

## THIN-LAYER INFRARED RADIATION DRYING OF GINGER SLICES

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### ABSTRACT

*A laboratory scale infrared-convective dryer was developed and single layer drying of ginger slices was carried out at infrared power levels of 300, 400 and 500 W, drying air temperatures of 35, 40 and 45°C and inlet drying air velocities of 1, 2 and 3 m/s. The average effective moisture diffusivity varied from  $1.15 \times 10^{-10}$  to  $2.91 \times 10^{-10} \text{ m}^2/\text{s}$  and was significantly influenced by infrared power and air temperature. The colour values (L value) of infrared-convectively dried ginger ranged between 26.5 and 37.08. The rehydration ratio of dehydrated ginger slices was found to be in the range of 3.16 to 3.77.*

**KEY WORDS:** *Ginger, Infrared-convective dryer, rehydration ratio*

### INTRODUCTION

Ginger is one of the spices that is being cultivated in India for consumption as fresh vegetable and also in a dried form. Ginger is obtained from the rhizomes of *Zingiber officinale*. The ginger family is a tropical group, abundant in Indo-Malaysian region, consisting of more than 1200 plant species in 53 genera. India is the primary producer and consumer of ginger in the world. In India, it is most commonly found in Assam, Karnataka, Odisha, West Bengal, Meghalaya, Sikkim and Madhya Pradesh, with a production 655 thousand tones and over an area of 133 thousand hectares during 2013-14 (Anonymous, 2015). In Gujarat, during 2013-14, it is grown in an area of 4.40 thousand hectares with a production of 70.65 thousand tones (Anonymous,

2015). Cochin ginger is widely considered to be one of the finest in the world, commanding a premium price, because of its lemon-like flavour, low fiber content and high moisture content. In India, Ginger has numerous applications in the food, beverage and pharmaceutical industries. Fresh ginger is consumed as a vegetable. The dried products are the major form in which ginger is internationally traded. Dried ginger is used directly as a spice and also for the manufacture of products like ginger powder, ginger oil and ginger oleoresin.

Presently the processing of ginger was done in which rhizomes were dug up, cleaned of dirt and roots and boiled in a wide mouthed vessel, and then dried. After drying for few days, the rhizomes were steeped in a diluted lime water, sun dried and again

steeped in a stronger lime water and buried for fermentation. Later the rhizomes were dried and marketed. The major drawbacks of convection dryer are higher drying time, uneven drying and comparatively low capacity. Moreover, the increasing rate of fuel consumption in agriculture has made it necessary not only to save energy by intensifying the drying process, improving design etc. but also using different techniques for drying process to reduce drying time and increase product quality. The infrared drying offers many advantages over conventional drying, as the energy transferring to the product directly and allowing to reach the rapidly suitable temperature levels, which activates the fundamental drying mechanisms of the operation (decrease drying time), high energy efficiency, high quality finished products, uniform temperature in the product while drying and a reduced necessity for air flow across the product (Sharma *et al.*, 2005). Infrared drying has more advantages than conventional drying.

#### **MATERIALS AND METHODS**

A laboratory scale infrared-convective dryer was developed for the present study wherein infrared power, air temperature and air velocity could be varied within the experimental range. The drying of ginger slices was done under various combinations of these process parameters.

##### **Experimental dryer**

The infrared-convective dryer comprised of two components i.e. a drying chamber having a tube type infrared heater and a hot air supply unit. The provisions were made in the dryer so that the infrared radiation intensity as well as air temperature could be varied by regulating the voltage through variacs. The air velocity was regulated with the help of a damper placed in the air supply line

to the drying chamber. A schematic view of the experimental drier is shown in Figure 1.

The drying chamber of 400 x 300 x 300 mm was made from a plywood sheet of 8 mm thickness having a single door opening at the front. The inner sides of the chamber were covered with an aluminum foil. Two openings, one of 150 mm diameter and another of 150·150 mm were made in the two opposite short walls for entering and exiting of hot air. An infrared heater (tube type) of 1000 W having diameter of 18 mm and length of 300 mm was fitted on the top inside surface of the drying chambers. The output power of the heater could be varied by regulating the voltage through a variance. A sample tray of woven wire mesh having dimension of 300·200 mm was placed beneath the infrared heater.

The hot air supply unit was made of GI sheet having insulation of asbestos from inside. It was fitted with a finned type electrical heater of 1000 W and a axial flow blower (rated capacity 12.5 m<sup>3</sup>/min) forcing the ambient air into dryer through electrical heater. Temperature of the drying air could be regulated through a variac and the air velocity was adjusted through a damper valve in the air supply line. The air velocity inside the drying chamber was measured, close to tray, using a hot wire thermo anemometer which had the working range of 0.4–30 m/s.

##### **Experimental procedure**

Locally available ginger was used in the present study. The hand peeled gingers were cut, with a sharp stainless steel knife, into slices of thickness  $3 \pm 0.4$  mm. Three measurements were made on each slice for its thickness, using a vernier caliper and their average values were reported. The moisture content of the ginger

slices was measured by oven dry method (Ranganna, 2000) and was expressed as g water/g dry matter. The initial moisture content of the ginger sample was 3.57 g water/g dry matter approximately. The dryer was run idle for about 0.5 h to achieve a steady state in respect of pre-set experimental drying conditions before each drying run. About 100 g of ginger slices after weighing were uniformly spread on the tray. Preliminary trial of drying the ginger slices, at infrared power of 600 W at 1.0 m/s air velocity and 60–70°C air temperatures darkened the product. The drying experiments were, therefore, carried out at infrared power 300, 400 and 500 W; lower drying air temperatures 35, 40 and 45°C and air velocities of 1.0, 2.0 and 3.0 m/s. The mass of the ginger slices was measured by a digital electronic balance throughout the drying experiment at an interval of 2 min for first half an hour and 10 min subsequently thereafter. For measuring the mass of the sample at any time during experimentation, sample along with tray was taken out of the drying chamber and weighed on

the digital top pan balance and placed back into the chamber. The digital top pan balance (2000 ± 0.01 g) was kept near to the drying unit and weight measurement process took about 10 s time. Drying time was defined as time required to reduce the moisture content of the product to 8% (dry basis), i.e. the average moisture content of a commercial dry product.

#### **Effective moisture diffusivity**

In drying, diffusivity is used to indicate the flow of moisture within the material. In the falling rate period of drying, moisture transfer occurs mainly by molecular diffusion. Moisture diffusivity of the foods is influenced mainly by moisture content and also by their temperature. Ginger slices were considered as infinite slab because the thickness of the slice (3 mm) was much less than its diameter (about 64 mm). The moisture diffusivity for infinite slab was, therefore, calculated by the following solution (Eq. (1)) proposed by Crank (1975) considering assumptions mentioned hereunder:

1. Moisture is initially uniformly distributed throughout the mass of a sample.
2. Mass transfer is symmetric with respect to the centre.
3. Surface moisture content of the sample instantaneously reaches equilibrium with the condition of surrounding air.
- 4 Resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample.
5. Mass transfer is by diffusion only.
6. Diffusion coefficient is constant and shrinkage is negligible.

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{8}{\pi^2} \exp\left(-\pi^2 \frac{D_{eff} t}{L^2}\right) \quad (1)$$

Where,

$D_{eff}$  is the effective diffusivity,  $m^2/s$ ,

$L$  is the thickness (here half) of slab, 0.0015 m,

$M_e$  is the equilibrium moisture content, g water/g dry matter,

$M_o$  is the initial moisture content, g water/g dry matter,

$M_t$  is the average moisture content at time ( $t$ ), g water/g dry matter and  $t$  is the time, s.

Eq. (1) is evaluated numerically for Fourier number,  $F_0 = \frac{D_{eff}t}{L^2}$ , for diffusion and can be rewritten as

$$MR = \frac{8}{\pi^2} \exp(-\pi^2 F_0) \quad (2)$$

$$F_0 = -0.101 \ln MR - 0.012 \quad (3)$$

The effective moisture diffusivity ( $D_{eff}$ ) was calculated using Eq. (4) as

$$D_{eff} = \frac{F_0}{\left(\frac{t}{L^2}\right)} \quad (4)$$

### Colour measurement

The colour of ginger rhizomes was determined by using Hunter Lab. The colour was measured in terms of Hunter L, a, and b values. Hunter L represents the lightness or darkness of the object and it is measured on a scale of 0 to 100. L values of 100 represent white and L of 0 represents black. Hunter a values represents redness or greenness. A Hunter b value represents yellowness or blueness. The samples were ground using a grinder and whole samples were used for color measurements. For each sample, three replications of the color test were performed.

### Rehydration ratio

Rehydration assays for the dehydrated ginger slices were carried out by immersing the dried samples in water. Approximately 10 g dried sample was put in 50 ml of distilled water in a 100 ml beaker kept in a hot water bath to maintain a water temperature of 35°C for 5 h (Kim and Toledo, 1987). The water of the beaker was drained and sample removed. The surface moisture from the sample was removed by wiping off the surface with a tissue paper gently. The sample was weighed again. The rehydration ratio was estimated from the ratio of weight of rehydrated sample to weight of dried sample.

### Optimization of process parameters

Optimization was done by response surface methodology (RSM), since this is useful statistical technique for investigation of complex processes;

hence the process parameters for infrared-convective drying of ginger slices have been optimized using this technique. RSM is a collection of certain statistical techniques for designing experiments, building models, evaluating the effects of the factors and searching for optimal conditions for desirable responses.

## RESULTS AND DISCUSSION

The data collected on loss in the moisture content with elapsed time were analyzed to study the drying behavior of the product and also the effect of operational parameters on the drying characteristics was analyzed and presented here under.

### Effect of air temperature

The drying curves of ginger slices at air velocity of 1.0 m/s, infrared power of 300 W and air temperatures of 35, 40 and 45°C are shown in Figure 2. The drying curves are typical to ones for food stuffs, i.e. moisture content of ginger slices decreased exponentially with elapsed drying time. As the air temperature increased, other drying conditions being same, the drying curves became steeper indicating higher moisture removal rates thus, resulted into substantial decrease in drying time (t). At air velocity of 1.0 m/s and infrared power of 300 W, drying time for the ginger slices at air temperature of 35, 40 and 45°C were about 80, 60 and 50 min, respectively. Similar drying trends were observed at air velocities of 2 and 3 m/s at other infrared power levels.

### **Effect of infrared power**

Drying curves at air velocity of 1.0 m/s, air temperature of 35°C as a function of infrared power are shown in Figure 3. The drying time reduced dramatically with increase in infrared power. Masamura *et al.* (1988) and Kazuhiko and Chung (1995) also observed increased drying rates of food products with increasing power supply to infrared heater. The drying time to reduce the moisture content of ginger slice to about 0.08 g water/g dry matter at infrared power of 300, 400 and 500 W was about 80, 60 and 40 min, respectively. The vapour pressure is considered to be a function of both temperature and moisture content (Rati *et al.*, 1989). The increase in infrared power might have caused a rapid increase in the temperature at surface of product, resulting into an increase in the water vapor pressure inside the product and thus, in higher drying rates (Datta and Ni, 2002). A similar drying trend was observed at other air velocities of 2, 3 m/s; and air temperatures of 40 and 45°C.

### **Effect of air velocity**

The air velocity also influenced the drying time of the ginger slices as shown in Figure 4. At a given air temperature and infrared power, an increased in air velocity decreased the drying time i.e. increased the moisture removal rate. The drying time for the ginger slices at air velocity of 1.0 m/s, air temperature of 35°C and infrared power of 300 W was 80 min, which decreased to 70 min when air velocity was increased to 3 m/s, the other parameters being unchanged. The increased in air velocity accelerated the cooling effect, reducing the temperature at the surface of product thus the water vapor pressure or the moisture driving force. ANOVA carried out to see the effect of process variables on the drying time of ginger

slices revealed that air velocity (v), air temperature (T) and infrared power level (P) had a significant effect on the drying time at 1% level.

The drying time for ginger slices under various drying conditions is given in Table 1.

### **Effective moisture diffusivity**

The variation in moisture diffusivity with moisture content is a complex and system specific function. The effective moisture diffusivity (Deff) of a food material characterizes its intrinsic mass transport property of moisture which includes molecular diffusion, liquid diffusion, vapour diffusion, hydrodynamic flow and other possible mass transport mechanisms (Karthanos *et al.*, 1990). The effective moisture diffusivity, Deff, for ginger slices under various drying conditions was estimated from Eq. (4). A typical variation in Deff of ginger slices with moisture content at different temperatures levels at air velocity of 1.0 m/s and infrared power 300 W is shown in Figure 5. The effective moisture diffusivity varied from  $1.15 \times 10^{-10}$  to  $1.78 \times 10^{-10}$  m<sup>2</sup>/s with decreased in the moisture content at air velocity of 1.0 m/s and infrared power of 300 W. This value is much higher as compared to diffusivity of  $3.42 \times 10^{-9}$  for ginger during convective drying (Phoungchandang *et al.*, 2009). However, the moisture diffusivity was higher at any level of moisture content at higher infrared power level, resulting into shorter drying time. The moisture diffusivity of food material is affected by its moisture content, temperature as well as its composition and porosity (Abe and Afzal, 1997). This may indicated that as the moisture content decreased, the permeability to water vapour increased, as it provided more pore structure open. The temperature of the product would have risen rapidly in the initial stages of

drying due to more absorption of infrared heat. This increased the water vapour pressure inside the pores resulted into pressure induced opening of the pores. Sharma and Prasad (2001) also reported similar trend in the variation in the moisture diffusivity for garlic cloves.

#### **Colour measurement**

The colour values (L value) of infrared-convectively dried ginger ranged between 26.5 and 37.08 and was significantly influenced by infrared power, air temperature and air velocity.

#### **Rehydration ratio**

The rehydration ratio was considered as one of the important quality attribute for the dried slices in the present study. The rehydration ratio values of dried ginger slices were estimated as discussed in earlier sections, using standard procedure. It varied between 3.16 and 3.77, under different drying conditions.

#### **Optimization of process parameters**

The optimized values for process parameters i.e. infrared power, air velocity and air temperatures were 300 W, 2.93 m/s and 45°C for which the colour value (L- value) and rehydration ratio (RR) were 36.0 and 3.76, respectively.

#### **CONCLUSION**

The infrared convective drying of ginger slices exhibited drying to have taken place in falling drying rate period. The drying rate was significantly influenced by infrared power, air temperature and air velocity. The drying time decreased with the increased in air temperature, air velocity at all infrared power applied, however, it reduced with increased in infrared power. The effective moisture diffusivity increased with decreased in moisture content of ginger slices. The colour of ginger powder tended to become lighter with increased in

infrared power at a given air temperature air velocity. The ginger slices dried under infrared-convective conditions had good rehydration ratio. The optimized value for infrared power, air velocity and air temperature, during infrared-convective drying of ginger slices, were found to be 300W, 2.92 m/s and 45°C respectively. There is good scope of producing a good quality dried slices using infrared radiations.

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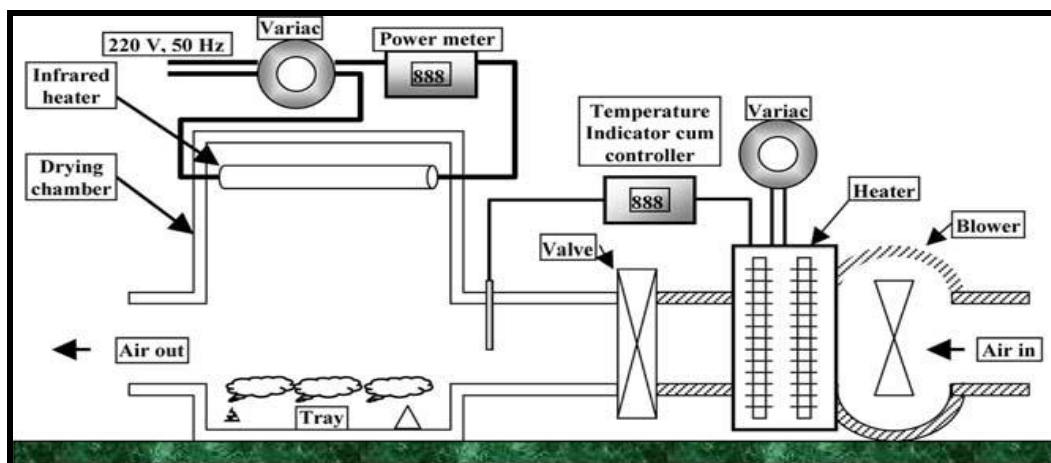
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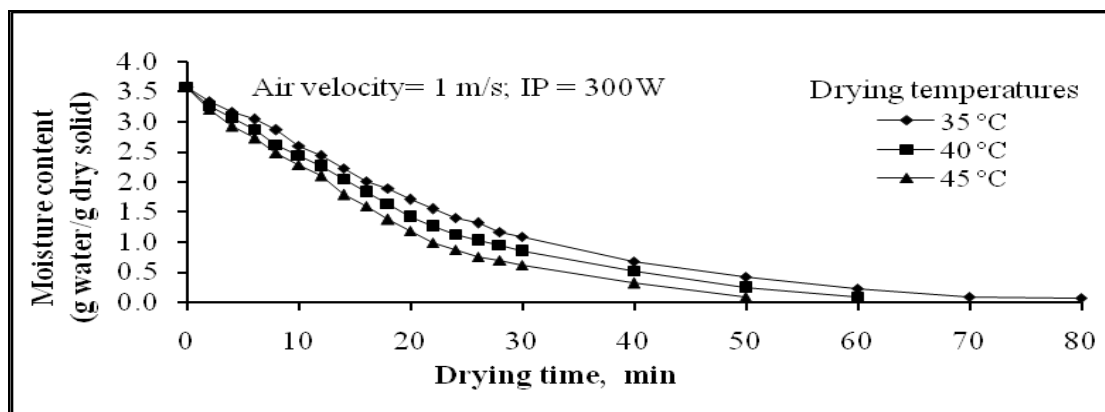
**Table 1: Drying time for ginger slices under various drying conditions**

| Treatment No. | Infrared Power (W) | Velocity (m/s) | Temperature (°C) | Drying Time (min) |
|---------------|--------------------|----------------|------------------|-------------------|
| 1             | 300                | 1              | 35               | 80                |
| 2             |                    |                | 40               | 60                |
| 3             |                    |                | 45               | 50                |
| 4             |                    | 2              | 35               | 70                |
| 5             |                    |                | 40               | 60                |
| 6             |                    |                | 45               | 60                |
| 7             |                    | 3              | 35               | 70                |
| 8             |                    |                | 40               | 60                |
| 9             |                    |                | 45               | 60                |
| 10            | 400                | 1              | 35               | 60                |
| 11            |                    |                | 40               | 50                |
| 12            |                    |                | 45               | 50                |
| 13            |                    | 2              | 35               | 60                |
| 14            |                    |                | 40               | 50                |
| 15            |                    |                | 45               | 50                |
| 16            |                    | 3              | 35               | 60                |
| 17            |                    |                | 40               | 50                |
| 18            |                    |                | 45               | 40                |
| 19            | 500                | 1              | 35               | 40                |
| 20            |                    |                | 40               | 40                |
| 21            |                    |                | 45               | 40                |
| 22            |                    | 2              | 35               | 40                |
| 23            |                    |                | 40               | 40                |
| 24            |                    |                | 45               | 40                |
| 25            |                    | 3              | 35               | 40                |
| 26            |                    |                | 40               | 40                |
| 27            |                    |                | 45               | 40                |

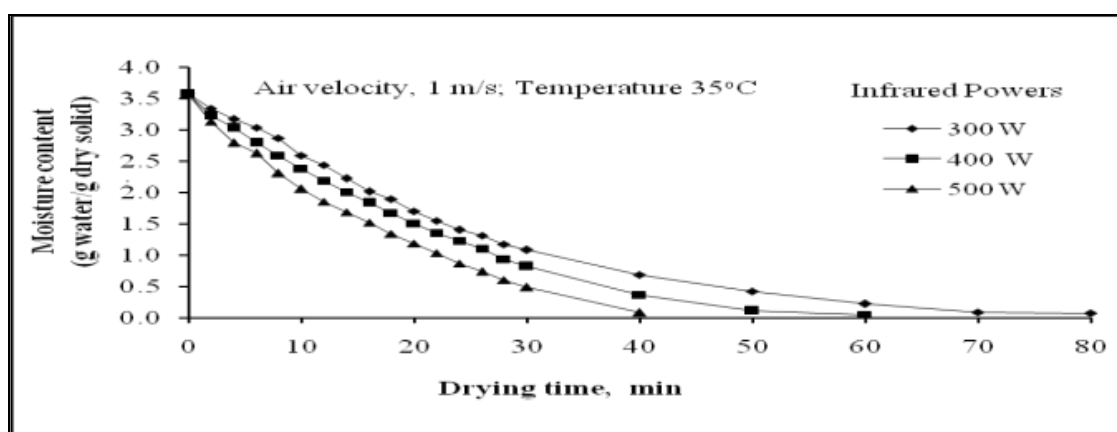


**Figure 1: Schematic view of experimental infrared drying setup.**

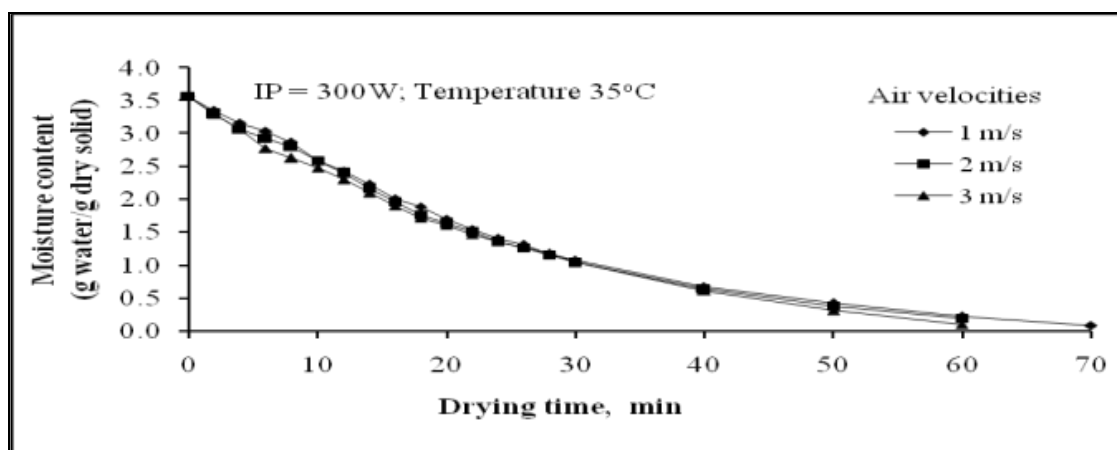




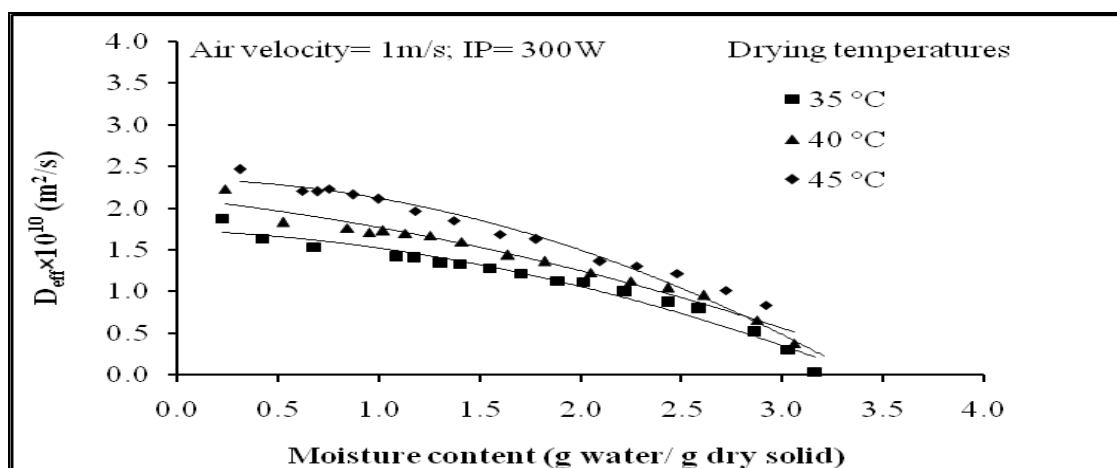
**Figure 2:** Drying curves for ginger slices at various air temperatures (°C) at air velocity 1.0 m/s, infrared power of 300 W.



**Figure 3:** Drying curves for ginger slices at various infrared power (W) at air velocity 1.0 m/s and air temperature of 35°C.



**Figure 4:** Drying curves for ginger slices at various air velocities (m/s) at temperature of 35°C, infrared power of 300 W.



**Figure 5: Variation in effective moisture diffusivity with moisture content at air velocity of 1.0 m/s and infrared power of 300**

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