processes occur simultaneously firstly the transfer of energy (mostly as heat) from the surrounding environment to evaporate the surface moisture and then transfer of internal moisture to the surface of the solid and its subsequent evaporation due to the first process. The rate by which the drying take place depends on the rate of above mentioned processes. One of the biggest requirements in drying processes is the achievement of uniform moisture content of the final product. Vertical flow in drying will improves the heat transfer rate due to the gravitational effect. Vertical flow through pipe has always higher compared with the horizontal pipe. Circular cross section drying chamber has a positive effect on drying, produces uniformity in drying. Circular cross section has more heat transfer area comparing with that of rectangular cross section even its volume is same. Forced draft at inlet will results in both increase in the velocity of flow as well as the creation of swirl motion at inlet. It will provide more uniform temperature distribution inside the drying chamber.

Drying temperature is very important because if increases the temperature more than drying temperature it may reaches the cocking temperature which will changes the chemical characteristic of the product. Ibrahim Doymaz *et al.* (2005) studied the drying properties of green peas who changes the drying temperature from 50°C to 70°C and moisture content varied from 90.3% to 14.5%. S. From these it concluded that the optimum drying temperature of green peas is in the range of 50°C-60°C.[1]

Several researchers done different paper on drying, among which Vázquez et.al.(1997) and Best et.al.(1996) suggested that the use of driers with heat pump as an alternative method to dry fruits and vegetables with lower values in consumption of energy, relative humidity and temperatures.[2,3].Prasertsan(1990) conducted experiment on heat pump assisted dryer with seeds of different culture as product and concluded that it accelerated drying process without elevating the temperature, less expensive to operate than traditional natural gas fired systems and produces high quality seed[4]. Rossi et.al (1992) compared the performance of an electrical heating drying with and without heat pump assisted drying for onion and they reported that the drying time can be saved by 40.7% and electrical energy by 40% in heat pump assisted drying [5]. Hence as a conclusion the use of heat pump assisted dryer good quality final product, less energy consumption and less drying time by compare with the other traditional dryer system.

Chua et.al (2001) found wastage of heat energy occurs through outlet, so he got focus on the utilization of this waste energy by giving some portion to inlet again. This utilization of waste energy improve more economical aspects for the drying process [6] . Surendra Kothari et al (2009) conducted experiment on dryer with and without recirculation. he drying and thermal efficiencies and heat utilization factors were recorded as 21%, 74% and 31% respectively, more compared to recirculation of exhaust air test[7].

Ozbey M. and Soylemez M. S (2005) [4] done studies to determine the parameters that affect drying. The way these parameters affect the drying has also been analyzed. The main parameters that have been studied have been temperature of air, velocity of air, material to be dried, size of the particles, time of drying etc[8]. According to Azhar Kareem Mohammed et al. (2013), studied the effect of the heat transfer through vertical and horizontal circular pipes and suggested that heat transfer rate will be higher through vertical pipe due to the gravitational effect comes in action.

At low velocity of flow gravitational effect will be present, and thus heat transfer will be more [9].

Priyanka BishtÅ et al.(2014), conduct a comparison study of heat transfer through a circular and rectangular cross section using Ansys Fluent, suggest that heat transfer rate will be more in the case of circular cross section.it will provide more heat transfer area even with same volume of two geometry[10]. Mustafa Aktas et al.(2017) suggest the use of circular drying chamber for the drying of mint leaf. Here uses a heat pump assisted system with inlet velocity in the range 2-3m/s. According to him the use of circular drying chamber will give more temperature distribution inside the drying chamber [11]. F T Ademiluyi et al conduct experimental and numerical study on drying of spherical particle in a rotary dryer. The air flow velocity is taken as 0.9-1.6m/s. drying temperature is taken as 115-200°C. From the study comparing the moisture ratio in the drying process. These will suggest the important of using circular cross section drying chamber in a drying process [12].

From the literature review, it is clear that no studies have been conducted previously for a heat pump assisted simple tray dryer system and investigate the influence of direction of flow and effect of recirculation on drying rate of the product. Thus, the objective of the present work is experimentally investigating the influence of direction of flow and effect of recirculation on drying rate of the product.

2. EXPERIMENTATION

2.1 Experimental Setup

Experimental setup consists of a heat pump unit, a heater, drying chamber and a fan. Incoming air is dehumidified by cooling it below the dew point temperature in the evaporator. Then the condenser itself of the heat pump is used to preheat the air which is further heated by the heater to the required temperature. Dehumidified, heated air enters the drying chamber. Draft fan forces the air through the network. Schematic diagram of the experimental setup is shown below.

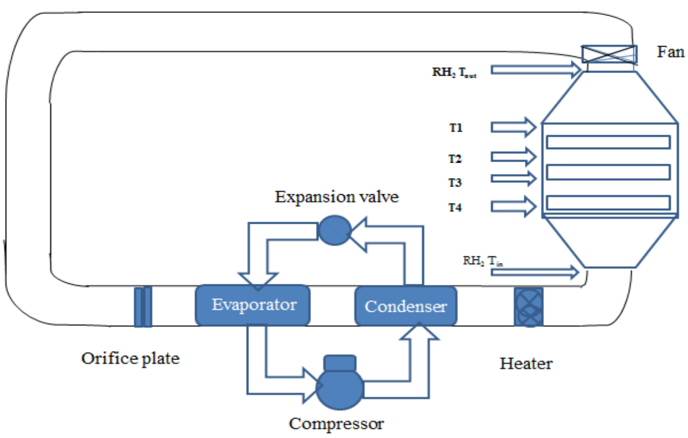

Fig. 1: Schematic Diagram of Experimental Setup for vertical flow without forced draft at inlet

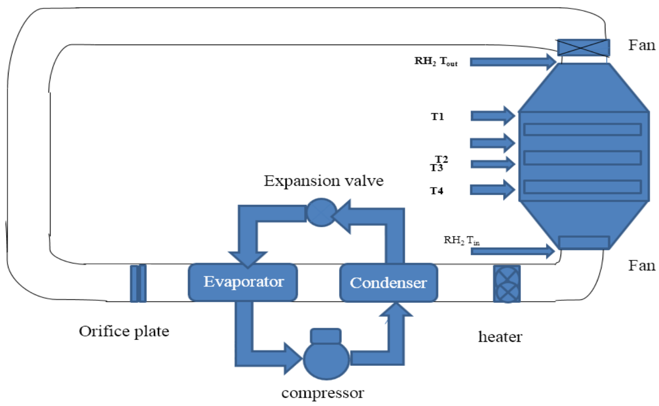

Fig. 2 Schematic Diagram of Experimental Setup for vertical flow with forced draft at inlet

2.2 Description of components used

(i) Heat pump dehumidifier

Specifications of heat pump as per design are given in

Table 4.1.

Evaporating capacity	1.1715 kW
Refrigerant mass flow rate	0.01098 kg/s
Compressor work	0.4326 kW
Condensing capacity	1.6042 kW
Coefficient of performance	3.7

Table 1: Specifications of heat pump

(ii) Electric Heater

It consists of an electric heating coil of 1500 Watts. A thermostat controls the operation of the heater. That means power supply to the heater will cut off when air temperature exceeds the preset temperature and turn on supply when temperature drops below the required value.

(iii) Drying chamber

Drying chamber is circular chamber of diameter 64cm and height of 40cm made of GI sheet with a door. Inner side of the chamber was insulated using plastic rexine of 2mm thickness. It consists of 3 trays made of wire mesh, placed at equal distance. Products to be dried are placed on this wire mesh

(iv)Draft fan

Draft fan facilitates the circulation of air through the system. Specification of the draft fan used is given below:

- Power: 60W
- Speed: 2400 RPM
- Air flow: 480 CFM

(v) Orifice plate

An orifice plate is manufactured with upstream diameter of 0.6 times diameter of pipe. Provisions for connecting manometer are provided (1.5 times diameter of pipe from upstream side and 0.6 times diameter of orifice to the other side from upstream side).

Measuring instruments used

i. Digital thermometer

These are digital temperature indicators used to measure temperature ranging from -50°C to 300°C. Digital thermometers used have an accuracy of ±1%. Four digital thermometers are placed along the drying chamber at equal distances and these four temperatures are recorded after certain time interval.

ii. Humidity – temperature sensor

Temperature humidity sensor used is DHT22. It is a basic, low-cost digital temperature and humidity sensor.DHT22 capacitive humidity sensing digital temperature and humidity module. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin. It requires 3-5V power for its operation. Good for -40°C to 80°C temperature, reads with ±0.5°C accuracy. Good for 0-100% humidity readings with ±2% accuracy.

iii. Micro-manometer

Micro – manometer is a Pressure and Flow Meter which is a portable microprocessor based instrument which measures low differential pressures in a choice of units, and velocity when paired with pitot tubes. It can measure differential pressure using the inbuilt, sensitive transducer. It is used in many industries where low pressures and airflows need to be measured with good accuracy. It can measure a pressure of ±600Pa with an accuracy of ±0.25%.

iv. Weighing scale

The weight of the material before and after the drying is done with the help of weighing scale. It is an electronic type weighing scale

2.3 Experimental Procedure

Experiment on heat pump assisted circular dryer is carried out with three different drying temperature of 50°C,55°C ,60°C. Green peas as product is taken for the experiment. Initially weight of the product to be dried is noted. The drying chamber is maintained at constant drying temperature with the help of temperature controller. After attaining the study state product is put into the dryer. Temperature and humidity at the inlet and outlet of the chamber is noted by DHT 22 temperature sensor. By using 4 temperature sensors temperature along the drying chamber is noted. A collecting tray with a pipe is provided at beneath of the evaporator. The condensate water from the evaporator is collected and weight is noted at an interval of time. Thus will get the weight of the green peas at each instant. Experiment is repeated for three different temperature.

Experiment model modified by providing a forced draft at inlet of drying chamber. Drying experiment is carried out for three different drying temperature by varying the speed of the forced draft into low, medium and high. At each case same experiment procedure as mention earlier is take place. Each case drying rate will calculated by getting the weight of the green peas which is obtained from the collected condensate water.

Fig3. Experimental set up

Instantaneous drying rate is calculated by,

$$\text{Drying rate, } D_R = \frac{W_{i-1} - W_i}{W_d * (t_{i-1} - t_i)}$$

Where,

W_i = Weight of product at any instant „i", (g).

t_i = Time at which weight is taken(minutes).

W_d = Weight of dried product (g).

3. RESULTS AND DISCUSSIONS

In the drying experiment, green peas is taken as the product to be dried. Three drying temperatures were considered, ie, 50°C, 55°C, and 60°C. Mass flow rate through the network is fixed. Temperatures along the drying chamber are obtained using temperature sensors placed along the drying chamber (T3, T4, T5 and T6). Drying chamber inlet and exit humidity is measured using humidity-temperature sensors (RH1, T1 and RH2, T2). Drying is terminated when the relative humidity difference reaches a constant value. Recorded values are then plotted with time to obtain drying curves. Drying rate is obtained by the using relation containing the weight of the product at each instant. Weight of the product at each instant is determined by collecting the condensate water which is absorbed from the product.

A forced draft is provided by fixing an exhaust fan at the inlet. Which is connected through a regulator. Three different speed of the gives different velocity of flow as well as the discharge. Experiment is conducted for three different speed of forced draft. Drying experiment is conducted for three different speed (low speed, medium speed, high speed) for each drying temperature (50⁰C, 55⁰C 60⁰C).

3.1 COMPARISON OF DRYING CURVES

For the three drying temperature 50⁰C,55⁰C and 60 ⁰C drying experiment is carry out and the condensate water that removed from the green peas is collected. For each 10 minutes collected water value is noted until the product is dried. Then the drying rate is calculated and is graph is plotted with time. Figure 4 shows the drying curve for each drying temperature.

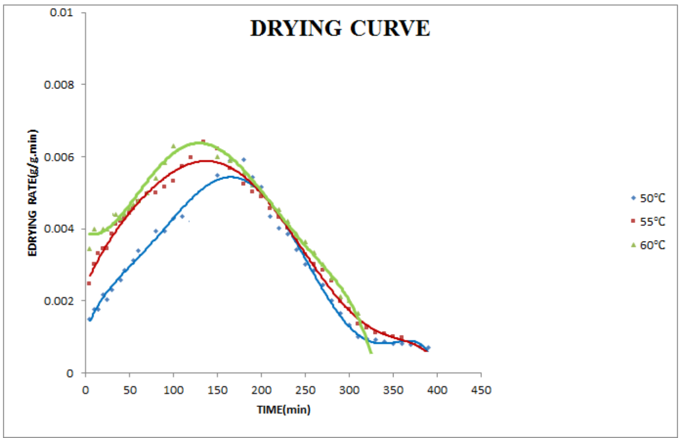

Fig 4 variation of drying rate for 50°C, 55°C, 60°C

It can be see that all the three curve shows the same trend. That is at initial stage drying rate will be increasing then it will reaches a peak value. At the final stage the drying rate will be decreasing. It clear that drying occurs in three different periods. In the initial period, where sensible heat is transferred to the product. This results in heating up of the product from the inlet condition to the process condition, which enables the subsequent processes to take place. For some cases, pre-processing of the product can reduce or eliminate this phase. The rate of evaporation increases significantly during this period with most of free moisture being removed.

During the second stage, or generally called constant rate period, free moisture persists on the surface and the rate of evaporation alters very little as the moisture content reduces. Drying rates are high in this period. There is a relatively small and gradual increase in the product temperature during this period. In the final stage, or falling rate period, migration of internal moisture to the surface of the green peas takes place which reduces the drying rate.

The percentage increase in the drying rate when the temperature increasing from 50°C to 55°Cand 60 °C is 23 and 44% respectively. The drying time reduced from 390 minutes to 360 and 320 minutes as temperature increased from 50 °Cto 55°C and 60 °C respectively.

COMPARISON OF DRYING CURVE WITH FORCED DARFT AT INLET

Fig.5 shows the comparison of drying rate for drying temperature of 50⁰C with and without the forced draft at inlet.

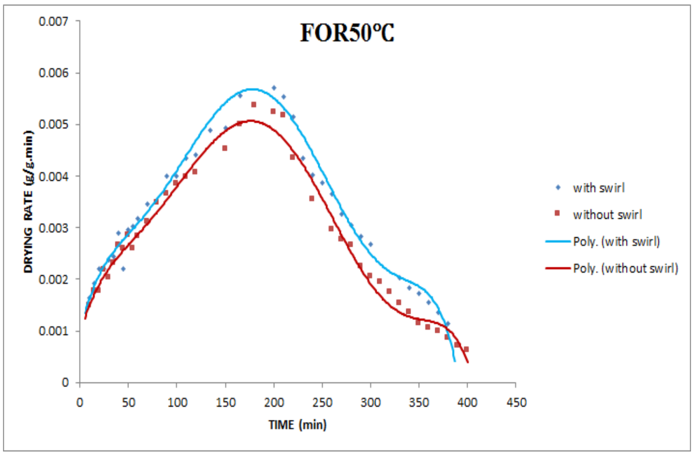

Fig.5 variation of drying rate with and without swirl motion at inlet 50°C

This graph shows the effect of the forced draft at the inlet. In all the three drying temperature the introduction of the forced draft at inlet results in increase of the drying rate. The presence of the forced draft at inlet will increases the velocity of the air flow. It also results in the production of a swirl motion inside the drying chamber. These effects more circulation inside the drying chamber. So hot air will comes in contact with more green peas inside it. This will increase the heat transfer rate between green peas and the hot air. As a result more moisture from the green peas will evaporate. So drying rate will increase. The increased velocity of the flow also increases in the heat transfer rate between the green peas and air. So as moisture removal rate and drying rate will increases. Thus drying time will decreases. In all three cases the drying curve shows the same trend, i.e. at initial stage drying rate is increasing with time at higher rate to a peak value. After reaching a peak value drying rate will start to decrease. It is due to at starting stage moisture from the top surface of the product will easily evaporate with less amount of energy. The depression in the curve is due to the large amount of energy requirement for the moister removal. To evaporate moister from the inner surface of the green peas more energy is required.

Here forced draft at low speed is considered. It can see that the drying rate is increased by the introduction of the forced draft. It can see that by providing the low speed draft drying rate value is increased to 18%.So the drying time also reduced. Time for complete drying at 50°C without draft fan at inlet is 400 minutes. Drying time with forced draft at inlet is reduced to 390 minutes. It proves that the presence of the draft will provide more heat transfer as well as proper air circulation inside the drying chamber. Similar to this case the drying rate comparison for drying temperature of 55⁰Cand 60⁰C shows the same trend The percentage of increase in drying rate for 55⁰C and 60°C is 15.2 and 14.8% respectively. In both cases the drying time reduced by 10 and 15 minutes respectively.

COMPARISON WITH DIFFERENT SPPED

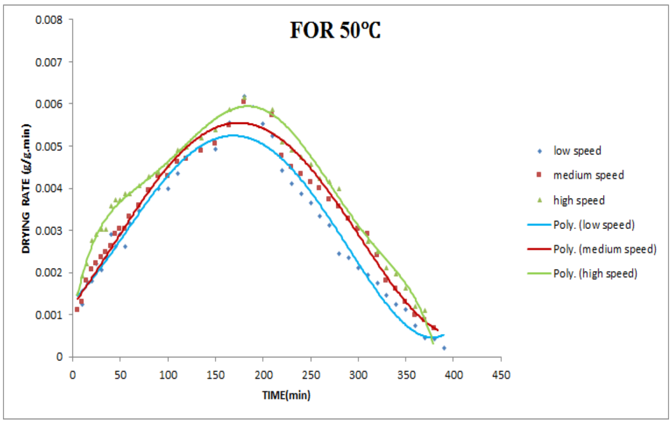

Fig.6 variation of drying rate for different draft speed for 50°C

Above figure shows the comparison of the drying curve for different forced draft fan speed at inlet for each drying temperature of 50⁰C. Here it can see the effect of the different draft fan speed on drying of the green peas. Drying curve shows the same trend that observed in the earlier case. At initial rate of moisture from green peas is high so dying rate will be high. Then it reaches a peak value then start to decrease. As the fan introduced, the velocity as well as the swirl motion will increases. Both will influence on the drying rate positively. With increase in the draft fan speed the velocity of air flow in drying chamber increases. So the moisture will quickly remove from the green peas. it can observed that the velocity of flow at initial without draft fan was 1m/s. after the introduction of the fan at inlet with low speed velocity of air in the system is increased to 1.3m/s. as the draft fan speed at inlet increased to medium and high velocity increased to 1.5m/s and 1.9m/s respectively. It can observed that as the velocity increases more amount of moisture evaporated from the green peas. Which increased the drying rate and reduce drying time.

Draft fan at inlet will produce a swirl motion to the drying chamber. swirl motion helps to circulate the air throughout the drying chamber properly.so hot air will comes in contact with each and every green peas present in the chamber. So more area of contact will produce, which will increase the heat transfer between air and green peas. So moisture removed from the product will increase, so the drying rate increase and drying time reduces.

For 50°C drying temperature, increase in drying rate by varying the speed of the forced draft can be visualize from the figure. Percentage increase from low draft speed to medium and high draft speed is about 12 and 22% respectively. The drying time also reduced. Drying time with low draft speed is observed as 390 minutes and that of with medium and high draft speed are 380,370 minutes respectively.

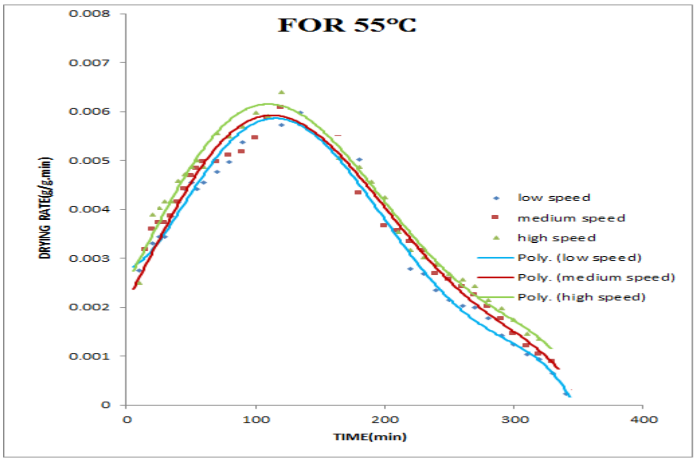

Fig.7 variation of drying rate for different draft speed for 55°C

Figure 7and Fig.8 shows the comparison of drying curve for different draft speed for the drying temperature of 55°C and 60°C. In both case it can observed that as draft speed increases the drying rate increased. For 55°C percentage of increase in drying rate by varying draft fan speed from low to medium and high speed are 8 and 18% respectively. In this case the time for complete drying reduced by increasing the draft fan speed from low to medium and high are 350, 340,330 minutes. It is again proves that the drying rate will increase as the drying temperature increases. It is clear that the drying rate is high for 55°C than 50°C.The percentage increase in the drying rate by varying draft speed from low to medium and high are 9.3 and 26% respectively. As a result drying time reduced from 300 minutes to 290 and 280 minutes.

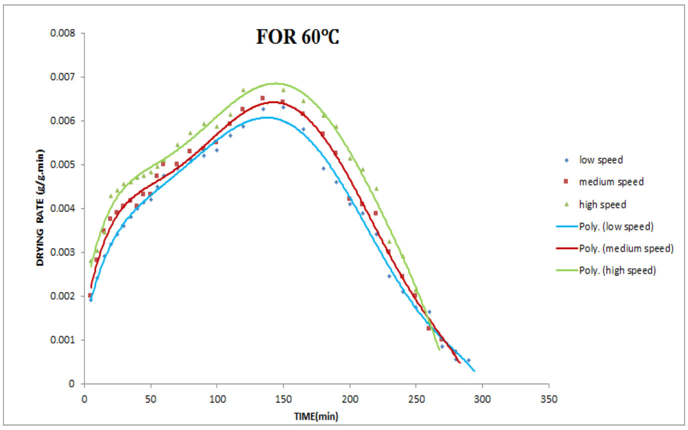

Fig 8: variation of drying rate for different draft speed for 60°C

4. CONCLUSIONS

Drying experiment on heat pump assisted circular dyer is carried out. Green peas is used as drying product. Experiment is conducted with three different drying temperature of 50°C,55°C and 60°C. As increasing the drying temperature drying rate is significantly increased. By increasing the temperature from 50°C to 60°C the drying rate increased to 44% and drying time reduced to 21% minutes. By comparing the result with that of a rectangular drying chamber of same volume flow rate it is concluded that drying rate is increased in each drying temperature and drying time reduced. The percentage increase in drying rate at 50 °C, 55°C and 60°C are 13%, 18%, 28% respectively. i.e. by changing the geometry to circular cross section increase in the drying rate is in the range of 13-28%. Significantly drying time also will reduces.

By providing an additional forced draft at inlet with different speed a velocity increase and a swirl effect is created. It positively influenced on the drying rate and drying time.by comparing drying rate in the case of with and without forced draft, it can see that dying rate is increased in the presence forced draft. The percentage increase in the drying rate for three drying temperature of 50°C, 55°C and 60°C with low speed draft is 16%, 15.2% and 14.8% respectively.

Experiment is conducted with three different draft speed for each drying temperature. It can see that in each case the drying rate is increased as increasing the speed of the forced draft. For 50°C the percentage increase in the drying rate is 12% and 22% as increasing the speed from low to medium and high speed. For 55°C percentage increase in drying rate with increase in 8% and 18% with increase in increasing the low speed to medium and high speed. For 60°C corresponding increase in drying rate is 9.3 and 26%.

It concluded that by changing the geometry from rectangular to circular and by providing a forced draft with at inlet will gives very high drying rate and less drying time for complete drying.

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