# Experimental Investigation of a Heat Pump Assisted Fluidized Bed Dryer

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## Abstract

The drying or dehydration is the controlled heating of food products to evaporate quantified amount of moisture that is originally present in it. Drying of food products is essential to enhance the shelf life of the product without quality losses over an extended period of time. It is an energy intensive process. The fluidized bed dryer with heat pump is one of the efficient method to reduce the energy. This project presents the design of fluidized bed dryer with heat pump. Drying was carried out in three different temperatures 50, 55 and 60°C. Comparisons of all three cases were made and it was found that inlet air temperature is the main parameter that affect the drying time. The drying time is decreases as the inlet temperature increases.
**Keywords- Heat Pump, Fluidized Bed Dryer, Drying Time, Relative Humidity, Drying Curve**

## I. INTRODUCTION

Drying by dehumidification refers to a process in which moisture is removed from a solid using heat as energy input. The mechanism of drying is a complex phenomenon involving combined heat and mass transfer. It is apparent that drying itself is an energy-intensive process because the latent heat is supplied to the material to evaporate the moisture.

R.E. Bahu (1991) studied energy consumption in drying and reported that industrial dryers consume on the average about 12% of the total energy used in manufacturing processes. In manufacturing processes where drying is required, the cost of drying can approach to 60%-70% of the total cost.

K. J. Chua, S. K. Chou, J. C. Ho, and M. N. A. Hawlader (2002) studied about the recent trends in heat pump dryers. Since drying is an energy intensive process, much attention has been given to the development of energy-efficient drying process. Heat pump-assisted drying is an energy efficient process because the heat is recoverable. In a conventional hot air dryer, substantial heat energy loss is inevitable in the process because air at relatively high temperature is vented off from the dryer. If the dryer is equipped with a heat pump, the exhaust energy of the dryer will be recycled.

Tai et al. (1982a, 1982b) Test of a R-114 heat pump dehumidification system was carried out. The heat pump coefficient of performance was plotted against the evaporating to condensing temperature lift, for several air bypass ratios and air velocities. Coefficients of performance in excess of 3 were attained with the experimental apparatus.

Adapa et al. (2002a, 2002b) have made a thorough study of a heat pump assisted drying of specialty crops. A specific moisture extraction rate (SMER) between 0.5 and 1.02 kg.kW-1.h-1 was achieved when chopped alfalfa was dried in a cabinet dryer in batches. Their simulation model and experimental work pointed to a preference of continuous bed drying over batch drying.

Ozbeyet .et al (2005) done research work on various type of dryers and found that, like other types of conventional convective drying processes, fluidized bed drying is a very energy intensive process in industry. The efficiency of a conventional drying system is usually low, depending on the inlet air temperature and other conditions. It is, therefore, desirable to improve the efficiency of the drying process. Fluidized drying of granular products of solids can be either batch wise or continuous. Batch operation is preferred for small scale production and for heat sensitive materials. Compared with other drying techniques, fluidized bed drying According to Murthy and Joshi (2007) has been made to study the dehydration of aonla fruits. Aonla fruits, being highly perishable, cannot be kept for long periods. Aonla contains a very high amount of vitamin C, which is highly volatile and susceptible to heat. Sun drying required the longest period of drying 660 min (11 hrs), while the shortest time of drying is with fluidized bed drying at 80 °C with 115 m/min air velocity 120 min (2 hrs). The results indicate that there is great loss of most of the ascorbic acid in the aonla slices. The retention of ascorbic acid in the samples dried in fluidized bed drying is greater compared to those dried under sun and hot air tray. Offers many advantages.

Jingsheng et al. (2008) observed that Soybean seeds were contacted with silica gel in a fluidized bed, where mass transfer is driven by moisture concentration gradient. It has the advantage of well-mixing the solid adsorbent (silica gel) with the material being dried (soybean seeds) in fluidization state, and thus the dried seeds quality could be improved since they are in a uniform environment of low humidity.

Thakur and Gupta (2007) reported that the experimental investigations were carried for the determination of suitable rest duration and the stage; at which resting will provide better redistribution of internal moisture in paddy grains subjected to fluidized bed drying. Incipient velocity was evaluated considering the drying conditions and the characteristics of the high moisture paddy. Intervening rest duration between first and second stage of drying, enhanced drying rate, reduced energy consumption and improved head rice yield. Energy requirement can be significantly saved (9–58 %) by providing rest durations (30–120 min) in comparison to the continuous drying.

Palancz.et al (1983) had proposed a mathematical model for continuous fluidized bed drying based on the two-phase theory of fluidization. According to this theory, the fluidized bed is divided into two phases, a bubble phase and an emulsion phase, which consists of gas and solid particles. Thus, higher inlet temperatures of drying air can be used which lead to shorter drying times. The enthalpy and the entropy of drying air also increase leading to higher energy efficiency. But increasing inlet air temperature should be limited to obtain good quality dried material.

## II. MATERIALS AND METHODS

### A. Experimental Setup

Experimental setup consists of a dehumidifier unit, a heater, fluidized bed dryer and a blower. Incoming air is dehumidified by cooling it below the dew point temperature in the evaporator. Then the condenser itself is used to preheat the air which is further heated by the heater to the required temperature. Dehumidified, heated air enters the drying chamber. Blower forces the air through the network. The heated dehumidified air after passing through the food particles inside the drying chamber recirculated back to the inlet of the heat pump. Following figure illustrates the experimental setup.

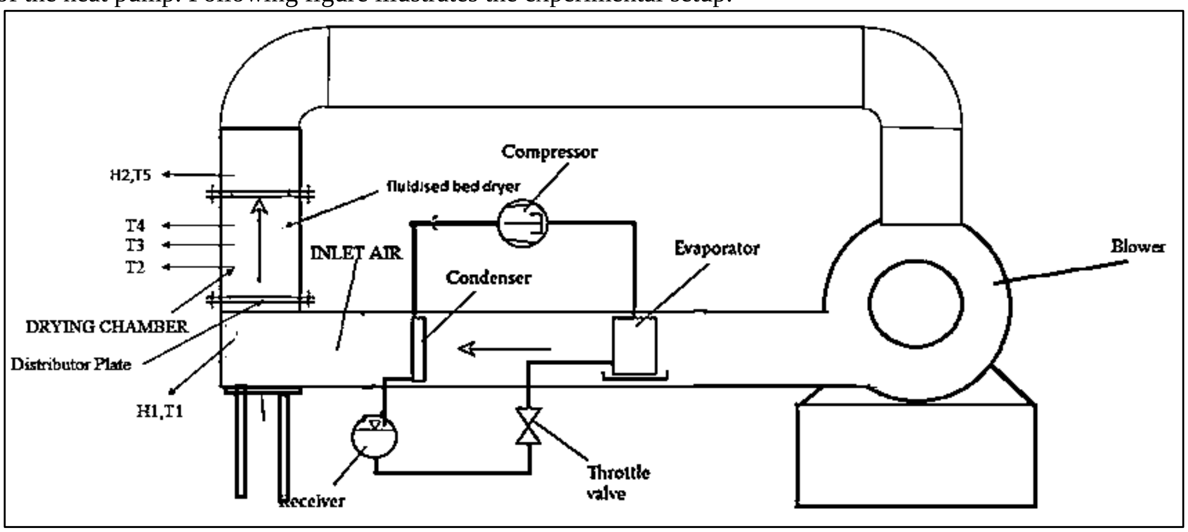


Fig. 1: Schematic diagram of Fluidized bed dryer with heat pump dehumidifier

### B. Details of components used

– Heat Pump

*1) Dehumidifier Components Design*

Assuming drying process starts from the atmospheric air at temperature of 30°C and relative humidity of 72.5% and it is heated to 55°C at the inlet drying chamber. The heat pump fluid is R134a, taking the evaporating temperature is 10°C below the dew-point temperature, condensing temperature is 5°C above the inlet air temperature at dryer inlet and compression is isentropic and throttling is adiabatic.

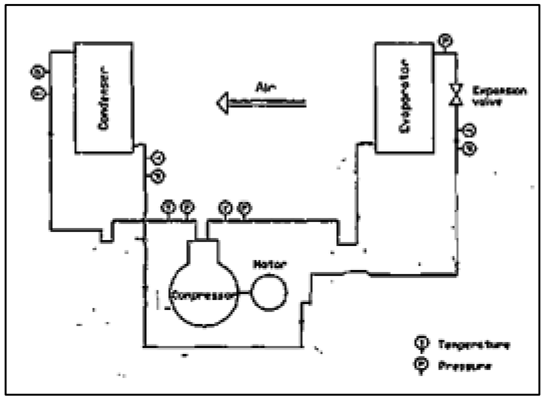


Fig. 2: Schematic Diagram of heat pump

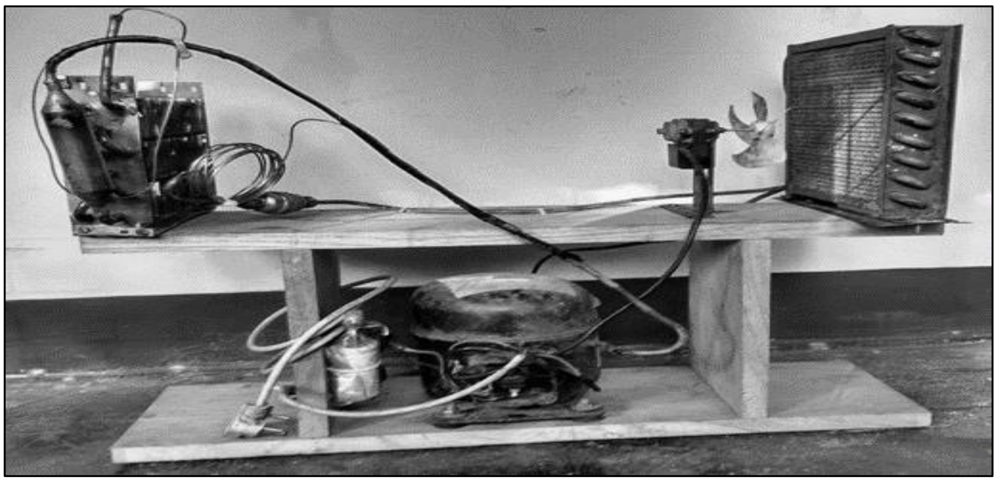

Fig. 3: Heat Pump Dehumidifier

With the above assumptions, the heat pump design calculation is done and is given below, from chart we get
$h_1$=593.71 kJ/kg , $h_2$=633.13 kJ/kg, $h_3$=$h_4$=487 kJ/kg
The evaporating capacity is calculated by,

$$Qeve= m_a \Delta h= 1.1715 \text{ kW} \quad (1)$$

The refrigerant mass flow rate is determined by

$$m_r = Q_{eve} /(h_1-h_4) =0.01098 \text{ kg/s} \quad (2)$$

The compressor work and the condensing capacity are determined as

$$W = m_r(h_2-h_3) \quad =0.4326 \text{ kW} \quad (3)$$

$$Q_{con} = mr(h_2-h_3) \quad =1.6042 \text{ kW} \quad (4)$$

The coefficient of performance of the heat pump

$$OP=3.708 \quad (5)$$

*2) Air Heater*

It consists of a heating coil of power 1200W. The temperature is controlled by a thermostat.

*3) Drying Chamber*

The particles to be dried were placed inside the chamber on the top of the distributor plate and drying air is feed from the bottom with the help of a blower. The drying chamber is made with G.I. sheet the temperature along the drying chamber is measured with the help of the thermometer.

*4) Orifice Plate*

An orifice plate is manufactured with the dimensions as shown in the figure below. It is used to measure the air flow rate.

*5) Pressure Measurement*

The refrigerant pressures were measured using Bourdon-tube-type pressure gauges. Refrigerant pressure measurement points were located, at the inlet and outlet of the compressor, condenser and evaporator, and the expansion valve. The pressure access valves were brazed into the piping and were connected by flexible hose to the high or low pressure valve stations. The pressure at orifice meter is measured using u tube manometer.

### *C. Experimental Procedure*

The air from the drying chamber recirculated to the drying chamber with the help of the blower. The air flow rate is controlled with the help of the valve. It first pass through the evaporating coil were it dehumidified and pass to condenser were it heated up. The addition heat required is given with the help of heater and it is controlled by thermostat (50, 55 or 60$^0$C). The dehumidified, and heated air pass to the drying chamber. All the required data are taken with the help of sensors at equal interval of time.


Fig. 4: Experimental Set up

## III. RESULTS AND DISCUSSION

The air flow through the drying chamber and heat pump system is at constant velocity ie, the minimum fluidization velocity (the minimum velocity that required to fluidize the particle inside the drying chamber). For drying experiment three different cases are considered ie, 50, 55 and 60$^0$C. The inlet velocity can be controlled with the help of the valve. And the flow rate is measured with the help of the orifice meter and the drying curve were given below.

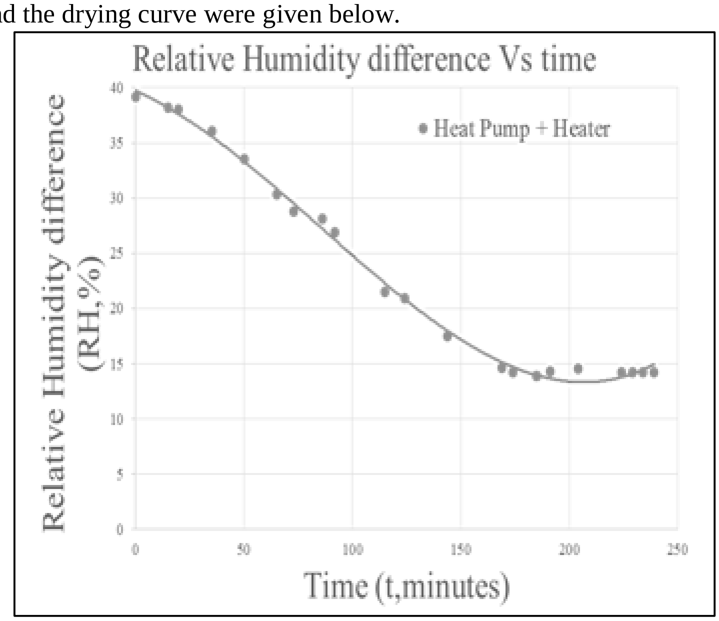


Fig. 4: Drying curve for 50$^0$C

Figure 4 shows the drying curve for $50^0$C. Initial relative humidity difference for $50^0$C is 40% and it became a constant after 190 minutes. Drying time for this case was 3 hours and 10 minutes. During the first stage humidity difference drops at a faster rate and finally become a constant.

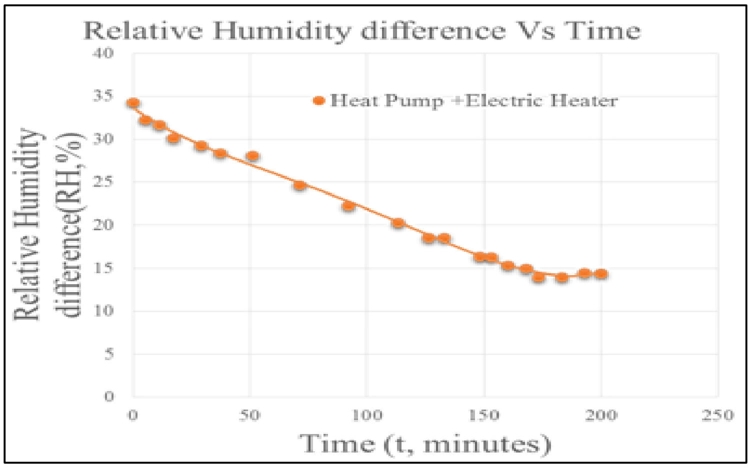


Fig. 5: Drying curve for $55^0$C

Figure 5 shows the drying curve for $55^0$C. Initial relative humidity difference for this case was 34.9%, clearly less than $50^0$C. The humidity difference becomes a constant value from 173 minutes. Drying time required was 2 hour 53 minutes. From this it can be observed that the drying time reduced in comparison with $50^0$C.

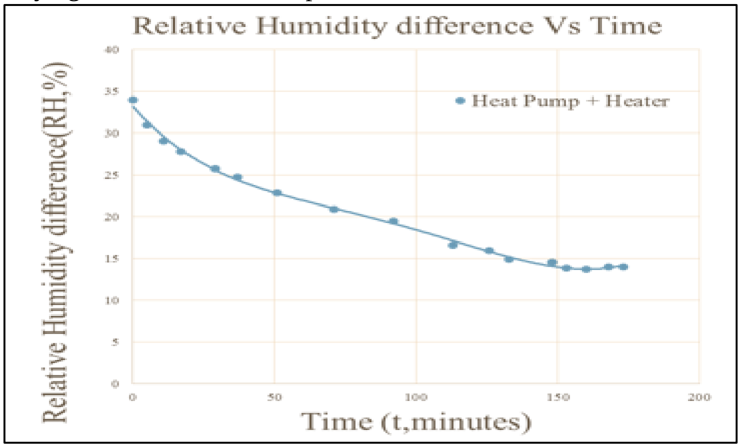


Fig. 6: Drying curve for $60^0$C

Figure 6 shows the drying curve for $60^0$C. Initial relative humidity difference was 34.1% and obviously lower than the other two. Drying time required was 152 minutes. So there is a considerable improvement in moisture removal rate and considerable saving in drying time while comparing with other two cases. Combinations of all the above cases are shown below

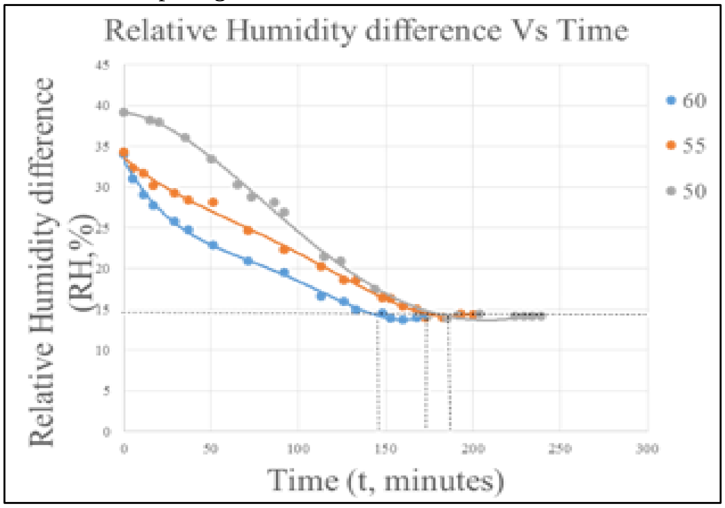


Fig. 7: Combination of 3 cases

The fig.7 shows the comparison of three cases. From the figure the influence of temperature on drying rate can be understood. Among different parameter the Temperature is the important process parameter that affect the drying rate. Increased temperature leads to increased moisture diffusivity and hence increased drying rate and decreased drying time. The nature of the material plays an important role in the choosing operating temperature.

## IV. CONCLUSIONS

An experimental study of a heat pump dehumidifier assisted fluidized bed dryer is conducted. Green peas drying process was carried out at three different temperatures (50, 55 & $60^0$C). During the experiment all the parameters such as temperatures along the cabinet, humidity, and air velocity are measured. Drying time is decreased significantly with increase in drying temperature. Drying rate also increases with temperature. Case 3, ie, $60^0$C, requires less drying time and shows highest drying rate. The maximum inlet temperature is depends on the properties of the product to be dried.

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