Solar Drying of Ivy Gourd: Influence of Various Dipping Solutions on Activation Energy and Moisture Diffusivity

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Research Article

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Solar Drying of Ivy gourd: Influence of Various Dipping Solutions on Activation Energy and Moisture Diffusivity

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Abstract

The study is aimed to enhance the shelf life of ivy gourd through solar drying method in open, forced and natural convection mode. Ivy gourd is treated as primary agent to prepare medicines and the stems, leaves; flowers are used to cure the diseases related diabetics, ulcer, skin. The normal shelf life is 2-3 days and it can be increased up to 6 months with an effective drying process. The experiment is intended to find the best drying process among the open, natural and forced convection mode with an initial dipping method with ascorbic acid, lemon juice, sugar solution, honey solutions individually and a control sample (without dipping). A 3kg sample of ivy gourd is dipped in 10g/L of the each of the solution and it is used for the three drying process individually. The obtained results are indicating that forced convection method for ascorbic acid is best among the other drying method with highest moisture diffusivity is 7.88×10^{-8} m^2/s and lowest activation energy 21.12 kJ/mol. It was observed that the drying kinetics of ivy gourd should be considered an indicator of efficiency for solar drying technique from environmental safety perspective. The influence of dipping solution and drying mechanisms on the functionalities of drying are discussed with suitable illustrations.

Keywords: Solar Drying; Dipping Pre-treatment; Ivy Gourd Drying Characteristics; Activation Energy; Moisture Diffusivity

1. Introduction

The developing countries are experiencing food scarcity due to the inefficacy to preserve food supplies compared to low production. The medicinal values existed in vegetables are partially using in the current situation due to inefficient and uneconomical preservation process. Ivy gourd is one of the tropical vegetables which remain under treated though it contains many nutraceutical properties. Solar drying is considered as one of the prominent food preservation techniques for many years which can be supportive to maintain nutritional and medicinal benefits for long time. However this process highly dependent on solar irradiation and it requires constant supply at longer duration. It is observed that the developing countries are facing post-harvest losses due to inefficiency at utilizing solar dryers and the mode of drying. As suggested by Bellesiotis et al, drying functions on two moisture transfer mechanisms such as transfer of moisture from the mass to the surface and transfer of moisture from the surface to the surrounding air (Belessiotis and Delyannis 2011).

1.1. Solar Drying of Perishable Crops

Vegetables and fruits are vital sources of necessary dietary nutrients but are characterized under perishable goods since their moisture content exceeds 80% (Changrue and Raghavan 2006). Storing the product dry and moisture-free are the prominent ways to sustain its quality and nutrition, but a majority of such storage mechanisms need low-temperature setups that require heavy maintenance. Around 20% of the world's perishable food supplies are subjected to drying in order to expand their shelf storage span and enhance food quality (Grabowski, S., Marcotte, M. and Ramaswamy 2003). Important quality attributes associated with vegetables include their sensory appeal, drying characteristics, microbial load, aroma, taste, retention of nutrients, and exclusion from pests and preservatives (Bhatta et al. 2020).

A curtailment in the post-harvest losses of agricultural crops can majorly influence the economy of developing countries positively (Chandra and Sodha 1991). About 80% of the agricultural products in countries like India are cultivated by small-scale farmers (Murthy 2009). These farmers use the natural sun for drying agricultural and other food products due to the abundant availability of sunlight in the form of solar energy. This process is regarded as open drying. However, open sun drying has its disadvantages which affect the standard of the end product making it inappropriate to consume. Also, certain crops are not supposed to be sun-dried as they may lose their desirable characteristics (Jairaj et al. 2009). Drying and removal of moisture content from the fruits and vegetables require a comprehensive analysis of the drying mechanism which helps in enhancing the drying efficiency and end product quality resulting in a considerable decrease in the post-harvest losses. Hot air convective drying is still the widely recognized and accepted drying method although it possesses several disadvantages like high energy consumption (Lewicki 2006). The features and standard of the products that are dried and their consumption are major factors considered while identifying the drying mechanism (Al-Juamily et al. 2007). An efficient drying system should be cost-effective and potential enough to optimize the energy consumption and to minimize the operational cost without compromising on the quality of drying of the product. Hence solar dryers incorporated with evolving novel technologies are perfect options for drying perishable crops which reduces both energy consumption and operational cost.

The adaption of solar thermal systems to preserve fruits, vegetables, and various other agricultural products is proven to be a more efficient, cost-effective, and environmentally friendly approach. The solar drying technique is a very clean and hygienic alternative that processes the vegetables and fruits in sanitary conditions. It occupies less area, saves energy and time, and makes the process highly efficient concerning drying time and drying characteristics (Funebo and Ohlsson 1998; Zhang et al. 2006). In comparison to conventional open sun drying techniques, solar drying is highly advantageous since it mitigates several issues like contamination, the possibility of spoilage, lack of control, and ambiguity over-drying conditions due to longer drying duration. The solar drying method is also economical, unlike the widely used convective hot air dryer method which has a high fuel consumption rate and energy cost. As solar energy is one of the prominent renewable energy sources and available abundantly, it is widely accepted for the dehydration of perishable food supplies. The main advantages of solar drying of agricultural crops include the possibility of an early harvest, long-term storage without deterioration, and selling a better-quality product. As an added advantage, it minimizes packaging requirements and reduces transport weight.

1.2. Pre-treatments before Solar Drying

As reported by Sablani, changes are happening with the evaluation of quality and standards of nutrition of the agricultural products after dehydration (Sablani 2006). The agricultural crops that are using solar drying should be capable of retaining their various quality features which include colour, texture and nutritional values post dehydration or drying. Quality enhancement is attained by different pre-treatment methods before drying. The application of appropriate pre-treatments before drying enhances the quality of drying by minimizing the time required for drying, improving drying attributes, and preserving energy-yielding higher-quality end products. Several pre-treatment methods are available that are incorporated with the drying mechanism and blanching is considered as the most generalized method. Dipping treatment which involves the dipping or soaking of an agricultural product mainly in organic acids (Karapinar and Gönül 1992) serves as an alternative to blanching which helps in reducing the quantity of conventional flora and pathogenic species and, some of them like acetic acid reportedly mitigate the activity of enzymes responsible for browning (Chiewchan et al. 2010). Dipping involves soaking washed, peeled, and sliced fruit and vegetables in a suitable liquid commonly called a dipping solution. Dipping is mainly tried in fruits such as apples, bananas, peaches, and pears and it prevents it from oxidizing. Commonly employed dipping solutions consider juices that are high in vitamin C such as orange, lemon juice, pineapple, grape, and cranberry juice or solutions of honey, ascorbic acid (Vitamin C), sodium bisulphite, and sugar solution which serve as antioxidants are found effective. The solution of ascorbic acid and water is the best way to prevent browning. Any fruit juice that has high vitamin C value is considered as a dipping solution, although it might not efficient as pure ascorbic acid. The solution of honey and water can also be used as a dipping solution for pre-treatment before carrying out the drying. Honey mixed with refined sugar solution and water as a dipping solution can enhance the taste of the dried fruit or vegetable in comparison with various other dipping solutions.

1.3. Drying Characteristics: Moisture Diffusivity and Activation Energy

Drying characteristics such as moisture diffusivity and activation energy have a huge impact on the process of solar drying which mainly determines the rate of drying and time required for drying. Drying characteristics depend on the crop properties, drying mechanism, and the pre-treatment used. Effective moisture diffusivity is stated as the rate of moisture movement and activation energy is the minimum energy required to start the drying mechanism or moisture transport.

Various research works have investigated the process of activation energy and diffusion of moisture into the thin layer drying of different food products such as onion slices (Demiray et al. 2017), beriberi fruit (Aghbashlo et al. 2008), hazelnuts (Özdemir and Onur Devres 1999), potato slices (Akpinar et al. 2003), candlenuts (Tarigan et al. 2007), plums (Goyal et al. 2007), grapes (Pahlavanzadeh et al. 2001), Tomato (Elavarasan E et al. 2021), Poovan banana (Anagh S Bhanu et al. 2021), red banana (Elangovan and Natarajan 2021b) and seedless grapes (Ibrahim Doymaz and Pala 2002). Moisture diffusivity of the drying product should be high which in turn increases the drying rate reducing drying time. Whereas activation energy should be less in order to initialize the drying task with less amount of energy maintaining very minimum drying time. An ideal range of moisture diffusivity lies between 10^{-9} to 10^{-11} m^2/s and activation energy is better to be below 35kJ/mol to have an effective drying process (Mirzaee et al. 2009).

Solar dryers incorporated with storage devices for storing thermal energy are important in the applications of food drying. Many researchers have used paraffin wax as PCM along with an indirect solar dryer (IDSD) which is capable of mitigating the losses in the form of heat and enhancing the thermal efficiency of the drying system by storing the thermal energy during daytime and using it after sunset. Hence PCM increases the operational duration of the solar dryer and controls the temperature used for the drying mechanism which consequently minimizes the drying time by 50% in comparison to the dryer without PCM (El-Sebaii and Shalaby 2017; Yadav and Chandramohan 2018). The ambient temperature and solar radiation essay a prominent role in deciding the potential influence of solar dryers. A review done by Sandali et al. (2019) mentioned various techniques to improve the overall efficiency of the drying system. The solar dryer integrated with a chimney augments the buoyant force applied on the air stream resulting in higher airflow velocity and increases the moisture removal rate. Also, a sustainable forced convection method using a fan running with the help of electricity produced by photovoltaic panels gives out forced air circulation and increases the moisture removal rate. The usage of concentrators results in increased air temperature inside the dryer which helps in decreasing the drying time. Saxena and Gaur (2020) introduced a novel solar-assisted greenhouse type dryer integrated with an evacuated tube solar collector to regulate and maintain the greenhouse conditions. It also consists of flow regulating devices, solar PV modules for providing forced circulation of solar-heated water, and a drying bed with water flow arrangement. The drying time is observed to be decreased by 2-4hrs by employing the setup. For obtaining the spatial drying homogeneity, Amjad et al. (2021) introduced a solar hybrid food dryer by incorporating a gas burner and evacuated tube solar collector with an inline perforation inside the drying chamber.

The following research gaps have been identified from the cited research literature:

(i) The influence of pretreatment of the samples on the overall drying period is not investigated.

(ii) The pretreated drying characteristics of Ivy gourd have been not analyzed.

(iii) Sensory appeal such as aroma, taste, color, shrinkage and texture after the drying is not estimated.

The current research is aimed to enhance the shelf life of ivy gourd through solar drying after pretreatment with different solutions. Section-2 presents the research design, experimental setup and mathematical equations to support the investigational study. Section-3 presents the obtained results and the relevant discussions performed through the observation. Section-4 concludes the article by presenting the overview and future scope of the research.

2. Research Methodologies

2.1. Sample Preparation

The experimental procedure starts with preparing the sample. 15 kg of fresh ivy gourd is purchased from the market. Washing, peeling, and slicing of ivy gourd to the required size is done. Dipping pre-treatment is performed by immersing the ivy gourd samples for 10 minutes in five types of dipping solutions namely ascorbic acid, lemon juice, sugar solution, honey, and control solution categorizing it into five different samples. 1kg of each (a total of 5kg) is taken for 3 different experimental setups.

2.2. Solar Dryer Setup and Temperature Monitoring

The three major solar drying setups used for experimental analysis are illustrated in Fig. 1, which includes an open sun dryer, a natural convection dryer, and a forced convection dryer. The natural convection dryer and forced convection dryer are equipped with a drying chamber made of a two-layered galvanized iron sheet (GI) of dimensions 1290mm×850mm and thickness 1.5mm. The top portion of the chamber is covered with a pane glass of 5mm thickness. The dryers were designed in a way that the heat gets trapped within the drying chamber effectively. In order to insulate the setup, coconut husk and thermocol are used with the GI sheets which act as an insulating medium and prevent heat transfer within the surfaces. The samples are kept inside the chamber over a mesh of dimensions 1190mm×750mm. There are inlet (Ø22mm) and outlet (Ø26mm) pipes placed for the circulation of ambient air. Forced convection dryer includes a fan blower in extra to complete the setup which is powered and can be controlled. Solar radiation and temperature are monitored using a pyranometer and two different thermocouple configurations, respectively. Nine thermocouples of K-type configuration are employed for determining the temperature inside various segments of the dryer and a thermocouple of J-type is used for determining the ambient temperature. Pyranometer (SR20-TI, secondary standard (ISO9060) having a sensitivity of 14.77×10^{-6} V/ (W/m^2) is used for determining the solar radiation (Kumar Natarajan et al. 2019). The thermocouples and pyranometer are connected to a data acquisition unit where the data is decoded and collected, and then monitored using a data logger (Agilent 34972A) (Natarajan and Elavarasan 2019).

Fig. 1 Solar dryer setup

2.3. Mathematical Correlations to Calculate the Drying characteristics

Moisture content can be calculated by measuring the wet weight (W_w) and the dry weight (W_d). Where the wet weight is defined as the weight of the ivy gourd before drying and dry weight is taken post drying. The equation given below defines the moisture content based on the drying characteristics by following equation (Ullah et al. 2020; Ahmad et al. 2021).

$$MC = \frac{W_w - W_d}{W_d} \quad (1)$$

The process drying of food material is mostly governed by diffusion mechanism as the rate of falling period. Therefore, Fick's 2nd law of diffusion is applied to find the effective moisture diffusion and is governed by (Elangovan and Natarajan 2021a) the Eq. (2):

$$\ln MR = \ln\left(\frac{8}{\Pi^2}\right) - \frac{\Pi^2 D_{eff} t}{L^2} \quad (2)$$

where MR represents the moisture ratio, D_{eff} is defined as the effective moisture diffusivity (m^2/s), t is the corresponding drying time (hrs), and L is the thickness of ivy gourd sample (m). The plot of ln (MR) against drying time gives out a straight line with a slope governed by the mathematical expression as shown in Eq. (3):

$$Slope = \frac{\Pi^2 D_{eff}}{L^2} \quad (3)$$

From the above equation, the effective moisture diffusivity can be evaluated by assuming negligible shrinkage and constant temperature during the drying process (Yogendrasasidhar and Setty 2019; Daş et al. 2021). Also, MR can be determined using the expression presented in Eq. (4), where M_t defines the amount of moisture content present for a given time t, M_o represents initial moisture content and M_e is moisture content at equilibrium.

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{4}$$

The Activation energy is determined by plotting ln (D_{eff}) against 1/T, where the effect of effective moisture diffusivity on temperature can be determined. This is governed by an expression called Arrhenius Eq. which states,

$$D_{eff} = D_o \exp\left(-\frac{E_a}{RT}\right) \tag{5}$$

where E_a is the activation energy (kJ/mol), R is universal gas constant (8.314kJ/mol K), T is temperature (K) and D_o is diffusion factor (m^2/s). The plot of ln D_{eff} against 1/T gives a straight line of slope K where the relation between Ea and diffusivity coefficients can be defined through linear regression analysis and activation energy (E_a) is evaluated by (Daş et al. 2021)

$$K = \frac{E_a}{R} \tag{6}$$

3. Results and Discussion

3.1. Solar Dryer Performance during Forced and Natural Convection

The performance of the natural convection and forced convection solar dryer was tested in terms of solar radiation per unit area, ambient temperature, temperature of drying air and temperature of the absorber plate. The Fig. 2 and 3 represents the variation of each against drying time for forced convection dryer and natural convection dryer, respectively. For the forced convection dryer, the highest temperature of the absorber plate (66.26°C) and drying air (63°C) has been obtained around 13hrs (1 pm) for a maximum radiation of 1062.32 W/m^2. For the natural convection dryer, the highest temperature of the absorber plate reached 58.01°C and the maximum drying air temperature was 55.47°C for a solar radiation of around 1000 W/m^2. A similar trend was observed in the experimental analysis conducted by Gatea (2011), where a solar drying system was fabricated and designed for analysing the solar collector efficiency used for the purpose of drying. The solar drying system acquired a maximum collector temperature of 71.4°C for a solar radiation of 750 W/m^2.

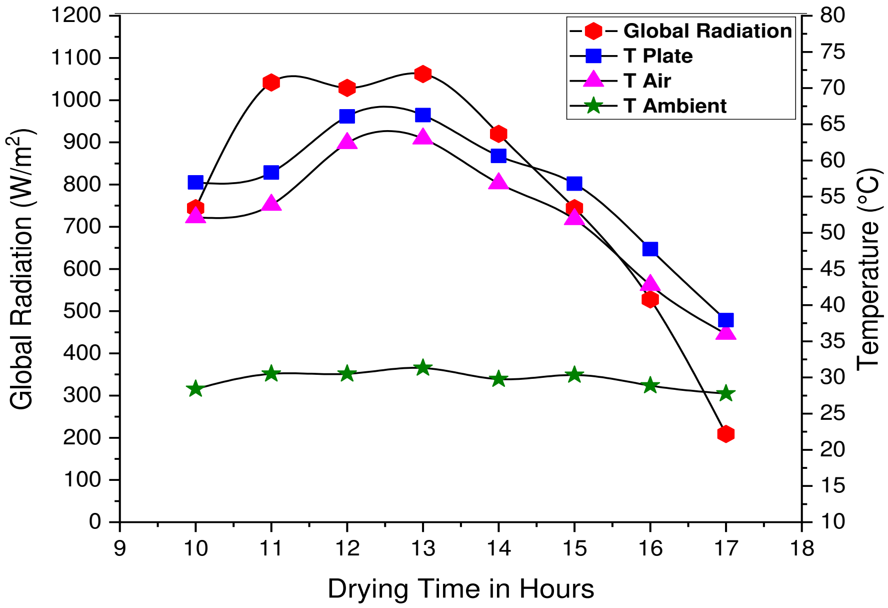

Fig. 2 Thermal performance of forced convection dryer

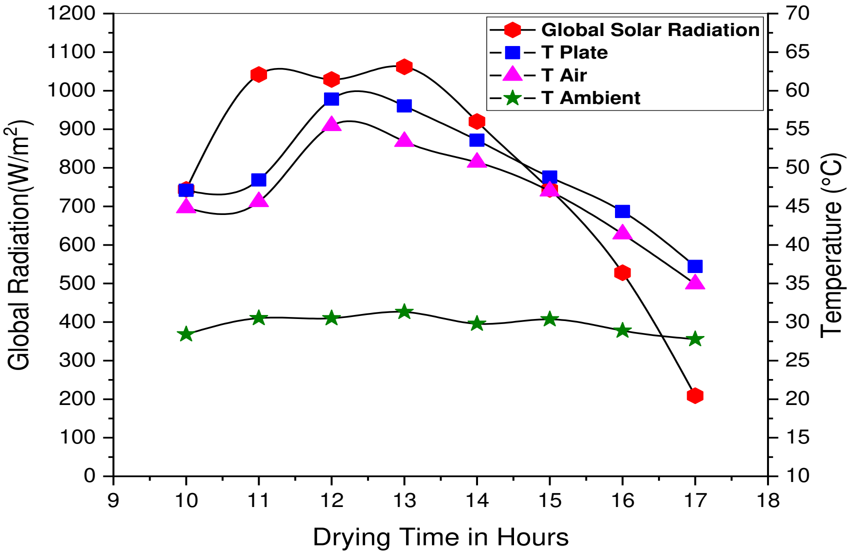

Fig. 3 Thermal Performance of Natural Convection Dryer

3.2. Moisture content

Moisture Content of all the samples and its variation with respect to drying time is illustrated from Fig 4 to 8. It can be inferred from the results that Ivy gourd with a moisture content of 1000 g before drying was reduced to 120g after drying in 11 hrs when dipped in a control sample, ascorbic acid, and lemon juice. The same drying process took 12 hrs when Ivy gourd was dipped in a sugar solution sample and 14hrs when dipped in a honey sample for an open sun drying method.

Similarly, for a natural convection dryer, the moisture content reaches the minimum value in 9hrs for control sample, ascorbic acid, and lemon juice. Whereas it takes 10hrs for sugar solution and 11hrs for honey sample. For forced convection dryer, the duration was less, and the moisture content was reduced to minimum value in 7hrs for control sample, ascorbic acid, and lemon juice and in 8hrs for sugar solution and honey sample. It was also observed from the results that forced convection dryer reduce the moisture content faster compared to other two methods. There exists a non-linear relationship between moisture content and drying time since the moisture content reduces with the increase in drying time. As reported in the work of Madan et al. (2014) the moisture content decreases with respect to time at a continuous rate irrespective of drying air temperature. A steep increase in the moisture removal rate is observed between 12 to 13 hrs for forced convection and between 13 to 14 hrs for natural convection, which gradually decreases with the reduction in moisture content.

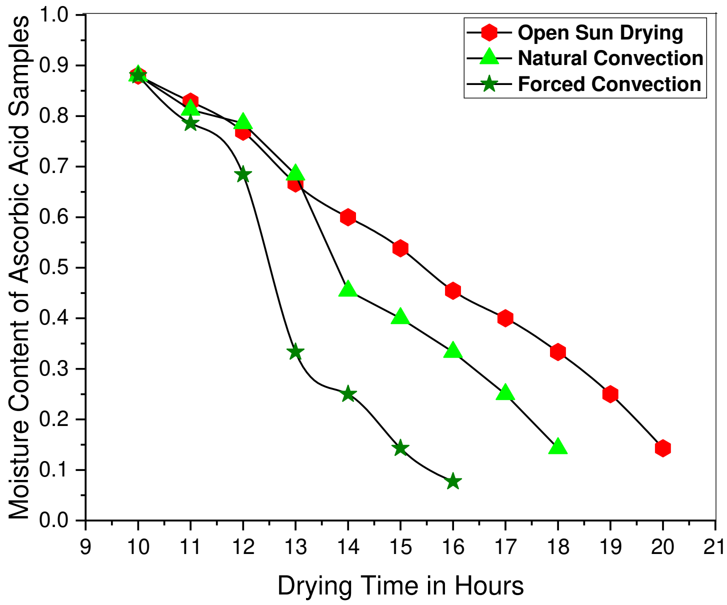

Fig. 4 Moisture content of ascorbic acid sample

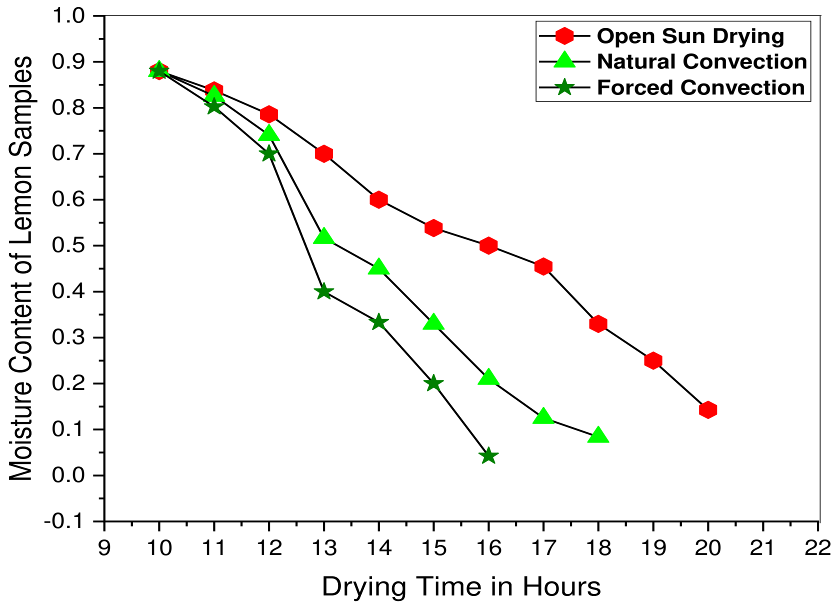

Fig. 5 Moisture content of lemon juice sample

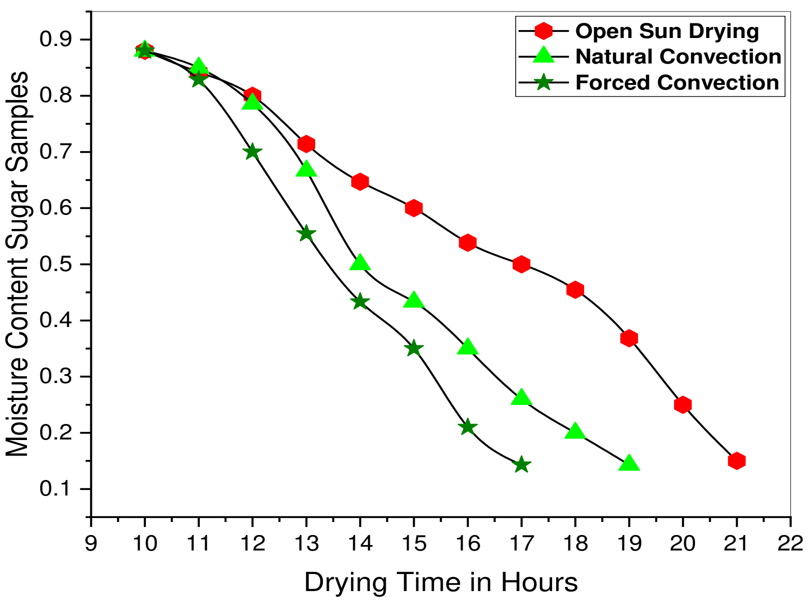

Fig. 6 Moisture content of sugar solution sample

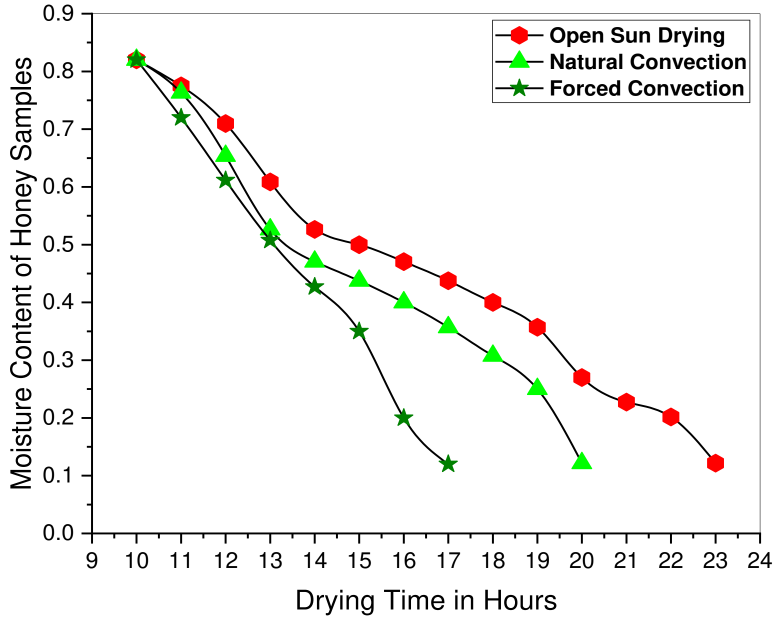

Fig. 7 Moisture content of honey sample

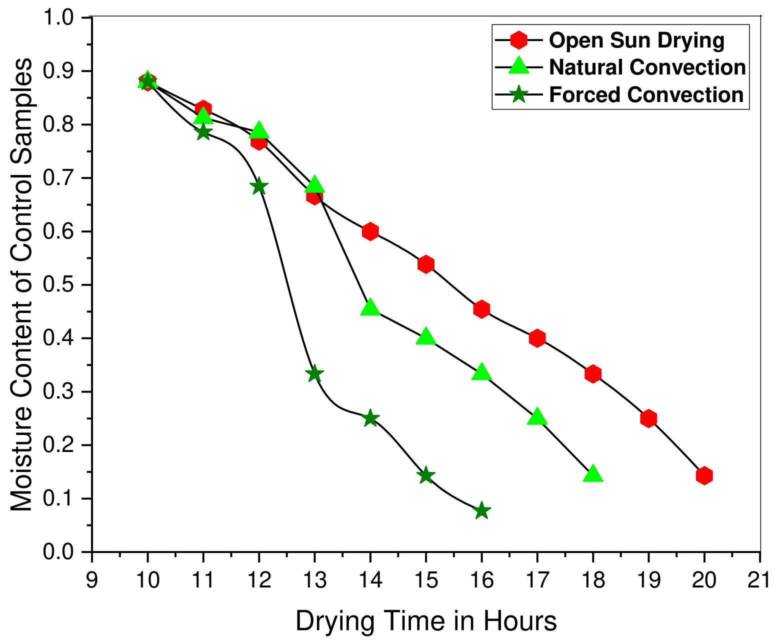

Fig. 8 Moisture content of control sample

3.3. Effective Moisture diffusivity

Fick's 2nd law as stated in Eq. (2) was applied for calculating the effective moisture diffusivity since drying occurs in the rate of falling period (Deshmukh et al. 2014). Therefore, the effective diffusivity (D_{eff}) of the ivy gourd for all the samples and for different drying method were evaluated by plotting ln (MR) against drying time as shown in Fig. 9 to 13, where the slope of the straight line governed by Eq. (3) gives the value of effective moisture diffusivity of the sample. The effective moisture diffusivity of the ivy gourd dipped in ascorbic acid is observed to have highest value (7.88×10^{-8} m^2/s) when dried under forced convection dryer (Table 1) followed by lemon juice, control sample, sugar solution, and honey sample. The results were better than the prescribed range of moisture diffusivity (10^{-6} to 10^{-12} m^2/s) provided in the literature of solar drying of food material (Elavarasan Elangovan & Sendhil Kumar Natarajan, 2021; Onwude *et al*., 2016). Viscosity of the dipping solution plays a major part in the process. The solutions which are less viscous are observed to have greater moisture diffusivity like ascorbic acid, lemon juice sample and the highly viscous solutions like honey are observed to have least moisture diffusivity. The obtained effective moisture diffusivities values were relatively higher than already reported many researchers for drying Red banana (Elangovan and Natarajan 2021b), Bitter gourd (Jadhav et al. 2010), Button mushroom (Kar A. and D. Gupta 2003; Singh et al. 2008), Apple (Aghbashlo et al. 2010), Tomato (Elavarasan E et al. 2021), Poovan banana (Anagh S Bhanu et al. 2021) of 5 mm same thickness.

Table 1 Moisture Diffusivity of Ivy Gourd Samples Pre-treated by Different Dipping Solutions

	Moisture Diffusivity (m^2/s)		
Samples	**Forced Convection**	**Natural Convection**	**Open Sun Drying**
Control Sample	5.53×10^{-9} to 3.39×10^{-9} with an avg. of 4.18×10^{-9}	5.70×10^{-9} to 1.42×10^{-10} with an avg. of 3.04×10^{-10}	8.31×10^{-10} to 2.69×10^{-10} with an avg. of 5.08×10^{-10}
Honey Sample	3.59×10^{-10} to 2.81×10^{-10} with an avg. of 3.81×10^{-10}	3.72×10^{-10} to 1.81×10^{-11} with an avg. of 2.91×10^{-11}	6.29×10^{-11} to 1.47×10^{-11} with an avg. of 1.76×10^{-11}
Lemon Juice Sample	5.62×10^{-9} to 1.61×10^{-10} with an avg. of 6.51×10^{-9}	1.29×10^{-9} to 2.01×10^{-10} with an avg. of 2.81×10^{-10}	4.82×10^{-10} to 1.51×10^{-11} with an avg. of 3.81×10^{-11}
Ascorbic Acid	9.61×10^{-8} to 5.54×10^{-9} with an avg. of 7.88×10^{-8}	7.42×10^{-9} to 2.06×10^{-10} with an avg. of 5.10×10^{-10}	9.79×10^{-10} to 2.16×10^{-11} with an avg. of 4.25×10^{-11}
Sugar Solution	5.31×10^{-9} to 1.98×10^{-10} with an avg. of 3.89×10^{-10}	5.86×10^{-10} to 2.96×10^{-10} with an avg. of 3.49×10^{-10}	7.01×10^{-10} to 1.10×10^{-11} with an avg. of 1.32×10^{-10}

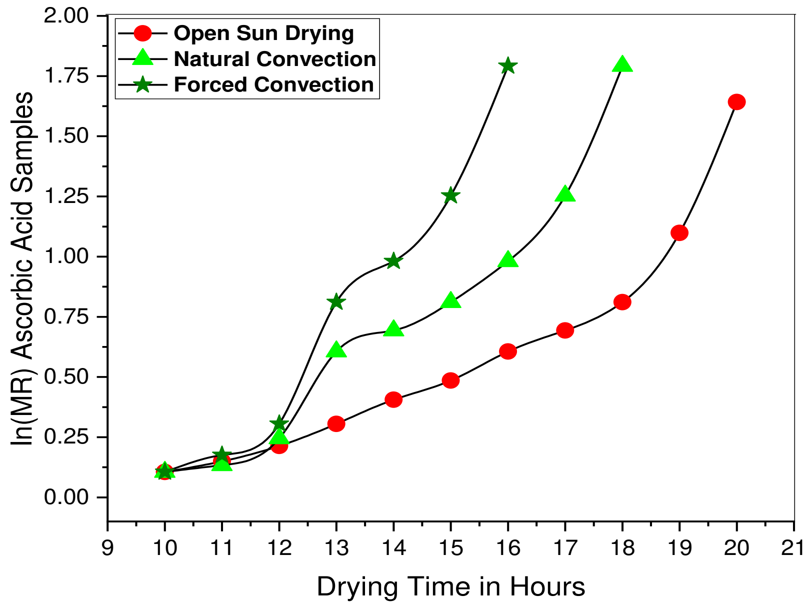

Fig. 9 Drying time V/s ln (MR) – ascorbic acid sample

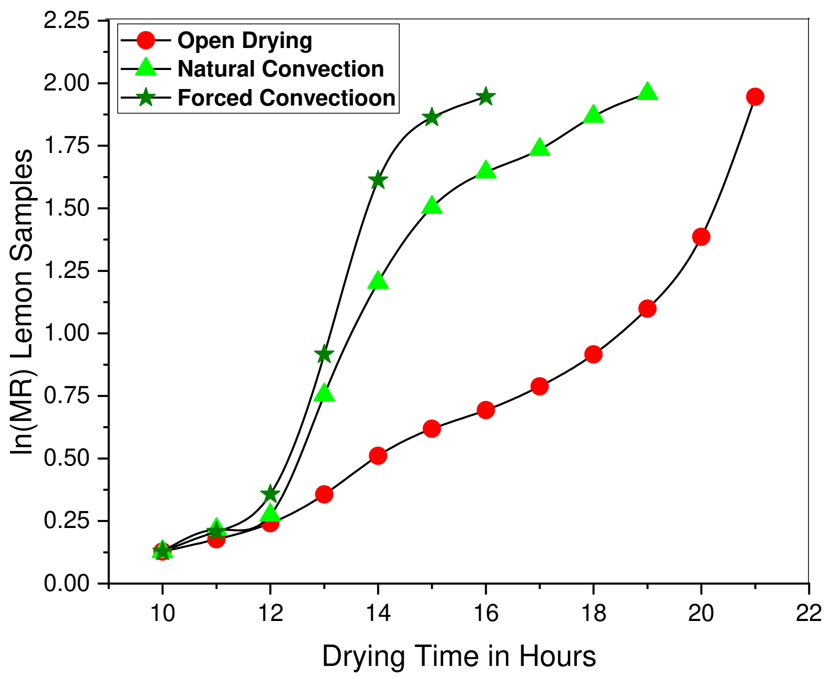

Fig. 10 Drying time V/s ln (MR) – lemon juice

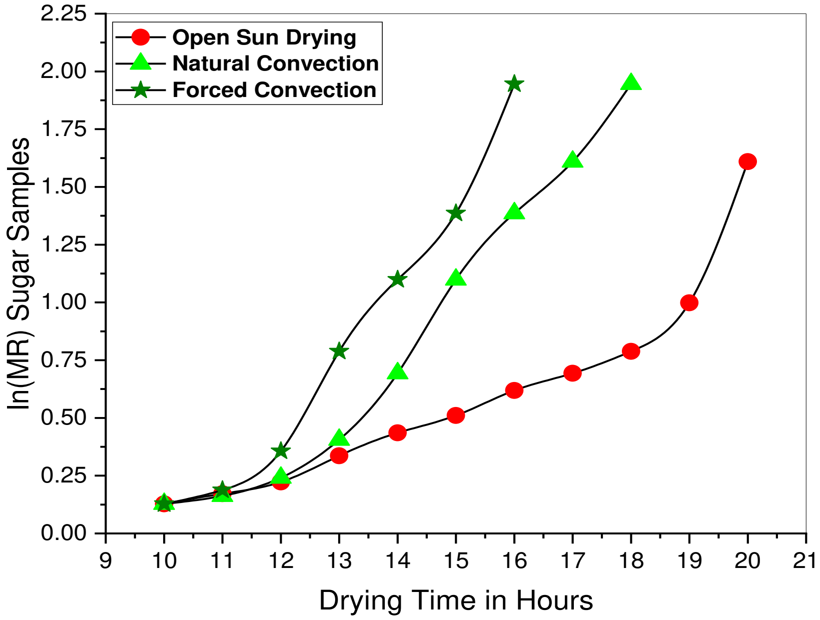

Fig. 11 Drying time V/s ln (MR) – sugar solution sample

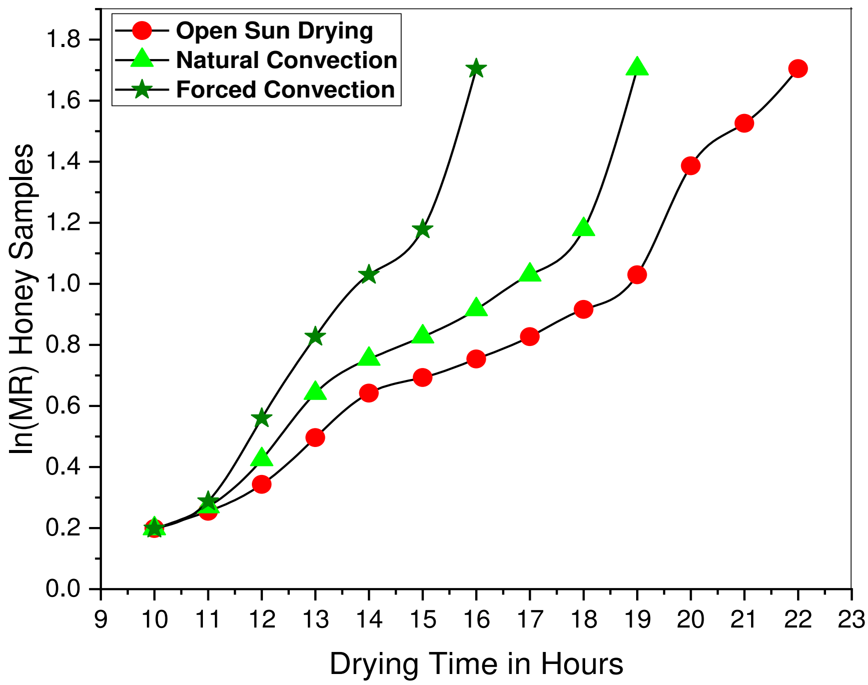

Fig. 12 Drying time V/s ln (MR) – honey sample

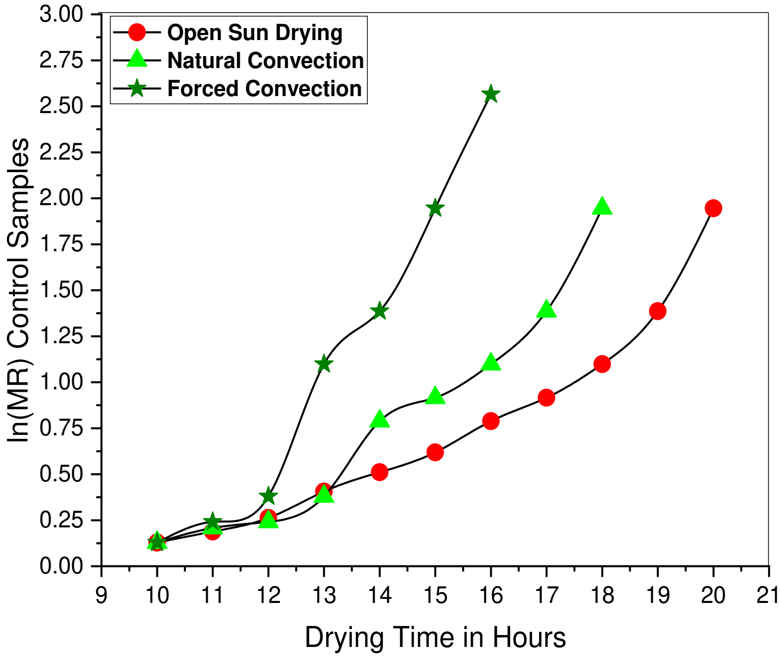

Fig. 13 Drying time V/s ln (MR) – control sample

3.4. Activation energy

Arrhenius expression, Eq. (5) (Chen et al. 2013) was applied to calculate the activation energy (Ea) as shown in Fig. 14 to 18 where the plot of ln D_{eff} against 1/T gives a slope equal to Ea/R from which the activation energy is calculated using linear regression analysis. The activation energy ranges from 12.7 to 110 kJ/mol for most of the food products (Rizvi 1986; Mirzaee et al. 2009). According to the results, the average value of activation energy varied from 21.12 to 34.96 kJ/mol for different samples and drying methods (Table 2 and 3). The lowest activation energy is observed for ascorbic acid samples when dried using the forced convection dryer followed by control, lemon juice, sugar solution and honey samples. Lower viscosity of ascorbic acid results in lower activation energy, which means the amount of energy required to activate the molecular diffusion mechanism is low. The high viscosity of honey when compared to other dipping solutions results in a higher amount of activation energy requirement for the samples during the drying process. The obtained activation energy value for drying ivy gourd samples were lower than already existing literature for drying Red banana (Elangovan and Natarajan 2021b), Apple (Aghbashlo et al. 2010), Tomato (Elavarasan E et al. 2021), Poovan banana (Anagh S Bhanu et al. 2021) of 5 mm same thickness.

Table 2 Activation Energy of Ivy Gourd Samples Pre-treated by Different Dipping Solutions

	Activation Energy (kJ/mol)		
Samples	**Forced Convection**	**Natural Convection**	**Open Sun Drying**
Control Sample	23.89 to 25.52 with an avg. of 24.57	25.01 to 32.50 with an avg. of 27.21	27.06 to 37.14 kJ/mol with an avg. of 32.71 kJ/mol
Honey Sample	26.52 to 29.11 with an avg. of 27.41	28.61 to 33.93 with an avg. of 30.73	32.60 to 40.21 with an avg. of 34.96
Lemon Juice Sample	22.02 to 26.41 with an avg. of 25.80	24.61 to 32.91 with an avg. of 28.01	27.05 to 34.27 with an avg. of 30.63
Ascorbic Acid	18.22 to 22.16 with an avg. of 21.12	20.11 to 30.74 with an avg. of 24.42	24.42 to 33.27 with an avg. of 28.68
Sugar Solution	25.53 to 28.05 with an avg. of 26.01	25.68 to 33.61 with an avg. of 29.25	27.63 to 41.69 with an avg. of 34.19

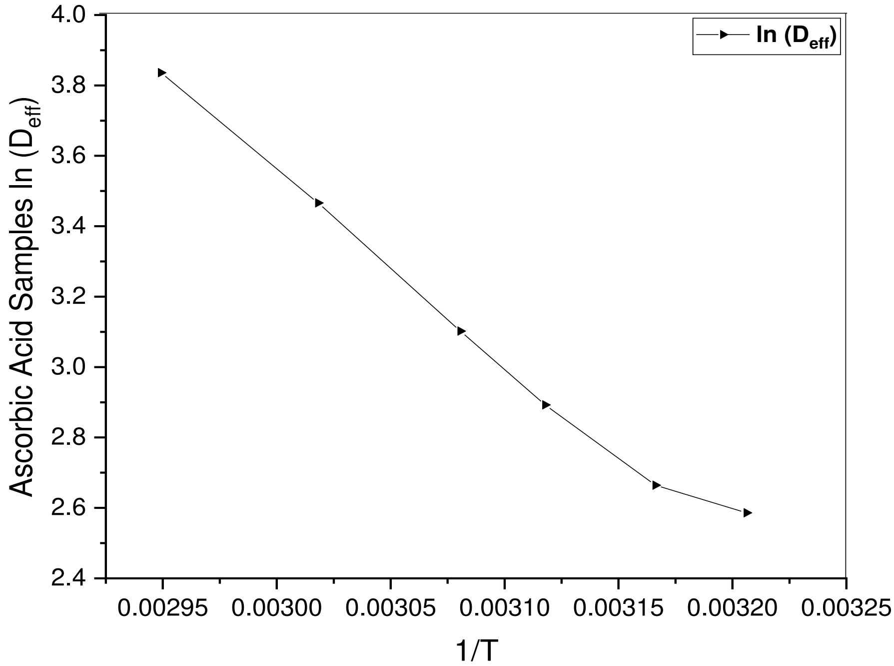

Fig. 14 1/T V/s ln D_{eff} - Ascorbic Acid Samples

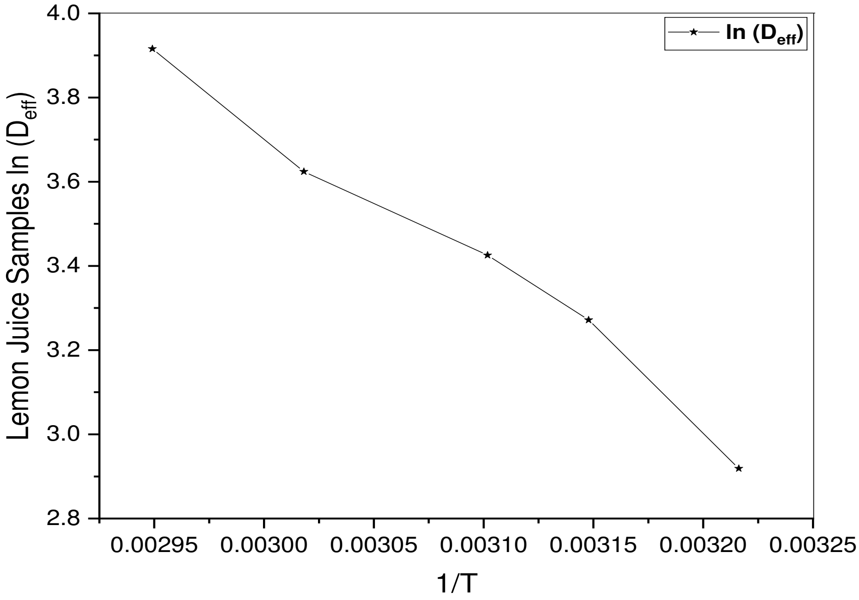

Fig. 15 1/T V/s ln D_{eff} - Lemon Juice Samples

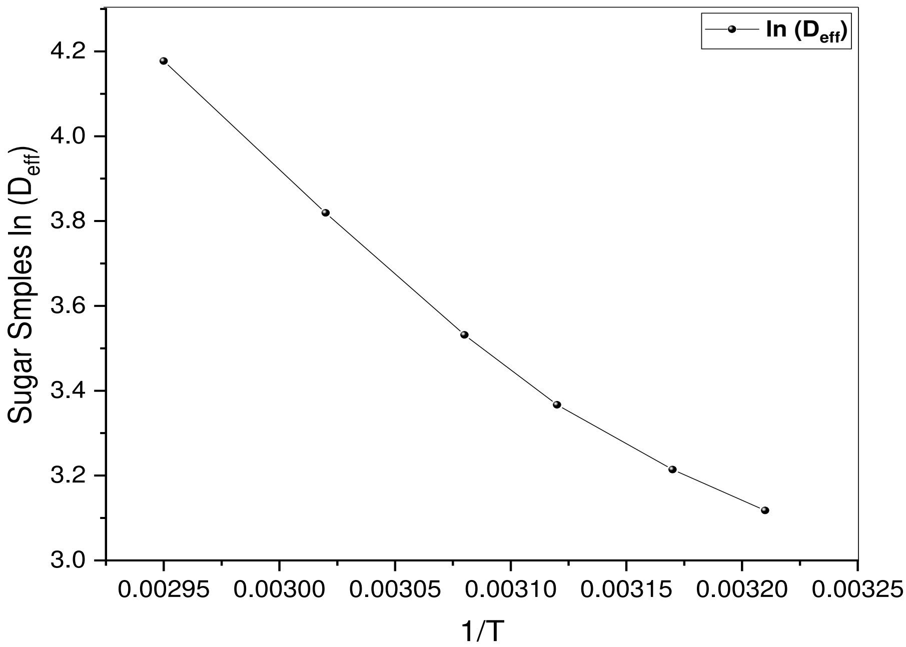

Fig. 16 1/T V/s ln D_{eff} - Sugar Solution Samples

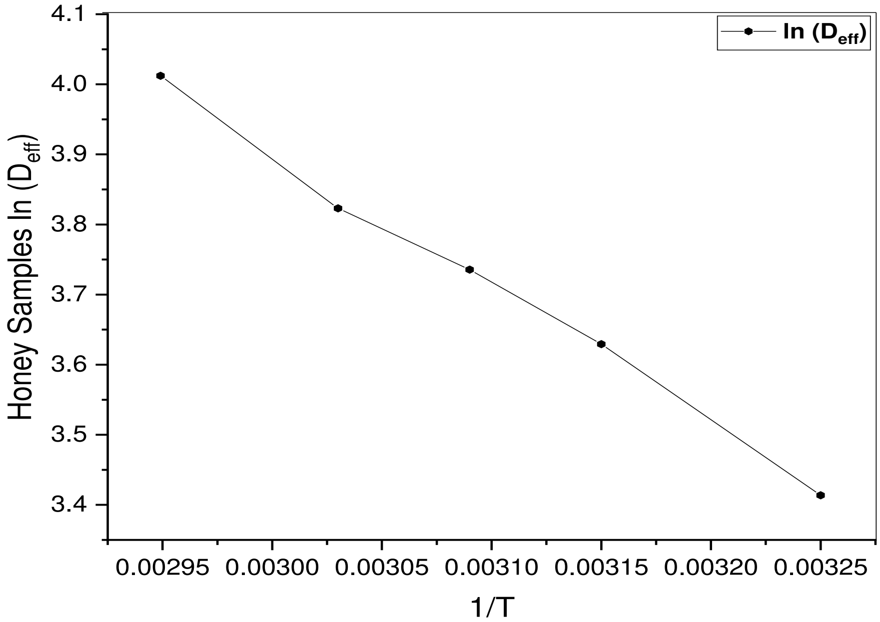

Fig. 17 1/T V/s ln D_{eff} – Honey Samples

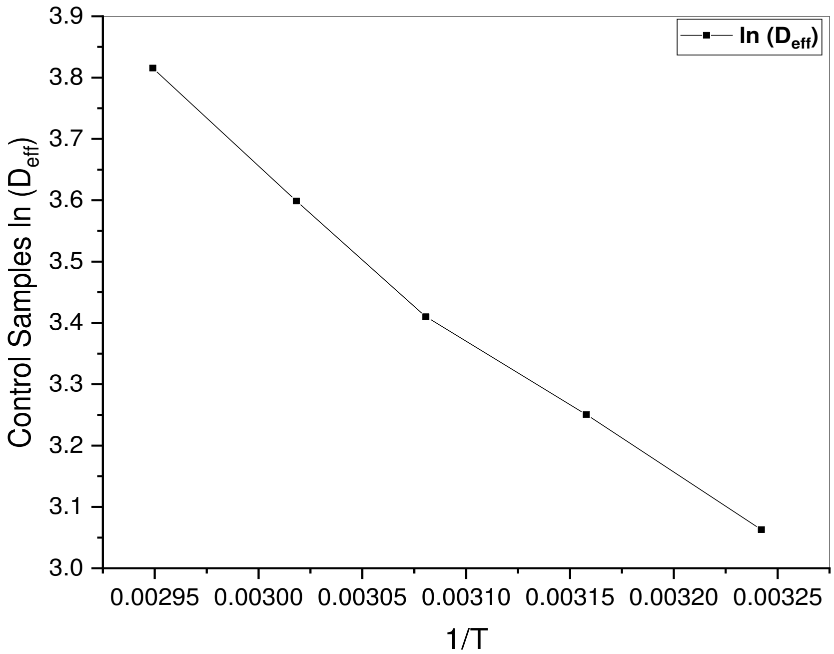

Fig. 18 1/T V/s ln D_{eff} - Control Samples

Table 3 Drying Characteristics of Ivy Gourd Samples Pre-treated by Different Dipping Solutions

Drying Characteristics Samples			
Rating	**Moisture Diffusivity**	**Activation Energy**	**Remarks**
5	Ascorbic Acid	Ascorbic Acid	Excellent
4	Lemon Juice	Control Sample	Very Good
3	Control Sample	Lemon Juice	Good
2	Sugar Solution	Sugar Solution	Average
1	Honey	Honey	Poor

3.5. Sensory characteristics

Sensory analysis is done with the help of 5 individuals who verified, smelled, and tasted each sample to comment on the sensory appeals of each represented by Table 4. The conclusion is made by giving individual ratings out of 5 in terms of appearance (colour, shrinkage) and taste (aroma, taste). Lemon juice sample is found to have better sensory appeal in terms of colour (darkness) and shrinkage followed by honey, ascorbic acid, and control sample, whereas honey dipped sample offers better taste followed by lemon juice dipped samples, control, and ascorbic acid dipped samples, respectively. A similar observation reported by existing literature for drying of pre-treated banana (E. E. Abano and L. K. Sam-Amoah 2011) and pineapple slices (Abano 2010).

Table 4 Sensory Characteristics of Ivy Gourd Samples Pre-treated by Different Dipping Solutions

Sensory Characteristics of Ivy gourd Samples						
Rating	**Colour**	**Shrinkage**	**Aroma**	**Taste**	**Texture**	**Remarks**
5	Lemon Juice	Lemon Juice	Honey	Honey	Ascorbic Sample	Excellent
4	Honey	Honey	Lemon Juice	Sugar Solution	Lemon Juice	Very Good
3	Ascorbic Acid	Sugar Solution	Ascorbic Sample	Ascorbic Sample	Control Sample	Good
2	Control Sample	Ascorbic Acid	Control Sample	Lemon Juice	Honey	Average
1	Sugar	Control	Sugar	Control	Sugar	Poor

Solution	Sample	Solution	Sample	Solution

3.6. Error Analysis

Errors and uncertainties in the experimental analysis can be introduced because of inappropriate instrument selection, inaccurate calibration, errors in analysis and observation, and test planning. While performing drying experiments in solar dryer for drying of Ivy gourds, the relative humidity, moisture diffusivity, and activation energy were measured using appropriate instruments. The uncertainties in the experimental analysis are measured to determine the accuracy of the analysis according to experimental data.

The analysis of effective moisture diffusivity of drying ivy gourd is given as:

$$MR=\frac{8}{\pi^2}\left(\frac{-\pi^2 tD_{eff}}{L^2}\right) \tag{7}$$

Rearranging the above equation (7)

$$x=\frac{L^2}{t\,\pi^2}log\frac{\pi^2}{8}\;y \tag{8}$$

$Where\ x = MR;\ \ y = D_{eff}$

Differentiating equation (8) with respect to y, the above equation is transformed as:

$$\frac{\partial x}{\partial y}=\frac{L^2}{y+\pi^2} \tag{9}$$

Differentiating equation 8 with respect to L, the diffusivity is given as:

$$\frac{\partial x}{\partial L}=\frac{2L}{t\pi^2}log\frac{\pi^2}{8}y \tag{10}$$

Differentiating equation 8 with respect to t, the equation is now given as:

$$\frac{\partial x}{\partial t}=\frac{-L^2}{\pi^2 t^2}log\frac{\pi^2}{8}y \tag{11}$$

The drying rate of the process is evaluated as shown in the equation below.

$$I=\sqrt{\left(\frac{\partial D_{eff}}{\partial MR}\sigma_1\right)^2+\left(\frac{\partial D_{eff}}{\partial L}\sigma_2\right)^2+\left(\frac{\partial D_{eff}}{\partial t}\sigma_3\right)^2} \tag{12}$$

$where\ \sigma_1$=0.577, σ_2= 0.005&σ_3= 0.577

$I = \pm\, 0.39$ m²/s

The activation energy of drying ivy gourd is defined as:

$$D_{eff} = D_O \exp\left(\frac{-E_a}{RT}\right) \tag{13}$$

Rearranging equation 13

$$x = -RT\, log\, \frac{y}{D_o} \tag{14}$$

Where $y = D_{eff}$; $x = E_a$

Differentiating equation 14 with respect to y , equation 14is transformed as:

$$\frac{\partial x}{\partial y} = \frac{-RT}{y} \tag{15}$$

Differentiating equation 14 with respect to D_o and equation 14 becomes

$$\frac{\partial x}{\partial D_o} = \frac{-RT}{D_o} \tag{16}$$

Differentiating equation 14 with respect to T and equation 14 becomes

$$\frac{\partial x}{\partial T} = -Rlog\left(\frac{y}{D_o}\right) \tag{17}$$

Now, the drying rate is given as:

$$I = \sqrt{\left(\left(\frac{\partial E_a}{\partial D_{eff}}\sigma_1\right)^2\right) + \left(\left(\frac{\partial E_a}{\partial D_0}\sigma_2\right)^2\right) + \left(\left(\frac{\partial E_a}{\partial T}\sigma_3\right)^2\right)} \tag{18}$$

where σ_1=0.42, σ_2= 0.25&σ_3= 0.577

$I = \pm\, 0.17$ kJ/mol

The drying rate of drying ivy gourd is given as:

$$DR = \frac{m_i - m_d}{t} \tag{19}$$

Rearranging equation 19

$$DR = \frac{m}{t} \tag{20}$$

Where $m = m_i - m_d$

Differentiating equation 20 with respect to t and the equation 20 becomes,

$$\frac{\partial x}{\partial t} = \frac{-1}{t^2} \tag{21}$$

Differentiating equation 20 with respect to m and the equation is given as:

$$\frac{\partial x}{\partial m} = \frac{1}{t} \tag{22}$$

$$I = \sqrt{(\frac{\partial x}{\partial t}\sigma_1)^2 + (\frac{\partial x}{\partial m}\sigma_2)^2} \tag{23}$$

where σ_1=0.577 σ_2= 0.577

I = ± 0.05 kg/s.

The measured uncertainty for temperature and solar radiation is ±0.04 °C and ±5.67 W/m^2, respectively. Considering the above parameters, the uncertainty of drying rate and kinetic parameter of drying ivy gourd in a SSSD is about ±0.05 kg/s and ±0.39 m^2/s, ±0.17 kJ/mol, respectively.

The uncertainty analysis during drying experiment of ivy gourd is illustrated in Table 5.

Table 5 Uncertainty analysis during drying experiment of ivy gourd

Sl no	Parameter	Unit	Uncertainty Value
1	K Type thermocouple	°C	±0.04
2	J Type thermocouple	°C	±0.02
3	Air velocity	m/s	±0.13
4	Relative humidity of air	%	±0.13
5	Moisture quantity	g	±0.001
6	Global solar radiation	W/m^2	±5.67
7	Kinetics parameters	m^2/s	±0.39
8	Drying rate	kg/s	±0.05

4. Conclusion

The effect of pre-treatment with dipping solutions on different solar drying processes of ivy gourd samples is investigated through an experimental study. It is observed that proposed pre-treatment worked in an effective manner compared to the control sample. Significant variation is observed in terms of high moisture diffusivity and low activation energy among the tested samples. The following observations have been made from this study and they are:

- In open sun drying, control samples are exhibited higher moisture diffusivity whereas the ascorbic acid samples shown higher moisture diffusivity and low activation energy followed by control, sugar solution, lemon juice, and honey samples in natural and forced convection.
- The highest moisture diffusivity and the lowest activation energy are observed in ascorbic acid based samples compared to other in three different drying processes.
- The sensory appeal is found best in Lemon juice sample in terms of colour (darkness) and shrinkage whereas the honey-dipped sample has better aroma compared to other samples.
- It can be declared that the ascorbic acid is the best dipping solution for the pre-treatment of ivy gourd in terms of drying characteristics whereas lemon juice is best choice if sensory appeals are given as priority.
- Forced convection drying is found as best method to observed better increment in shelf life of ivy gourd. Thus, solar drying of food products to be cost effective, environmentally safe and sustainable for food industries

Further investigation on the nutritional and physicochemical properties of the pre-treated solar dried ivy gourd samples is required since the drying process and conditions significantly influence the chemical composition and nutritional values. The influential factors include the type of food, drying method, dipping solution, operating conditions, and storage conditions. The dipping pre-treatment mainly affects the nutritional values which is out of the scope of this paper and requires future work.

Declarations

Ethics approval and consent to participate*:* Not applicable

Consent for Publication: Not applicable

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Competing interests: The authors declare that they have no competing interests.

Funding: Not applicable

Author Contributions - CRediT author statement

Elavarasan Elangovan: Data Curation, Conceptualization, Investigation, Formal analysis, Writing Orginal Draft preparation, Supervision.

Gulivindala Anil Kumar: Resources, Validation, Project administration, Writing-Review and Editing, Conceptualization.

References

Abano EE (2010) Assessments of drying characteristics and physio-organoleptic properties of dried pineapple slices under different pre-treatments. Asian J Agric Res 4:155–161. https://doi.org/10.3923/ajar.2010.155.161

Aghbashlo M, Kianmehr MH, Arabhosseini A (2010) Modeling of thin-layer drying of apple slices in a semi-industrial continuous band dryer. Int J Food Eng 6:1–15. https://doi.org/10.2202/1556-3758.1922

Aghbashlo M, kianmehr MH, Samimi-Akhijahani H (2008) Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (Berberidaceae). Energy Convers Manag 49:2865–2871. https://doi.org/10.1016/j.enconman.2008.03.009

Ahmad G, Khan AA, Mohamed HI (2021) Impact of the low and high concentrations of fly ash amended soil on growth, physiological response, and yield of pumpkin (Cucurbita moschata Duch. Ex Poiret L.). Environ Sci Pollut Res 28:17068–17083. https://doi.org/10.1007/s11356-020-12029-8

Akpinar E, Midilli A, Bicer Y (2003) Single layer drying behaviour of potato slices in a convective cyclone dryer and mathematical modeling. Energy Convers Manag 44:1689–1705. https://doi.org/10.1016/S0196-8904(02)00171-1

Al-Juamily KEJ, Khalifa AJN, Yassen TA (2007) Testing of the performance of a fruit and vegetable solar drying system in Iraq. Desalination 209:163–170. https://doi.org/10.1016/j.desal.2007.04.026

Amjad W, Waseem M, Munir A, et al (2021) Solar Assisted Dehydrator for Decentralized Controlled and Homogeneous Multi-Product Drying. J Sol Energy Eng 143:1–9. https://doi.org/10.1115/1.4047671

Anagh S Bhanu, Elavarasan E, Sendhil Kumar Natarajan AA, M SH (2021) Experimental Investigation of Drying Kinetics of Poovan Banana under Forced Convection Solar Drying. In: Current Advances in Mechanical Engineering. pp 621–631

Belessiotis V, Delyannis E (2011) Solar drying. Sol Energy 85:1665–1691. https://doi.org/10.1016/j.solener.2009.10.001

Bhatta S, Janezic TS, Ratti C (2020) Freeze-Drying of Plant-Based Foods. Foods 9:1–22

Chandra R, Sodha MS (1991) Testing procedures for solar air heaters: A review. Energy Convers Manag 32:11–33. https://doi.org/10.1016/0196-8904(91)90139-A

Changrue V, Raghavan VGS (2006) Microwave drying of fruits and vegetables. Stewart Postharvest Rev 2:1–7. https://doi.org/10.2212/spr.2006.6.4

Chen MQ, Xu XX, Jia L, et al (2013) Analysis of Moisture Migration of Typical Msw Matrices At Medium Temperature. Chem Eng Commun 200:628–637. https://doi.org/10.1080/00986445.2012.717312

Chiewchan N, Praphraiphetch C, Devahastin S (2010) Effect of pretreatment on surface topographical features of vegetables during drying. J Food Eng 101:41–48. https://doi.org/10.1016/j.jfoodeng.2010.06.007

Daş M, Alıç E, Kavak Akpinar E (2021) Numerical and experimental analysis of heat and mass transfer in the drying process of the solar drying system. Eng Sci Technol an Int J 24:236–246. https://doi.org/10.1016/j.jestch.2020.10.003

Demiray E, Seker A, Tulek Y (2017) Drying kinetics of onion (Allium cepa L.) slices with convective and microwave drying. Heat Mass Transf und Stoffuebertragung 53:1817–1827. https://doi.org/10.1007/s00231-016-1943-x

Deshmukh AW, Varma MN, Yoo CK, Wasewar KL (2014) Investigation of Solar Drying of Ginger (Zingiber officinale): Emprical Modelling, Drying Characteristics, and Quality Study . Chinese J Eng. https://doi.org/10.1155/2014/305823

E. E. Abano and L. K. Sam-Amoah (2011) Effects of Different Pretreatments on Drying Characteristics of Banana Slices. ARPN J Eng Appl Sci 6:121–129

El-Sebaii AA, Shalaby SM (2017) Experimental Investigation of Drying Thymus Cut Leaves in Indirect Solar Dryer with Phase Change Material. J Sol Energy Eng Trans ASME 139:1–7. https://doi.org/10.1115/1.4037816

Elangovan E, Natarajan SK (2021a) Experimental Study on Drying Kinetics of Ivy gourd Using Solar Dryer. J Food Process Eng 1–39. https://doi.org/https://doi.org/10.1111/jfpe.13714

Elangovan E, Natarajan SK (2021b) Experimental Research of Drying Characteristics of Red Banana in a Single Slope Solar Dryer Based on Natural and Forced Convection. Food Technol Biotechnol 59:1–28. https://doi.org/https://doi.org/10.17113/ftb.59.02.21.6876

Elavarasan E, Kumar Y, Mouresh R, Natarajan SK (2021) Study of Drying Kinetics of Tomato in a Solar Dryer. In: Current Advances in Mechanical Engineering. pp 349–358

Elavarasan Elangovan and, Sendhil Kumar Natarajan (2021) Effects of pretreatments on quality attributes, moisture diffusivity, and activation energy of solar dried ivy gourd. J Food Process Eng e13653. https://doi.org/10.1111/jfpe.13653

Funebo T, Ohlsson T (1998) Microwave-assisted air dehydration of apple and mushroom. J Food Eng 38:353–367. https://doi.org/10.1016/S0260-8774(98)00131-9

Gatea AA (2011) Design and construction of a solar drying system , a cylindrical section and analysis of the performance of the thermal drying system. J Agric Res 6:343–351. https://doi.org/10.5897/AJAR10.347

Goyal RK, Kingsly ARP, Manikantan MR, Ilyas SM (2007) Mathematical modelling of thin layer drying kinetics of plum in a tunnel dryer. J Food Eng 79:176–180. https://doi.org/10.1016/j.jfoodeng.2006.01.041

Grabowski, S., Marcotte, M. and Ramaswamy H. (2003) Drying of Fruits, Vegetables, and Spices in Handbook of postharvest technology: cereals, fruits, vegetables, tea, and spices

Ibrahim Doymaz, Pala M (2002) The effects of dipping pretreatments on air-drying rates of the seedless grapes. J Food Eng 52:413–417. https://doi.org/https://doi.org/10.1016/S0260-8774(01)00133-9

Jadhav DB, Visavale GL, Sutar PP, et al (2010) Solar cabinet drying of bitter gourd: Optimization of pretreatments and quality evaluation. Int J Food Eng 6:. https://doi.org/10.2202/1556-3758.1503

Jairaj KS, Singh SP, Srikant K (2009) A review of solar dryers developed for grape drying. Sol Energy 83:1698–1712. https://doi.org/10.1016/j.solener.2009.06.008

Kar A. and D. Gupta (2003) Studies on air-drying of osmosed button mushroom. J Food Sci Technol 4:23–27

Karapinar M, Gönül ŞA (1992) Removal of Yersinia enterocolitica from fresh parsley by washing with acetic acid or vinegar. Int J Food Microbiol 16:261–264. https://doi.org/10.1016/0168-1605(92)90086-I

Kumar Natarajan S, Sankaranarayanasamy K, Ponnusamy S, et al (2019) Experimental Comparative Study on Reduction in the Moisture Content of Cucumber in a Double Slope Solar Dryer with Open Sun Drying Method. J Phys Conf Ser 1276:1–6. https://doi.org/10.1088/1742-6596/1276/1/012054

Lewicki PP (2006) Design of hot air drying for better foods. Trends Food Sci Technol 17:153–163. https://doi.org/10.1016/j.tifs.2005.10.012

Madan A, Pare A, A NGN (2014) Mathematical Modelling of Thin-layer Drying Process of Bamboo (Bambusa bambos) Shoots at Varying Temperature. Res Rev J Bot 3:1–9

Mirzaee E, Rafiee S, Keyhani A, Emam-Djomeh Z (2009) Determining of moisture diffusivity and activation energy in drying of apricots. Res Agric Eng 55:114–120. https://doi.org/10.17221/8/2009-rae

Murthy MVR (2009) A review of new technologies, models and experimental investigations of solar driers. Renew Sustain Energy Rev 13:835–844. https://doi.org/10.1016/j.rser.2008.02.010

Natarajan SK, Elavarasan E (2019) Experimental Investigation of Drying Potato for Karaikal Climatic Condition. IOP Conf Ser Earth Environ Sci 312:1–7. https://doi.org/10.1088/1755-1315/312/1/012021

Onwude DI, Hashim N, Janius RB, et al (2016) Modeling the Thin-Layer Drying of Fruits and Vegetables : A Review. ComprehensiveReviews inFoodScienceandFoodSafety 15:599–618. https://doi.org/10.1111/1541-4337.12196

Özdemir M, Onur Devres Y (1999) Thin layer drying characteristics of hazelnuts during roasting. J Food Eng 42:225–233. https://doi.org/10.1016/S0260-8774(99)00126-0

Pahlavanzadeh H, Basiri A, Zarrabi M (2001) Determination of parameters and pretreatment solution for grape drying. Dry Technol 19:217–226. https://doi.org/10.1081/DRT-100001363

Rizvi SSH (1986) “Thermodynamic Properties on Foods in Dehydration”. In Engineering Properties of Foods, Edited by: Rao, M.A. and Rizvi, S.S.H. New York: Marcel Dekker

Sablani SS (2006) Drying of fruits and vegetables: Retention of nutritional/functional quality. Dry Technol 24:123–135. https://doi.org/10.1080/07373930600558904

Sandali M, Boubekri A, Mennouche D (2019) Improvement of the Thermal Performance of Solar Drying Systems Using Different Techniques: A Review. J Sol Energy Eng Trans ASME 141:1–11. https://doi.org/10.1115/1.4043613

Saxena G, Gaur MK (2020) Performance Evaluation and Drying Kinetics for Solar Drying of Hygroscopic Crops in Vacuum Tube Assisted Hybrid Dryer. J Sol Energy Eng 142:1–14. https://doi.org/10.1115/1.4046465

Singh U, Jain SK, Doshi A, et al (2008) Effects of pretreatments on drying characteristics of button mushroom. Int J Food Eng 4:1–21. https://doi.org/10.2202/1556-3758.1179

Tarigan E, Prateepchaikul G, Yamsaengsung R, et al (2007) Drying characteristics of unshelled kernels of candle nuts. J Food Eng 79:828–833. https://doi.org/10.1016/j.jfoodeng.2006.02.048

Ullah H, Shahab A, Rashid A (2020) Volatilization characteristics of selenium during conventional and microwave drying of coal slime: an emerging contaminant in mining industry. Environ Sci Pollut Res 27:11164–11173. https://doi.org/10.1007/s11356-020-07757-w

Yadav S, Chandramohan VP (2018) Numerical analysis on thermal energy storage device with finned copper tube for an indirect type solar drying system. J Sol Energy Eng Trans ASME 140:1–13. https://doi.org/10.1115/1.4039273

Yogendrasasidhar D, Setty YP (2019) Experimental studies and thin layer modeling of pearl millet using continuous multistage fluidized bed dryer staged externally. Eng Sci Technol an Int J 22:428–438. https://doi.org/10.1016/j.jestch.2018.10.010

Zhang M, Tang J, Mujumdar AS, Wang S (2006) Trends in microwave-related drying of fruits and vegetables. Trends Food Sci Technol 17:524–534. https://doi.org/10.1016/j.tifs.2006.04.011

Figures

Figure 1

Solar dryer setup drying. The solar drying system acquired a maximum collector temperature of 71.4°C for a solar radiation of 750 W/m2.

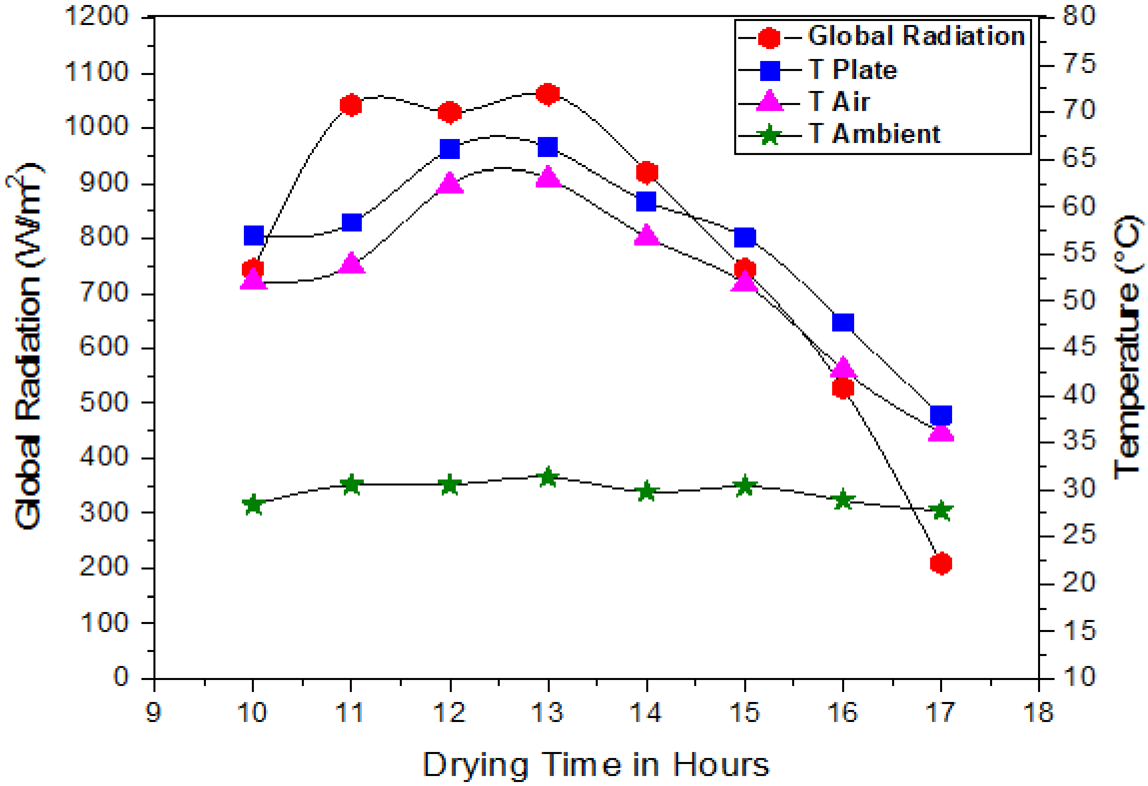

Figure 2

Thermal performance of forced convection dryer

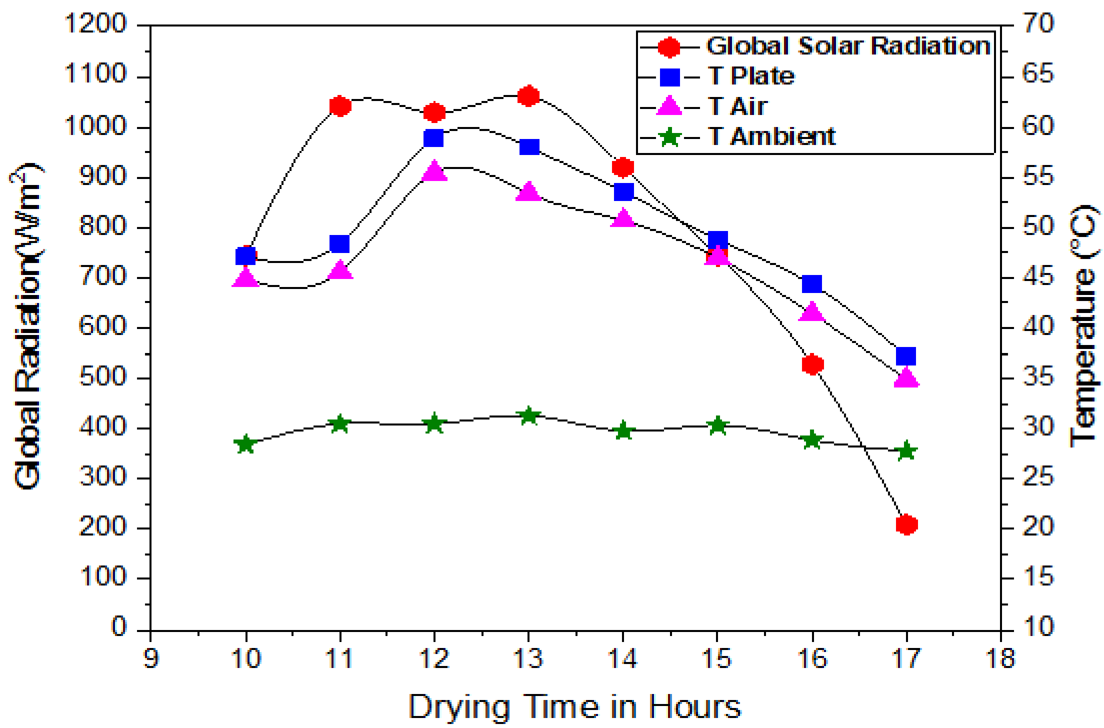

Figure 3

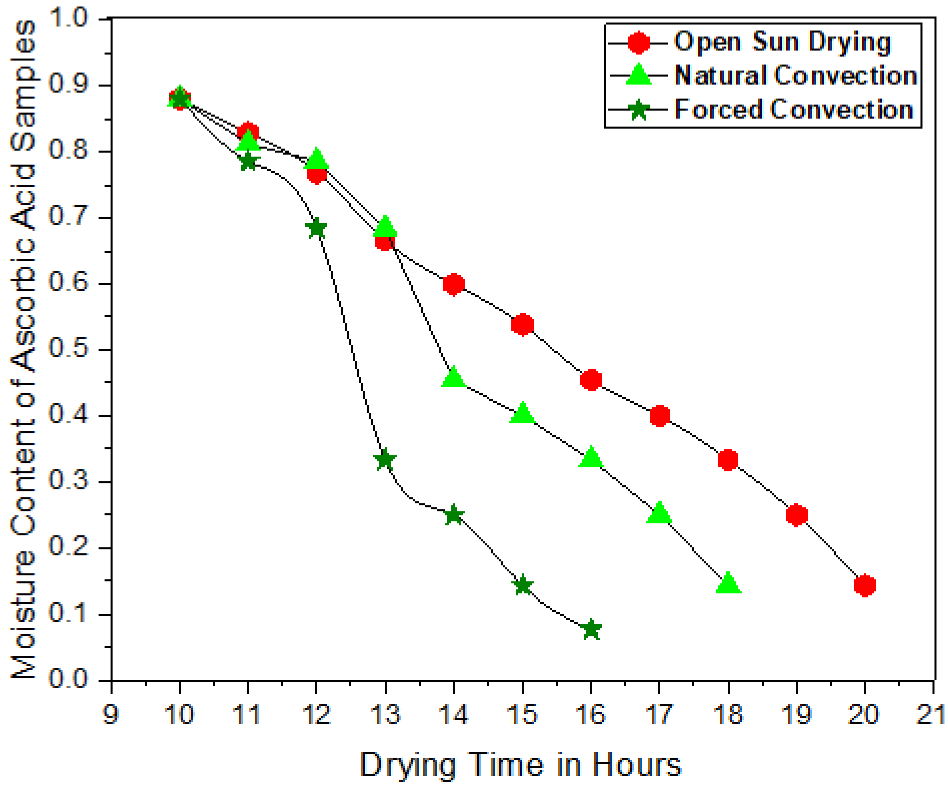

Figure 4

Moisture content of ascorbic acid sample

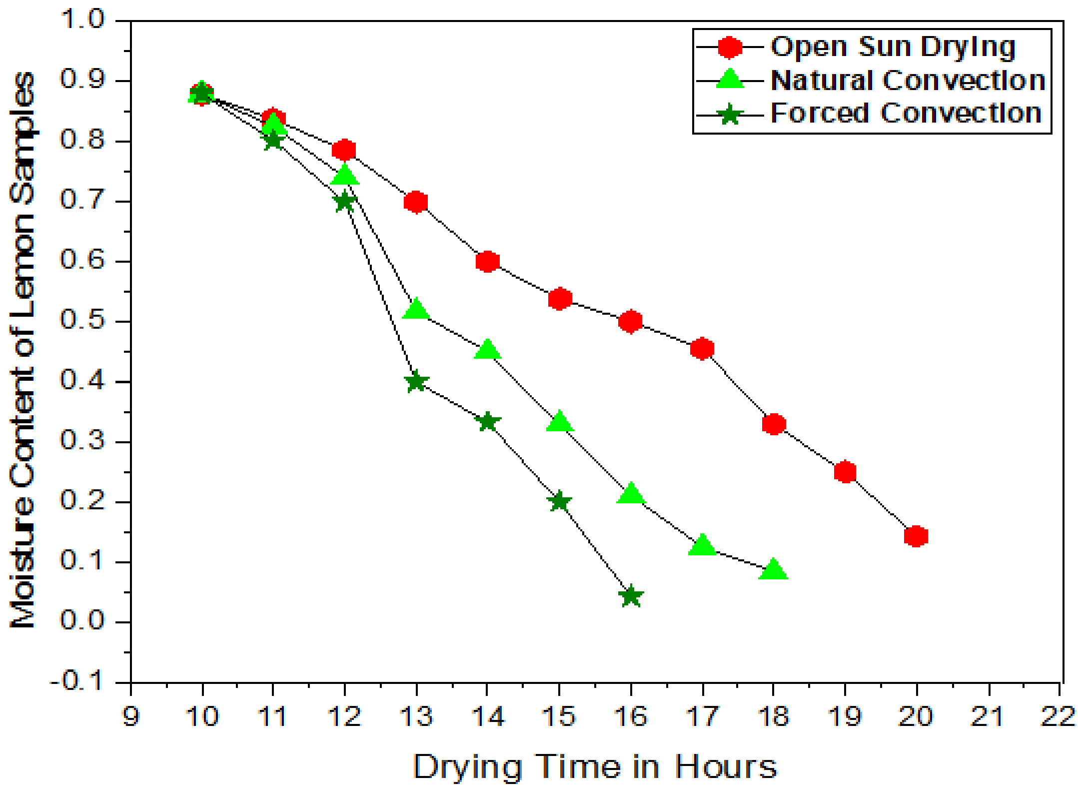

Figure 5

Moisture content of lemon juice sample

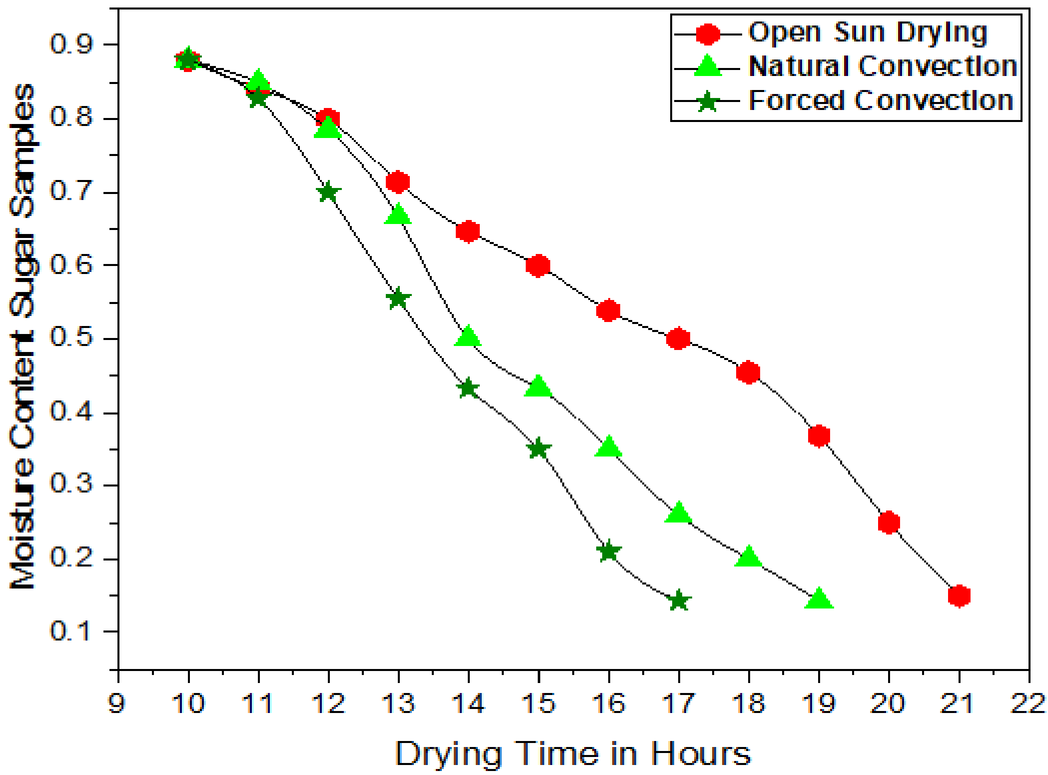

Figure 6

Moisture content of sugar solution sample

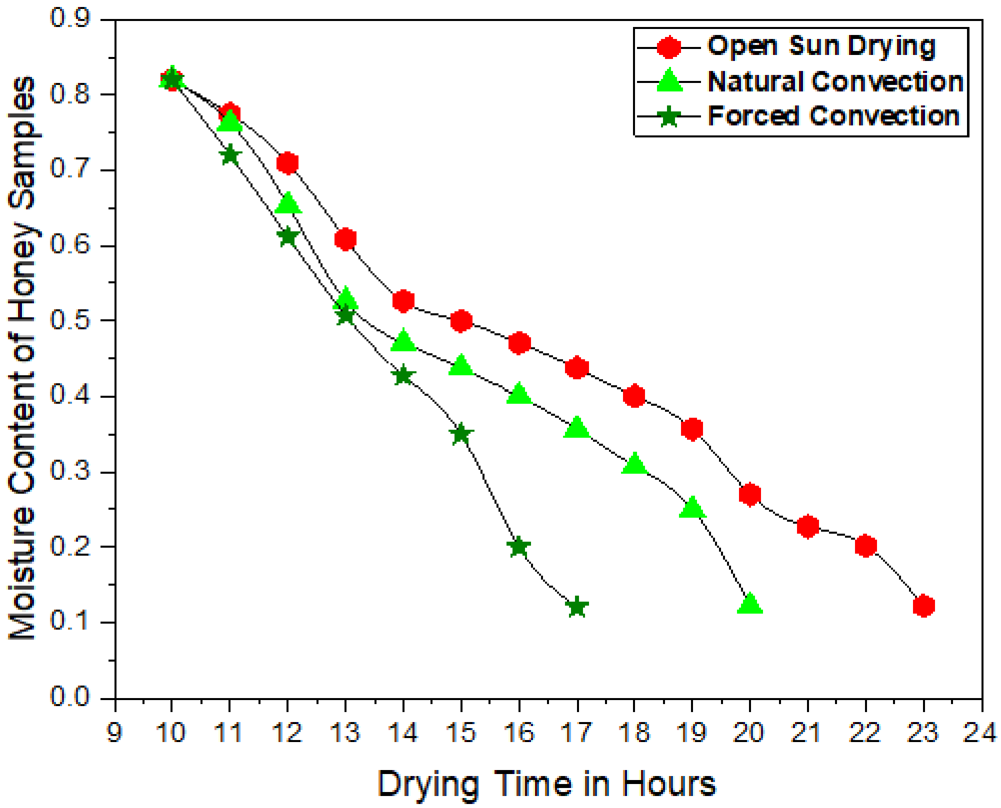

Figure 7

Moisture content of honey sample

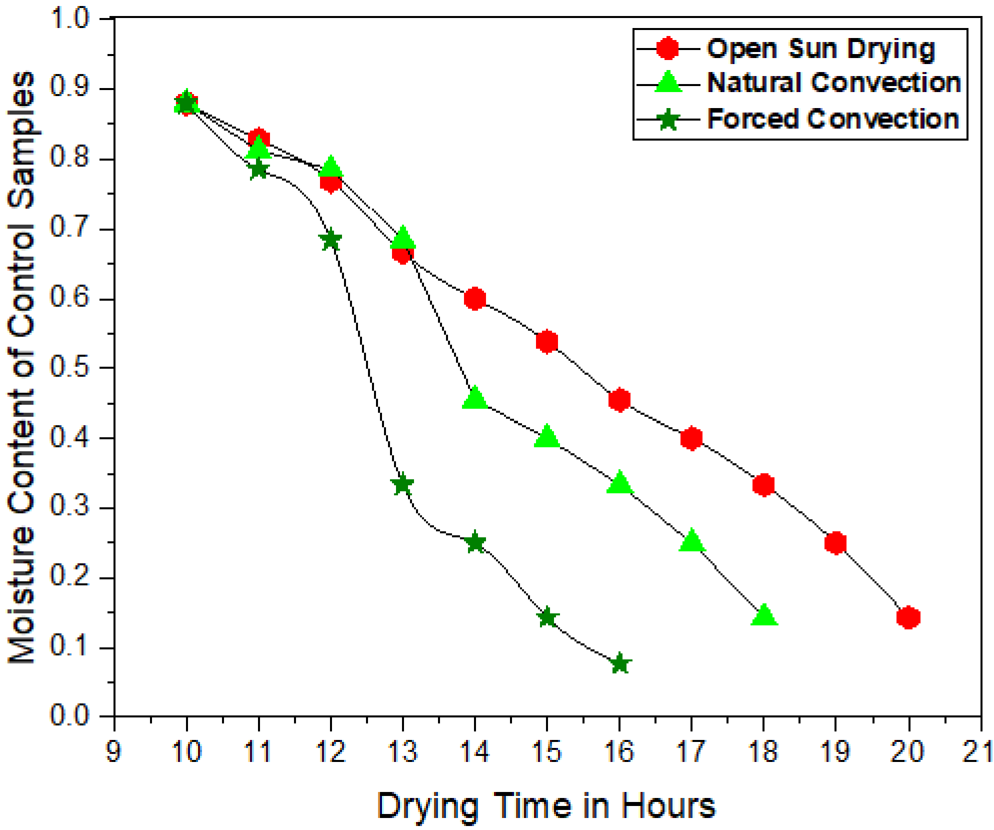

Figure 8

Moisture content of control sample

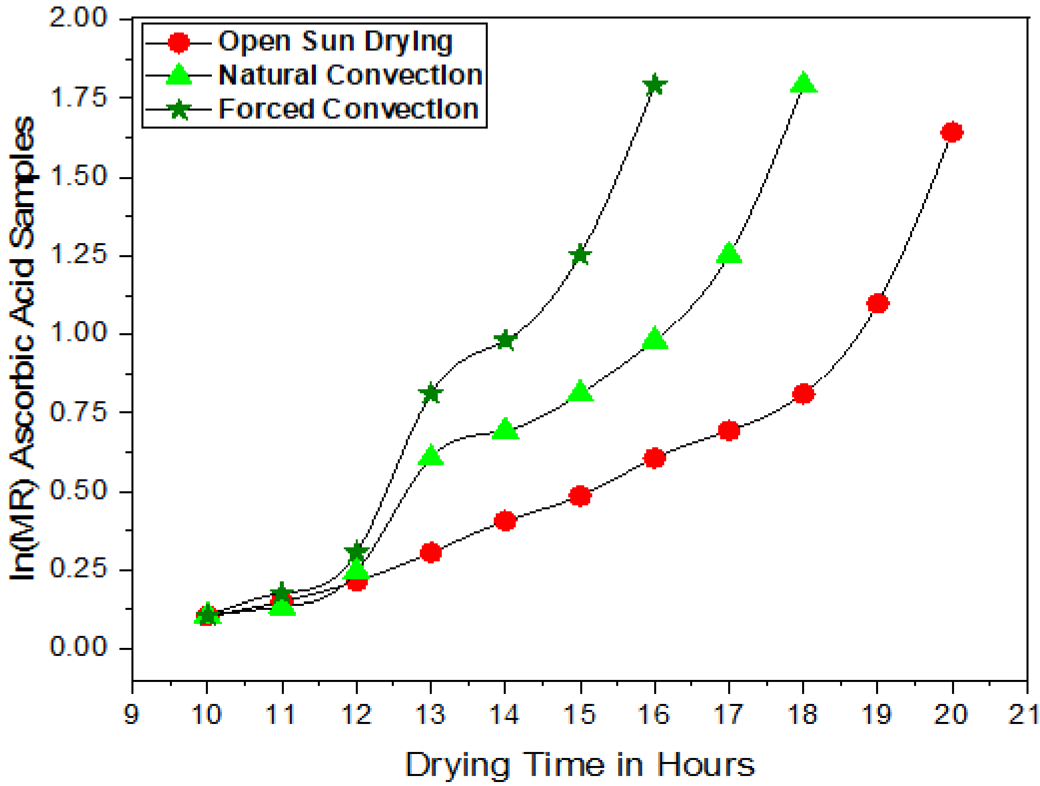

Figure 9

Drying time V/s ln (MR) – ascorbic acid sample

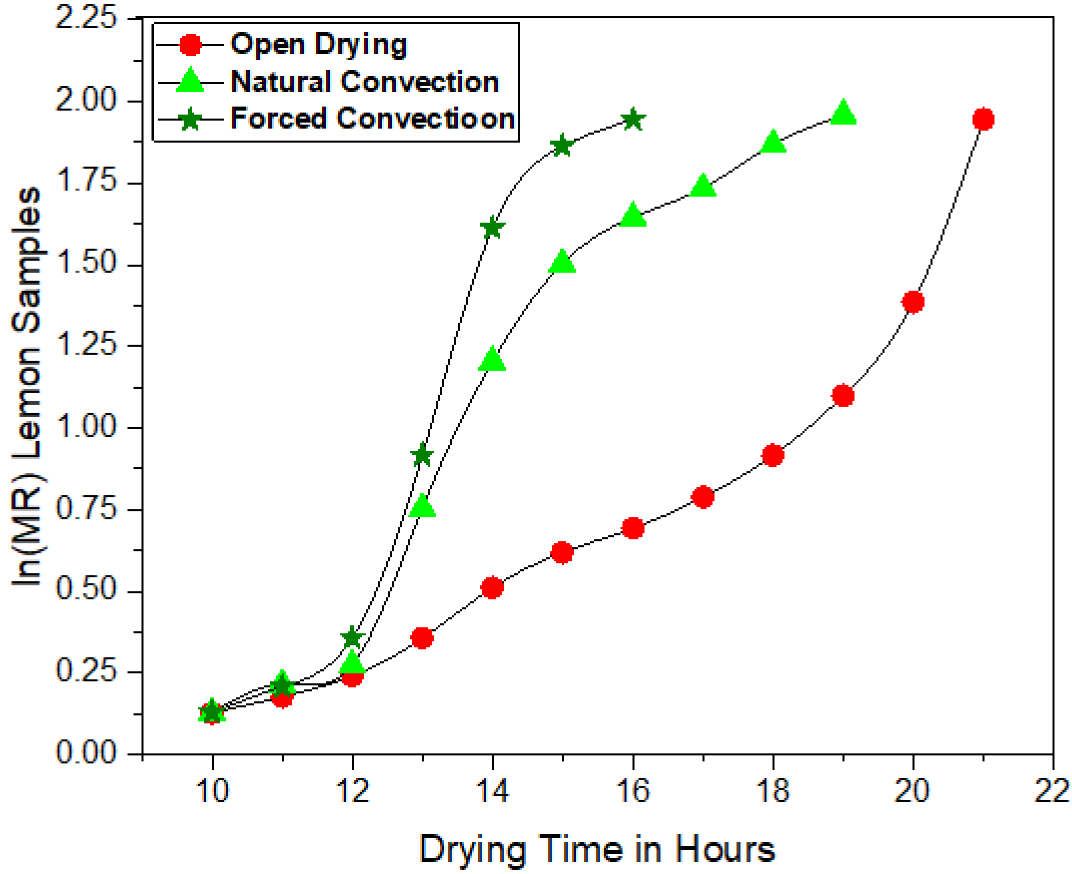

Figure 10

Drying time V/s ln (MR) – lemon juice

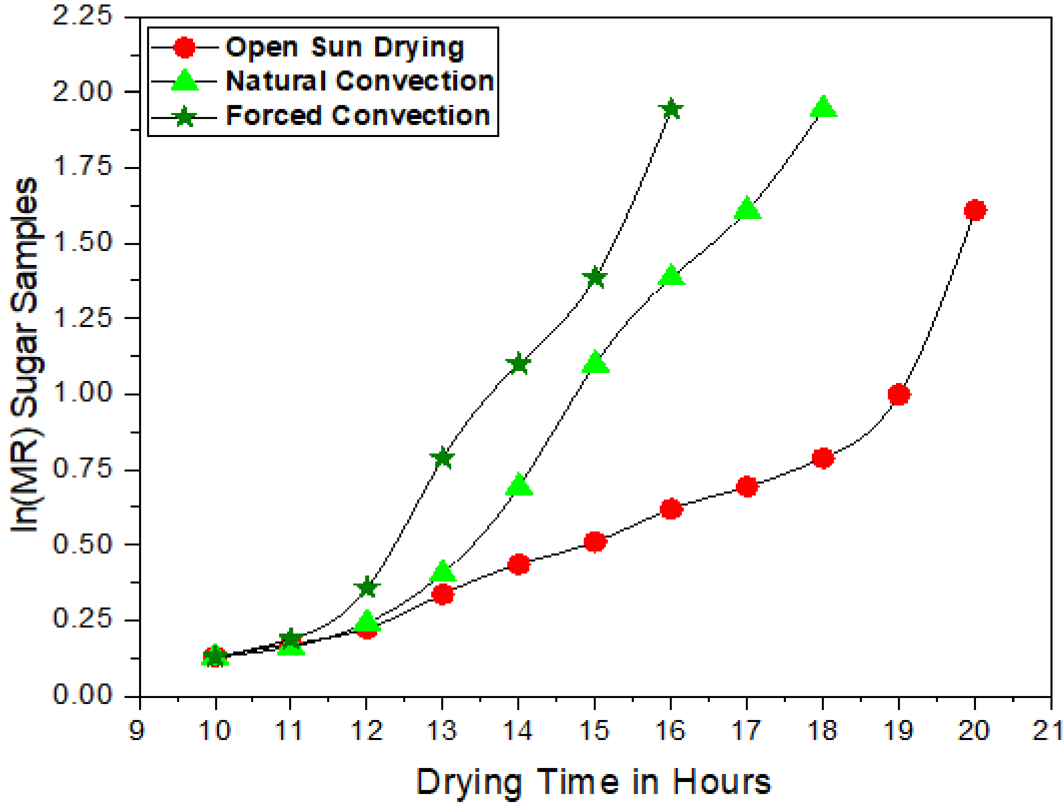

Figure 11

Drying time V/s ln (MR) – sugar solution sample

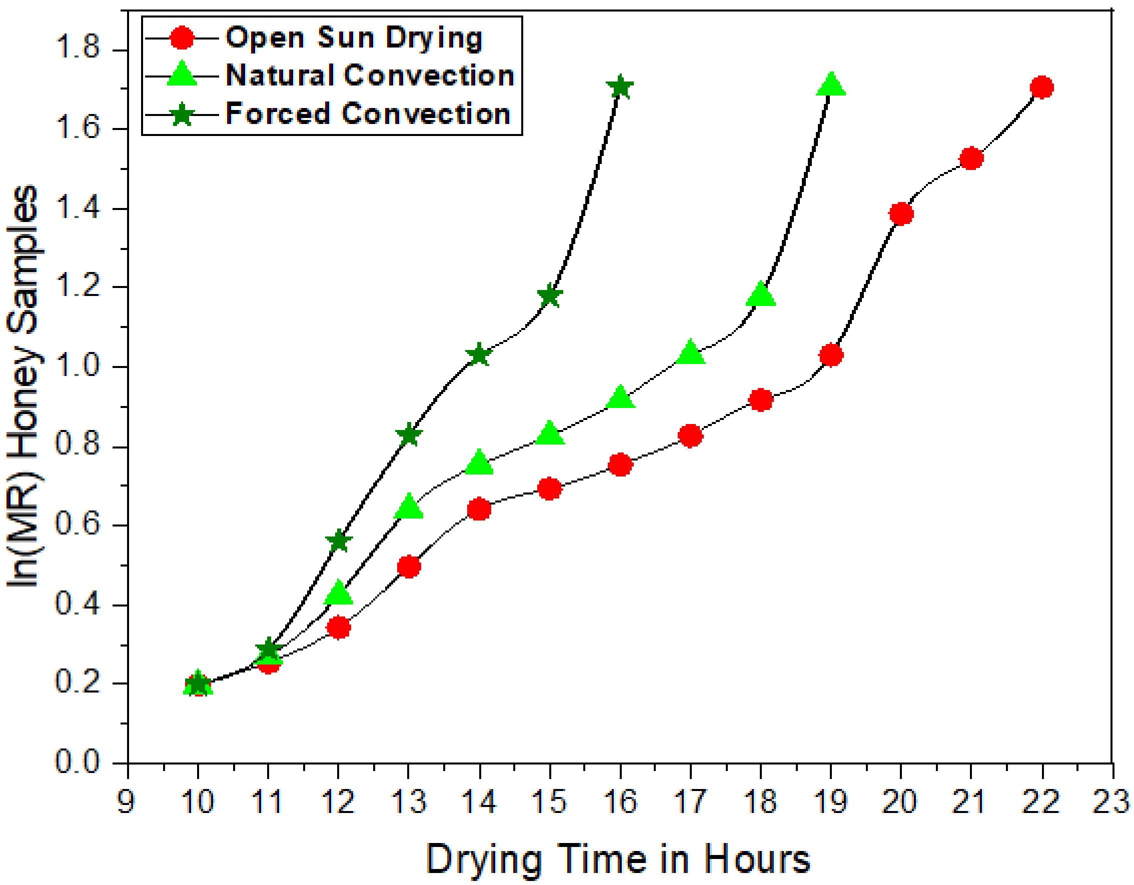

Figure 12

Drying time V/s ln (MR) – honey sample

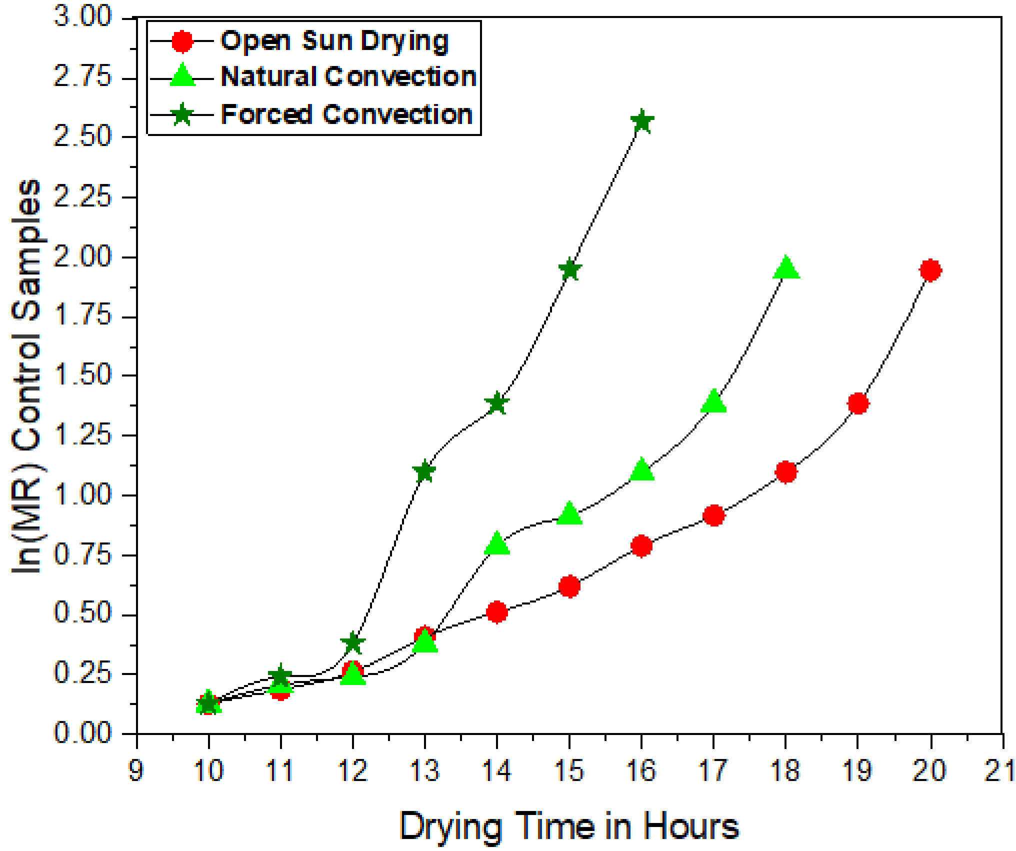

Figure 13

Drying time V/s ln (MR) – control sample

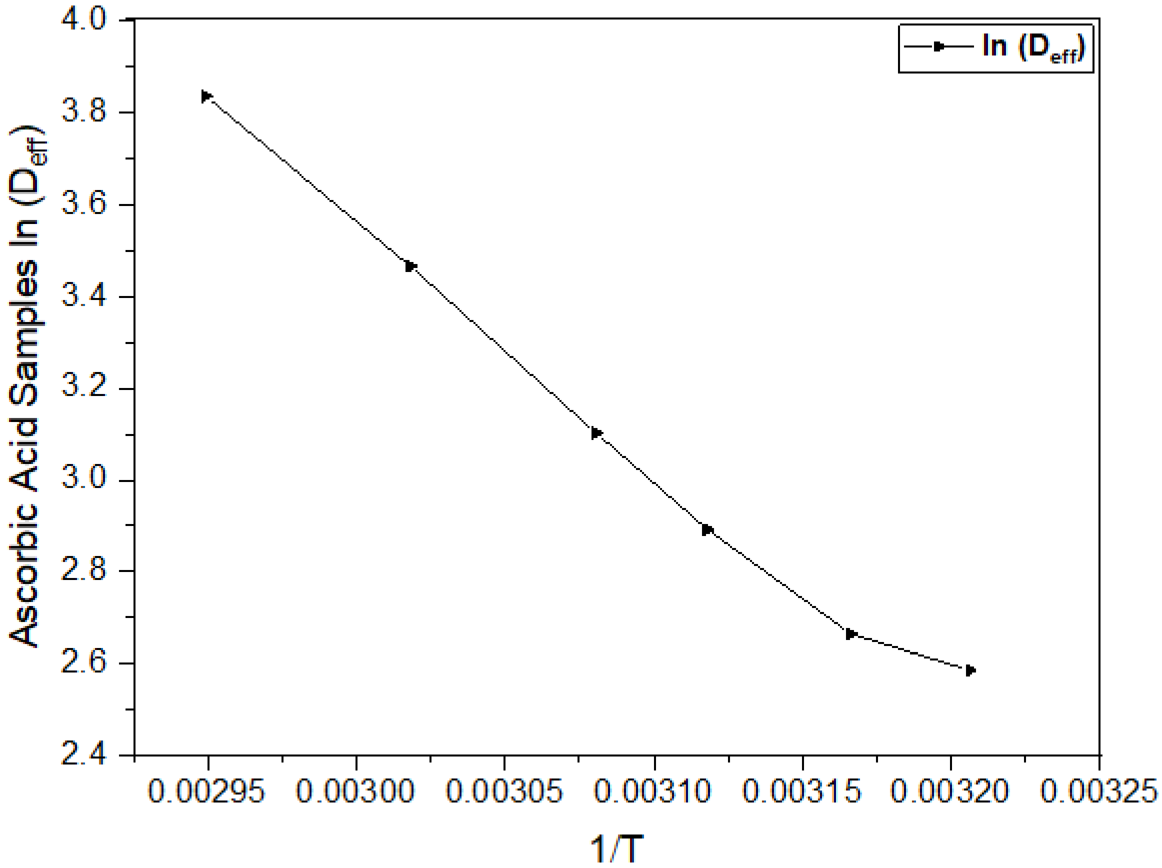

Figure 14

1/T V/s ln Deff - Ascorbic Acid Samples

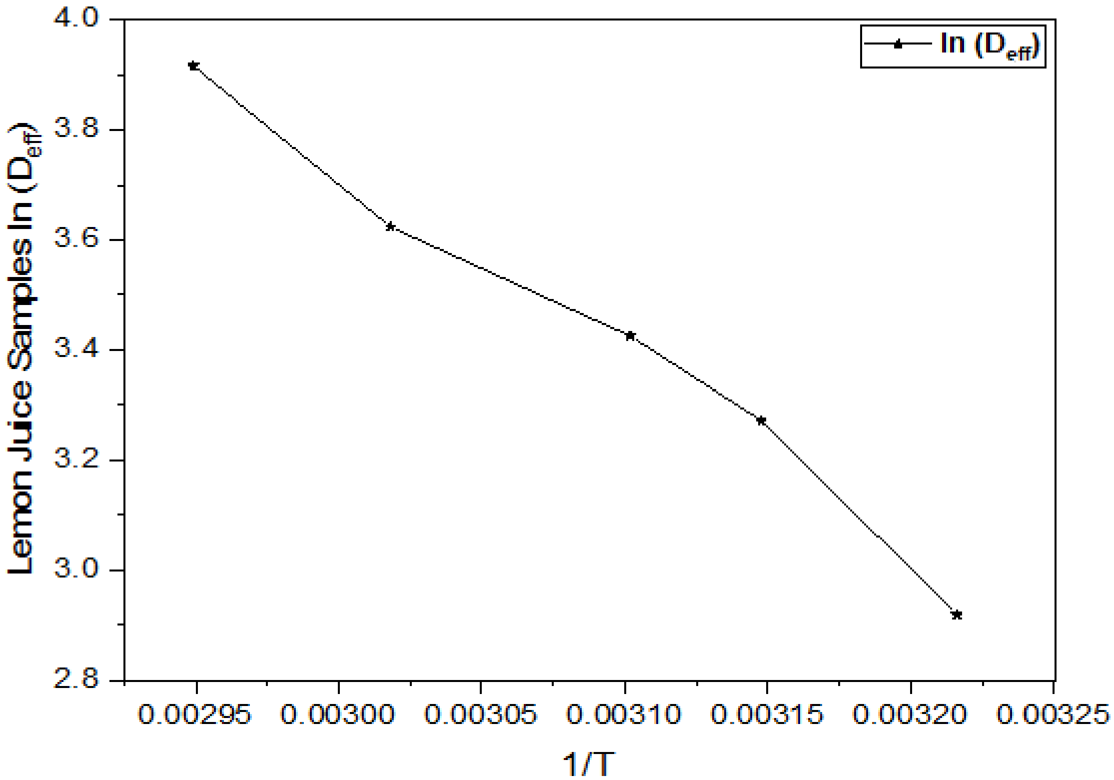

Figure 15

1/T V/s ln Deff - Lemon Juice Samples

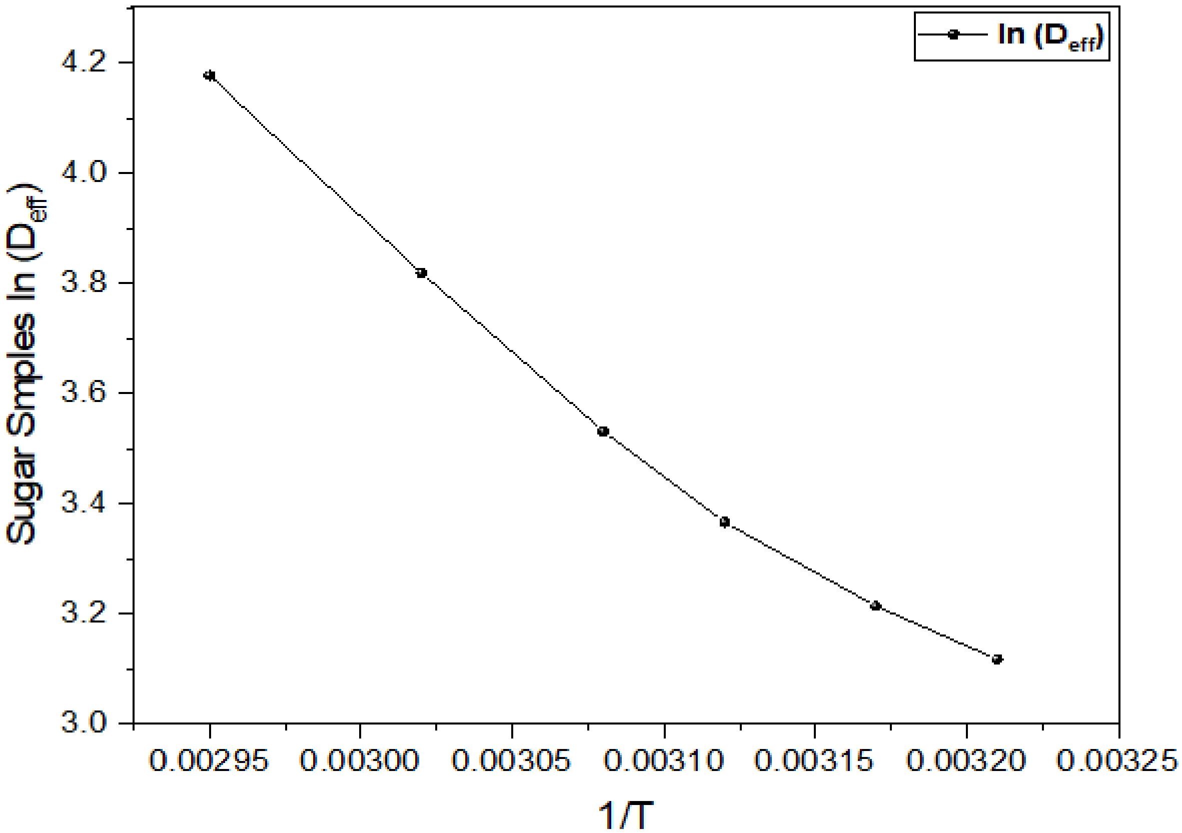

Figure 16

1/T V/s ln Deff - Sugar Solution Samples

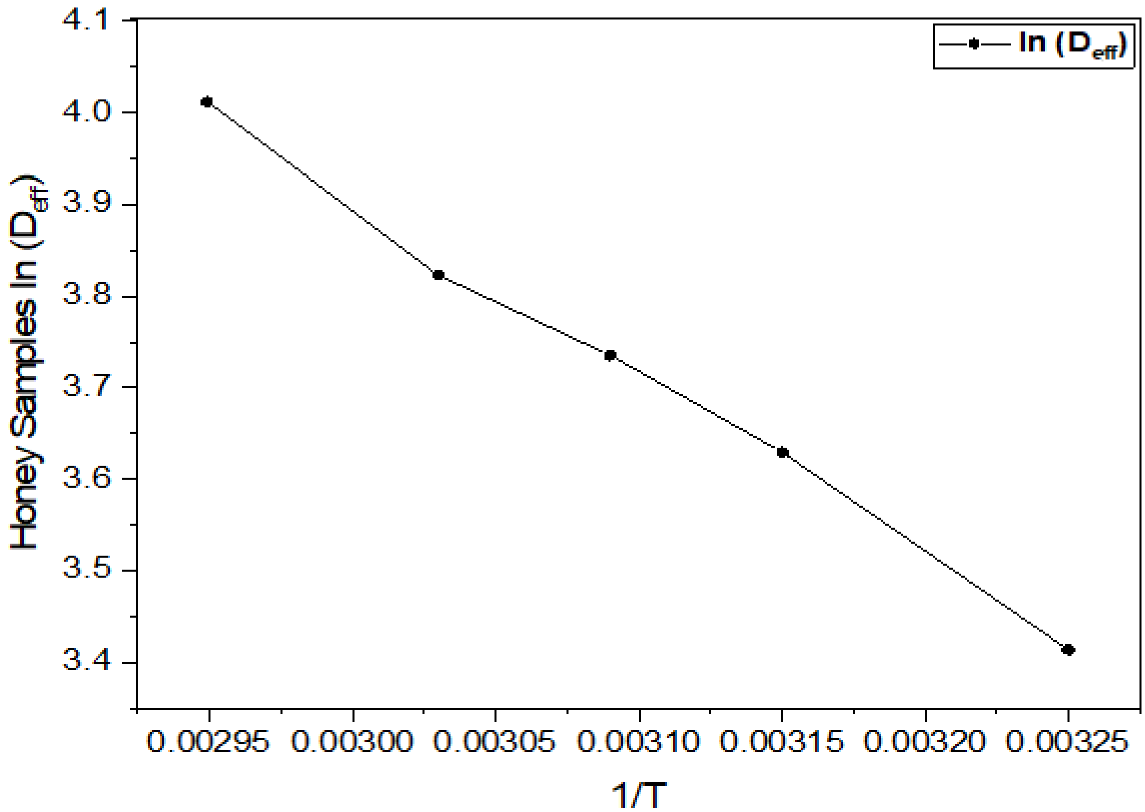

Figure 17

1/T V/s ln Deff – Honey Samples

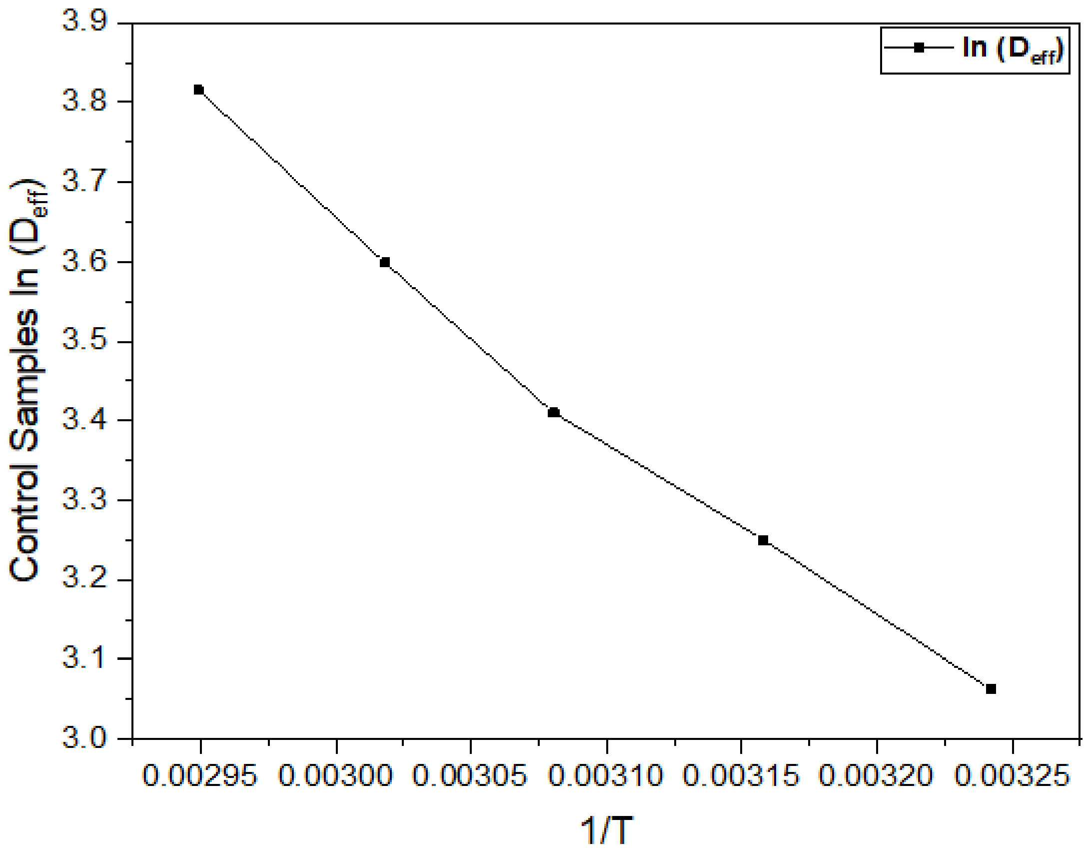

Figure 18

1/T V/s ln Deff - Control Samples

Supplementary Files

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