Microcontroller based optimized controller for fruit drying

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Abstract : Fruits are a seasonal crop and get spoiled quickly, They are dried to preserve them for a long period. The natural drying process requires more time. The investment on space requirement and infrastructure is large, and cannot be afforded by a middle class farmer. Therefore there is a need for a comparatively small unit with reduced drying time, which can be afforded by a middle class farmer.

A controlled environment suitable for fruit (grape) drying is simulated within a closed chamber and is a three step process. Firstly, the infrared light is used to internally heat the preheated fruit to speedily remove the water content inside the fruit for fast drying. Secondly, hot air of a specified temperature is blown inside the chamber to maintain the humidity below a specified level and exhaust the humid air of the chamber. Thirdly, the microcontroller idles disconnecting the power to the chamber after the weight of the fruits (grapes) is reduced to a known value of its original weight. This activates a buzzer for duration of ten seconds to indicate the end of the drying process

Key words : CFM (Cubic Feet per Minute), CMM (Cubic Meter per Minute), DBT (Dry bulb Temperature), IR (Infrared), RPM (Revolution per minute)

I. INTRODUCTION

The uneven population and uneven production of fruits of different kinds in the world demand the transportation of fruit from the food production areas to the fruit required areas. This requires a proper preservation of fruit during transportation, as the transportation period is always greater than the natural life of the fruit. To avoid fruit damage fresh fruits are converted to dry fruits.

2. PRESENT SITUATION

Natural Drying: This process is carried out manually and does not have any controls. A strict monitoring of every process is required to ensure the quality of the product. However, the drying stage, which is the longest and most important process, is left uncontrolled. This leads to inconsistency in the product, leading to economic losses.

a) The area required to dry the fruit is quite large, leading to mis-utilization of valuable agriculture land.

b) Fruits are not dried uniformly.

c) Drying is not possible in a humid environment.

d) The exposure of the product to the open air a long duration can be considered risky due to various factors like birds eating fruits / dust from the external environment.

After going through the various details of the process and considering all the factors above, we felt that the automation of the fruit drying process is the need of the hour. This will ensure.

a) Drying even in poor weather conditions because of an enclosed chamber

b) Accurate control over the drying process due to a closed loop control system.

c) Reduced drying time due to higher temperatures and the penetration power of infrared rays.

d) Compact drying chamber due to the confinement of heat energy.

3. IDENTIFICATION AND ROLE OF PROCESS VARIABLES:

a) A good quality fruit should preserve its original taste without leading to caramelization (Sugar Burning) and reduction in nutritional value.

b) The quality and color of the dried fruit depends upon the technique used for the drying process.

c) The drying rate also affects the colour of the dried fruit.

d) The initial drying of the fruit can be done at a higher temperature till it reaches 60% of the original weight, and later the temperature can be reduced to avoid caramelization.

e) Dried fruit should not contain more moisture as this leads to deterioration in storage.

f) The variables, which play an important role in the fruit drying process, are as follows.

i) Moisture contents of the fruit.

ii) Drying temperature.

iii) Rate of drying.

4. IDENTIFICATION AND CONTROL OF VARIABLES:

The functional requirement of the system is to dry the fruit, measure the moisture level of the fruit, and control the drying temperature and the rate of drying [1].

The moisture contents of a substance are expressed in terms of either Moisture Contents on Wet Basis (MCWB) or Moisture Contents on Dry Basis (MCDB)

$$MCWB = (W_i - W_f) / W_i \quad (1)$$

$$MCDB = (W_i - W_f) / W_f \quad (2)$$

Where W_i = Initial weight, W_f = Final weight

The change in moisture level can be calculated by measuring initial and final weight.

The drying of fruit is done by creating a moisture gradient within and outside the product; the higher the gradient the faster is the rate of drying. This can be achieved by drying fruit with a continuous flow of hot air.

a) The sensed parameters are
   i) Temperature near fruit
   ii) Humidity inside chamber

b) Thus the control variables of the system are
   i) Infrared radiation.
   ii) CFM of hot air blower

c) They can be controlled by regulating by
   i) Heater control by integral cycle control as the time constant of the heater is high.
   ii) Infrared control by extinction angle control.

d) CFM control by extinction angle control.

e) Microcontroller based logic.

The overall physical diagram of the fruit drying system is shown in Fig.1.

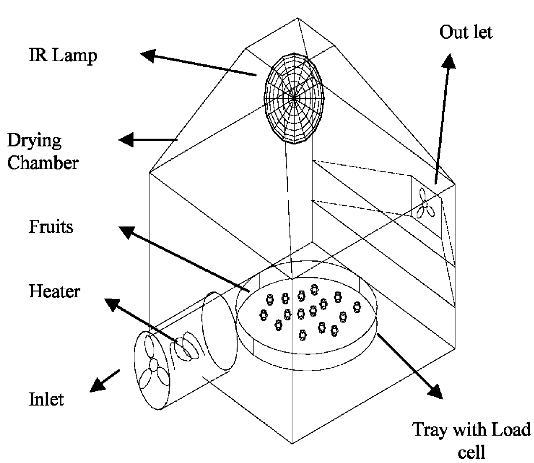

Fig. 1: Typical grape Drying System.

5. DRYING PROCESS

The drying refers [2]-[4] to the removal of liquid generally water from fruits. The phases of drying are shown in Fig. 2

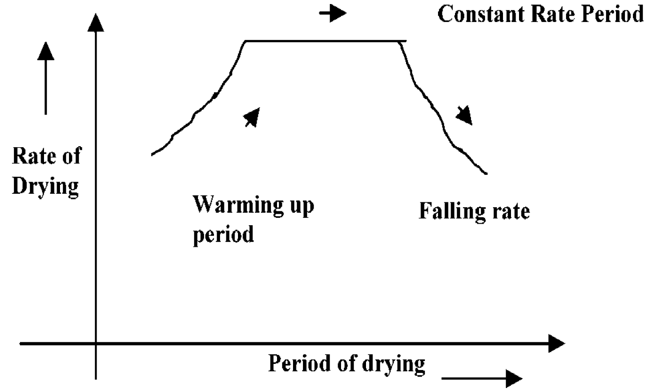

Fig 2 : Drying Phases of a fruit.

The process of drying a wet object involves the transfer of heat from the drying air to the liquid in order to cause evaporation, and to promote the movement both of internal moisture in the solid and of the evaporated liquid from the surface of the solid. These actions occur simultaneously and the physical factors controlling their rates determine the rate at which the solid can be dried. The drying is thus concerned with

a) The internal movement of moisture : The internal movement is obviously a complex process which will vary with the nature, size and the moisture content of the material to be dried. In general, the maximum moisture gradient that can be tolerated without causing damage to the material or producing surface hardening determines the rate at which internal moisture can be removed during drying of a material. This is controlled by setting up external drying conditions that have been found in practice.

b) The external evaporation of moisture from the surface of a solid : The external variables that appreciably affect the drying rate are air temperature, relative humidity, velocity, degree of turbulence , size of material and method of contact.

When the air temperature exceeds the temperature of the water surface, heat will flow from the air stream to the water by a diffusion rate proportional to the temperature gradient through the laminar film, as per the following fundamental equations for mass and heat transfers

$$m = k (p_s - p_p)$$

$$Q = h (T_{DBT} - T_w)$$

Where

m = (mass evaporating) in Kg/m^2 - sec .

k_δ = evaporation coefficient in Kg/m^2 - sec

p_s = Saturation vapor pressure at the temperature of the water surface

p_p = partial pressure of the vapour in the main air stream.

Q = (heat flow) in watt

h = Heat transfer coefficients

T_{DBT} = DBT of air

T_w = water surface temperature

c) Critical Moisture Content

The moisture content at which the constant rate period comes to an end is referred to as the Critical Moisture Content of the material. This varies considerably depending on the variety of the fruit and is of great importance in problems of drying; i.e. if a material is to be dried to a moisture content equal to or greater than the critical moisture content, the whole of the drying process (except the warming) consists of drying under constant rate conditions. On the other hand, when drying material, which already has a moisture content below the critical value, the whole of the drying process falls within the falling rate period.

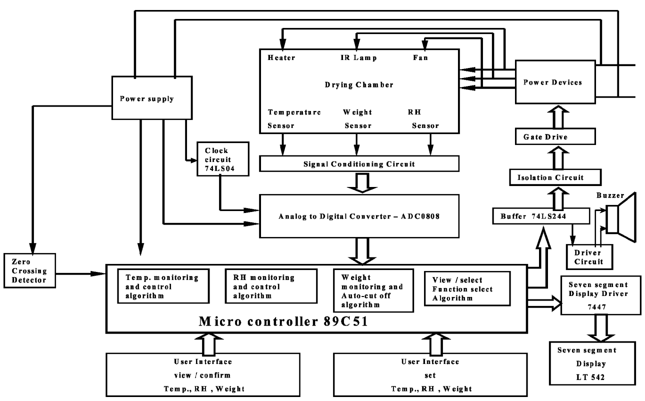

Fig. 3 : Block Diagram of Microcontroller based Fruit Drying System

d) Equilibrium Moisture Content

When a dried material is exposed to a given atmosphere over an extended period, it will tend to attain a constant moisture content referred to as equilibrium moisture content. The equilibrium moisture content will increase with an increase in the RH (Relative Humidity) of air for a given temperature over a range of relative humidity .The moisture content of material equilibrium is known as Bound Moisture and any excess is referred to as free moisture. Equilibrium moisture content is of great importance in the storage of foodstuffs, which in the dried state and normal atmospheric conditions are very hygroscopic. This means that the food when dried must be stored under controlled conditions in order to ensure a long life and in many cases entails storage in sealed containers. When a dried fruit has to be stored under normal atmospheric conditions, it is wasteful of heat to dry the material below the equilibrium moisture content corresponding to the air conditions of ultimate storage.

e) Maximum Temperature for Drying:

Both over drying and under drying are harmful [5], [6] for agricultural products. Over drying causes discoloration due to caramelization and reduction in nutritional value. On the other hand, under drying or slow drying results in deterioration of food quality due to fungal and bacterial action.

High temperature can be used only in the beginning of the drying process; in the first phase (60% of the total drying time) the drying rate is faster. While in the second phase (40% of the total drying time) the drying rate is slowed down due to a thick collapsed outer surface and IR heat plays a very important role in penetrating the heat and removing the moisture in the second phase.

f) Minimum Relative humidity for drying:

The relative humidity for drying should be maintained depending on the final humidity content of the dried fruit.

The dependence of drying time on temperature is much stronger than the dependence on air velocity & relative humidity. It is advantageous to increase the drying air temperature for increasing the drying rates instead of increasing air velocity or decreasing the humidity of drying air. As there is a limit on the maximum drying temperature, increasing airflow is also important

g) Final Moisture content in Dried Fruit:

For the storage of dried fruit at ambient conditions, the final moisture content is very important, as higher moisture in dried fruit can lead to fungal infection. If the moisture is less it can cause a hardening of the skin of the dried fruit due to which the texture of the dried fruit becomes rough.

6. IMPLEMENTATION

Data Acquisition & Control Unit:

The data acquisition and control circuit consist of following sections. Refer Fig. 3

a) Interrupt generation Logic unit: It generates an interrupt pulse to the microcontroller at every natural zero of the AC power supply taken from the synchronizing transformer. We are using pin INT0 of the micro controller to generate interrupt to it .for every zero crossing detection from the AC supply to generate correct pulses synchronously.

b) Temperature Sensing: For this we have used integrated circuit AD590. It has a resolution of 1 μA / K.

c) Humidity Sensing: We use a polymer humidity sensor BTH make P-HS-220 which has a resolution of 33 mV / % RH with a range of up to 95 % RH for a supply voltage of 5 V. The output is directly interfaced to ADC0808 through channel 1 (CH1).

d) Weight Sensing: the load cell does the weight sensing. The excitation voltage is given as 15 V. The output is fed to a differential amplifier through the non-inverting buffer.

e) ADC: The ADC0808 is a successive approximation 8 bit, 8 channel A to D converter with a conversion time of 110 μSec. The analog input is fed to channels CH0, CH1 and CH2 .The reference voltage is stepped down to 4.7 V by a zener diode to have constancy during fluctuation.

f) Microcontroller 89C51: It is the main control of the whole system. The IR lamp and Fan area controlled by extinction angle control through pins P2.0 and P2.1; the Heater is controlled by Integral cycle control through pin P2.5, the display unit is connected through the port P0. The port P1 is used for data communication ADC 0808. The control signals to ADC 0808 are fed through the pins P3.4 (EOC), P3.5 (A), P3.6 (B), P3.7 (OE), P2.7 (SOC & ALE). The interrupts zero crossing detection is fed to INT0 and the display select switch interrupt to INT1. The clock frequency is of 11.0592 MHz. The display status LEDs are connected from pin P2.3, P2.4, P2.5 through buffer 74LS244, and the buzzer is connected to pin P2.6 through buffer 74LS244.

g) Display: We have used two common anode seven-segment displays LTS542. They are connected to port zero of 89C51 through the BCD to seven segment decoder 74LS47.

h) MOSFET Gate Drive Circuit - MCT6E is a dual opto isolator and OPAMP - OP07 are used for signal conditioning.

i) Gate Drive for TRIAC: Here the TRIAC BT139 controls the heater load, which is of 500 W. For driving the triac we use an opto-isolated TRIAC trigger IC MOC 3010

j) Power control Unit: This is done using MOSFET (IRF 840 / 830) for controlling the IR lamp and fan by extinction angle control, and TRIAC (BT139) for controlling the heater by integral cycle control. Since the MOSFET cannot work on an AC supply, it is converted into DC by using a bridge with its output shorted by the MOSFET; at the supply side of the bridge the load is connected. The snubber of the MOSFET is used to reduce the switching losses in the device.

k) The overall operation of the circuit: When the circuit is switched on, the IR lamp and the fan go through a soft start procedure by which they are turned in a very slow manner. When they attain the full power, the micro controller starts getting data from the data acquisition unit through the ADC. It scans the temperature, humidity and weight and compares it with the set point. Here we have implemented integral control, by which if the measured variable is below the set point, it increases the extinction angle at the rate of 5 degree / sec. If the measured variable is above the set point, it decreases the extinction angle at the rate of 5 degree / Sec. If the measured variable is equal to the set point it remains in the same extinction angle. The integral control is implemented to control the IR lamp (by sensing temperature) and the fan (by sensing humidity). The heater is controlled in an open loop manner. It is operated at 33.33 % duty cycle i.e. one cycle on and two cycles off. If the weight goes below 30 % of the initial weight, the micro controller enters the idle mode after switching OFF everything and beeping for 10 Sec. Here a single timer is used for controlling two devices, the fan and IR lamp, by programming logic.

l) stimation of heat required for drying 1 Kg. of fruit:

The rate of drying of fruit with an initial moisture content above 82 % [7] during the early drying period is a function of external drying parameters

Air Temperature
Air humidity
Air velocity

To calculate the amount of heat required to dry a given quantity of fruit for storage, the following equation is used [8] .

$$W_1 (100 - M_1) = W_2 (100 - M_2) \quad (3)$$

Where W_1 is weight in Kg of fresh fruit.

M_1 is % initial moisture content in fresh fruit

W_2 is weight in Kg of dried fruit.

M_2 is % final moisture content in dried fruit.

m) To calculate the Energy required to circulate hot air into the chamber:

The removal of water from a surface requires an amount of heat equal to the latent heat of the evaporation of water, plus a current of air moving past the surface to carry away the water vapor produced.

$$m_v * h_{fg} = (T_f - T_i) * m_a * C_p \quad (4)$$

Where m_v mass of water evaporated

m_a mass of air circulated
h_{fg} latent heat of evaporation
C_p specific heat of air
T_f and T_i are the final and initial temperatures in ^{O}K
Using gas law

$$Va / m_v = (m_a / m_v) * RT / P \quad (5)$$

Where Va = volume of air required to be circulated in the chamber

m_v = Mass of water evaporated
m_a = Mass of air circulated .
R = Universal gas constant
T = Temperature in degree kelvin
P = Atmospheric pressure

The amount of heat energy required to circulate hot air to carry away the water vapour produced during the drying process is given by

$$P = m' * C_p * (T_f - T_i) \quad (6)$$

Where
P = Power required in Watts.
m' = CMM / v = is mass flow rate of air to be circulated.
C_p = specific heat of air at constant pressure
T_f = final temperature
T_i = Initial Temperature
v is the specific volume in m^3 / Kg

7. TEST RESULTS

Fig. 4 shows that the drying period decreases with an increase of temperature. The temperature to be maintained within the chamber depends on the initial contents of the fruits and the effect of temperature on the contents. The temperature is also dependent on the final desired contents in the fruit and the final humidity content that is required to be maintained.

We created a humidity gradient to remove the water content in the fruit. The variation was achieved by varying the fan speed. It was observed that the temperature gradient plays an important role in the initial period of the drying phase and the humidity gradient plays an important role in the later part of the drying phase to retain the original flavour of the fruit and to avoid caramelization.

Fruit Drying with varying Temperature (Weight. Versus Time)

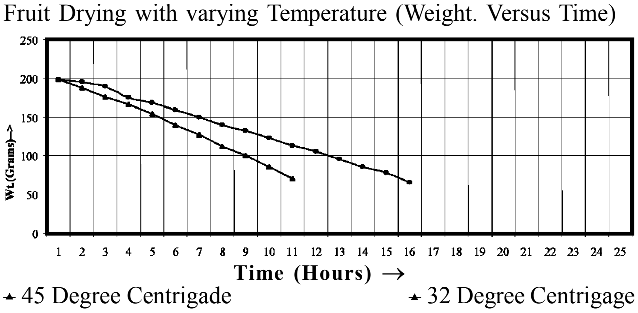

Fig. 4 The variation of the grape drying period with varying Temperature. The drying period decreases with an increase in temperature. The maximum drying temperature is a function of fruit property.

Fruit Drying with Varying Fan Speed (CFM) (Wt. Vs Time)

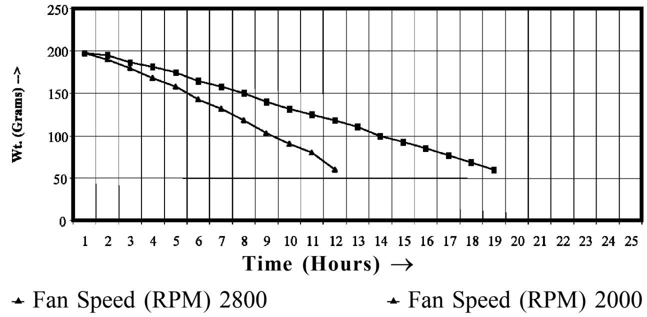

Fig. 5 shows the variation of the grape drying period with varying fan speed i.e RPM. It is observed that drying period is reduced with increasing fan speed (RPM) at constant temperature.

8. CONCLUSION

The system can be made more economical by using a tubular type of IR lamp, stacking the fruits in a multi layer, and using a drum type fan for circulating air. A smaller and less expensive PIC micro controller can replace the 89C51 microcontroller, ADC 0808.

To make it economically viable for farmers, an application specific integrated circuit by embedding the digital circuit into achip, can be produced on a large scale.

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