Drying Studies of Single Layer Thompson Seedless Grapes.

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Abstract

For determination of drying kinetics of Thompson seedless grapes a suitable experimental unit for online measurement was designed and fabricated. The drying characteristics of oil emulsion pretreated grapes were measured using ambient air under controlled air temperatures (50 to 80ºC) and velocity (0.25 to 1.00 m/s) conditions. Out of the three models considered (Page's, Single term and Two term exponential) Page's model was found to be the most suitable for describing the drying behaviour of the grapes. The dependence of drying constant K of the Page's model on process variables (Temperature and Velocity of Air) was analyzed using Arrhenius and Power Equations. It was found that the Arrhenius Equation gives better values of K than the Power Equation. It is also found that the dependence of another drying constant N of the Page's equation on the process variables can not be described in terms of Arrhenius or power Equations.

Introduction

The dried fruits have always been an important contributor source to the agricultural economy. Raisins are one of the most important dried products obtained by drying of grapes. The raisins are directly used as ingredients in the confectionery and in the form of raisin paste applied in fillings, baked goods, sauces, microwavable coating and also for natural colouring of other food products (Veronique and David, 1993). Thompson seedless and other varieties like sultana, muskat and black coraith account for most of the world raisin production (Winkler et. at., 1974). The raisins are generally produced either by traditional means (i.e. open sun or shade drying) or in mechanical dryer.

For drying studies, Grapes is considered to be rather complex system with an outer waxy cuticle and pulpous material inside. During drying of the grapes the waxy cuticle is main obstacle which restricts and controls the moisture diffusion in the grapes. (Grnearevic and Radler, 1971). Also the shrinkage of material during drying causes an increase in thickness of the waxy cuticle which reduce the permeability of water through it. Chemical pretreatment (hot or cold) is applied to the grapes to decrease the skin resistance for improving moisture diffusion through waxy cuticle (Dudman and Grnearevic, 1963 ; Grncarevic et.al., 1968; Ponting and Mebean, 1970). The hot dip pretreatment dries grapes more quickly while cold dip pretreatment gives raisins an attractive golden brown colour without producing checks or cracks on the grape berries (Grncarevic, 1963; Radler, 1964).

The type of chemical pretreatment and origin of the product significantly effect the drying behavior of the grapes. For their delicate nature and in order to obtain the quality raisins accurate prediction of the drying rates (as dependent on process variables, pretreatment and origin) is very much required. For design optimization of any dryer, knowledge of the drying constants and their dependence on drying air parameters is necessary input. A detailed study on determination of drying parameters for grapes in all usable range of temperature and velocity of the supplied ambient air has been made and the results are presented in this paper. The drying constants K and N of the Page's equation were determined from the experiments conducted and dependence of these parameters on process variables (temperature and velocity of supplied ambient air) is obtained in terms of the Arrhenius and Power model.

Mathematical Models

In single layer drying of agricultural produce numerous models have been proposed to calculate the rate of moisture loss with time. If we treat the moisture removal phenomenon similar to the convective heat loss from hot bodies (Newton's law of cooling) drying rate should be proportional to the difference in moisture content between the material to be dried and the equilibrium moisture content (EMC) at the drying air state (Hukill and Schmidt, 1960), Mathematically it can be written as,

$$\frac{dM}{dt} = - k\,(M-M_e) \qquad \text{.............................}(1)$$

Where M is the moisture content (kg/kg. on dry basis) at any time t; M_e is material equilibrium moisture content (kg/kg); k is drying constant (hrs^{-1}) and t is time, hrs. The solution of the above equation (1) yields one term exponential equation which is generally used to fit the drying curves of various agricultural produce (Henderson and Pabis, 1961).

$$\frac{M - M_e}{M_0 - M_e} = MR = A_o \exp(-k_o\, t) \qquad \text{...........................}(2)$$

Where, MR is moisture ratio, M_o is moisture content kg/kg at time t = 0,

Sharaf-Eldeen et. al. , 1979; Noomhorn and Verma, 1986 found that the accuracy of prediction of drying kinetic of material can be improved by adopting two term exponential equation having the following from:

$$MR = A_1 \exp(-k_1 t) + A_2 \exp(-k_2 t) \qquad \text{...........................}(3)$$

For the composite nature of some agricultural produce above exponential models were found to be inadequate for predicting loss of moisture from composite materials. For such materials Page proposed a modified impirical relation (Page Equation) which gives better results (Misra and Brooker, 1980; Dimante and Munro, 1991). The Page's equation is given by

$$MR = \frac{M - M_e}{M_o - M_e} = \exp(-K\, t^N) \qquad \text{...................................}(4)$$

Where N is constant, t is time, hrs.

The value of equilibrium moisture content (M_e). of raisins for different air temperature at corresponding humidity conditions applicable to present study can be computed using well known GAB equation (Singh and Singh, 1996). The dependence of Page's drying constant K and N on the experimental variables (temperature and velocity of the supplied ambient air) is obtained through the empirical Arrhenius model and Power model, in the following form

Arrhenius type model : $K \text{ or } N = \alpha_0 V^{\alpha_1} \exp\left(-\frac{\alpha_2}{T_{ab}}\right)$ ……………………………(5)

Power model: $K \text{ or } N = \beta_o V^{\beta 1} T^{\beta 2}$ ………………………………………………(6)

Where V is the velocity of drying air (m/s); T is the temperature of air (ºC); T_{ab} is absolute air temperature (K).

Data Analysis

The nonlinear least square regression method was used in the present study to evaluate the drying constants K and N, with the help of Scientific and Technical Graphics package (Microcal Origin; 1991). The coefficient of determination (R^2) and Chi^2(X^2) between the stated model calculations and experimental observations were used to evaluate the goodness of fit. The lower the value of chisquare, the better the model was taken to fit. The chi square is defined as

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{expi} - MR_{cali})^2}{N-n} \quad \text{……………………………………(7)}$$

Where MR_{expi} is the experimental moisture ratio of observations i; MR_{cali} is the calculated moisture ratio at that observation; N is the number of observations and n is the number of constants, i.e. (N-n) is the degree of freedom.

Experimental Procedure

Thin layer experimental dryer

Successful collection of thin layer drying data depends on accurate measurement of moisture removed from the sample through out the drying process. The dryer design was so developed that the instantaneous weight of the sample at different times of drying process could be measured without disturbing the sample position in the dryer. The developed experimental dryer (Fig.1) consists of air supply and flow control section; Air heating and temperature control section; Drying test chamber and Measurement units. The air required for drying was taken from the ambient by a centrifugal blower. The required air flow rate was maintained using manually operated flow control valve (V1). The air flow rate was measured using a flat plate orifice and u-tube manometer provided in the line. The ambient air is heated to the desired temperature in the heating chamber having four resistance electrical heaters of capacity 1 KW. The air temperature in the drying chamber was regulated at the required state using a dimmerstat. The entire flow section was well insulated to reduce heat losses. Temperatures at two places in the supply line were measured using mercury bulb thermometers (T_1 and T_2) and temperature of the air in the drying test chamber was measured with the help of a Pt-100 digital thermometer.

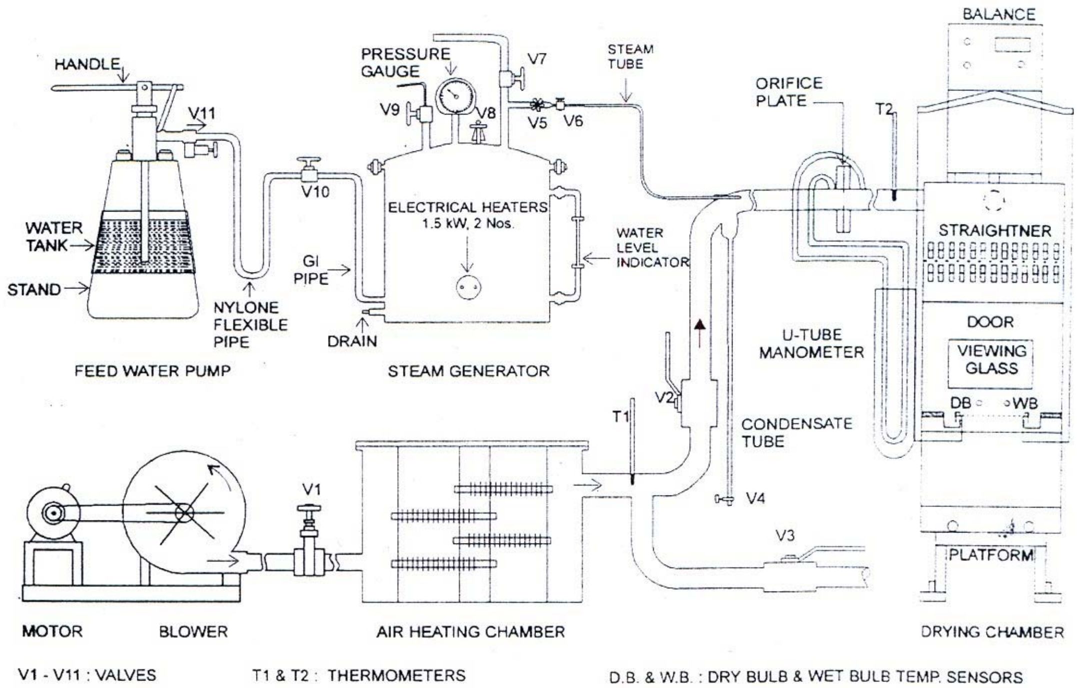

Figure: 1 Experimental Laboratory Dryer Set-up

The drying test chamber is a vertical chamber made of 8 mm thick waterproof plywood of 360 mm x 360 mm cross section and 880 mm height. The drying test chamber was divided in two parts, a plenum chamber in upper part and the sample test chamber in the lower part. Before air reaches to the sample, air passes through two flow straightners between which a wire mesh resistance is provided to ensure even pressure distribution. The straightners avoid the twisting or turbulent air flow over the sample. The entire drying test chamber was innerlined using Aluminium foil to provide thermally uniform condition in the drying chamber. A door with glass window was provided on the front side of drying test section for loading and unloading of sample tray. In the test chamber a wooden platform fitted at surface level of weighing pan with a oil channel (width 35 mm and depth 22 mm having size 180 mm x 180 mm) filled with light oil was fixed. Below the test platform the extended vertical chamber length helped in straghtning the air flow and also isolating the sample tray from the ambient conditions. The two hanger rods were suspended from a beam of a balance (capacity 200 gms. And 0.0001 resolution) placed above the test chamber. At the other end of rods a weighing pan is attached on which the sample tray (100 mm x 100 mm) was placed. The frame of the sample tray was made from Aluminum sheet and a wire mesh (5 mm x 5 mm) on which sample was placed. The bottom edges of the weighing pan was dipped in the oil. By this arrangement all the air was forced through the sample tray with oil providing an air seal.

Sample Preparation and Pretreatment

Fresh ripe hand harvested Indian Thompson seedless grapes from Nashik region were used for the drying test. The procured grapes were stored at temperature 4ºC (± 1ºC). Before the start of an experiment the grapes were kept open in the room for about two hours to bring them at room temperature.

For ensuring the uniformity of the physical characteristics of the grapes dried. The berries for each experiment were selected from the same bunch. The weight of the sample size (consisting of 36±1 berries having an average berry diameter 18 mm ± 1 mm) was kept at 77 ± 2.0 gms. After picking berries from the bunch, the characteristics such as size, sugar content, moisture content and acidity of the grapes were determined. The initial moisture content of each sample was obtained by vacuum oven method (AOAC, 1975). The selected sample was cleaned with lap water to make sample free from dust and foreign materials. To increase the water permeability through the waxy cuticle, the grapes were dipped for 3 minutes in a dipping solution consisting of a mixture of 2% proprietary dipping oil and 2.5% K_2CO_3 in water having pH value of about 10-11 (Grncarevic and Radler 1971; Winkler, 1974), After completion of the pretreatment the sample was immediately placed on the sample tray for drying test.

Experimental Measurements

The drying time for bringing the moisture content of the raisin to 0.17 to 0.18 kg/kg. dry basis (this is considered to be the safe moisture content for longer storage) was measured with the help of experimental unit. In grapes drying, the drying time is dependent on many factors such as grape variety; soluble sugars; chemical pretreatment and drying conditions. Except drying conditions all factors are assumed to be constant in this study. Air temperature (T) and air velocity (V) are taken to be the independent variables of the drying time (t). in open shade drying the maximum temperature to which grapes are subjected in the tropical climate reaches up to 45ºC. Hence 50ºC was selected as the lower limit of the temperature to which air was heated in the experiment. From the earlier studies (Possingham, 1974; George Lof, 1962), it has been concluded that the open shade drying at lower temperature is not an efficient method for the longer drying time. To dry the grapes temperature is not an efficient method for the longer drying time. To dry the grapes efficiently in mechanical dryer the air is generally heated to higher temperatures. For drying of sultana grapes the maximum permissible air temperature is considered to be 77ºC (Van Arsdel and Copley, 1964; Pointing and Mcbean, 1970). Hence the maximum temperature to which air was heated in the experiment was taken to be 80º C. In addition to these two limits, experiments were also carried out at two intermediate temperature levels of 60 and 70ºC.

It has been observed (An Arsdel and Copley, 1964) that for air velocities higher than 4 m/sec, the effect of air velocity on drying rate is negligible. Taking in to account the earlier studies (Eissen et. at., 1985; Tsamparlis, 1990) 1.00 m/s and 0.25 m/s were selected as upper and lower limits of the air velocity for our experiments. 0.50 m/s and 0.75 m/s was also used as intermediate air velocity levels. To obtain the steady state conditions in the drying test chamber at the desired level of air temperature and velocity, the hot air was passed through the test chamber for at least two hours before placing the grapes on the sample tray. The pretreated sample was arranged in single layer uniformly on the sample tray which was then placed on the pan in the drying test chamber, after it had acquired the steady state condition. The loss in moisture of the sample was determined by taking the weight of the sample plus tray when air was flowing trough the sample and also when the air flow through the test chamber was stopped for a brief period of about 10 seconds. For this the hot air from the heater box was released in to the atmosphere through the bypass arrangement using control valves (V_2 and V_3) provided for the purpose.

The observations were taken for every half hour till the moisture content of the sample reached about 17-18 % (dry basis). Air temperature at the location indicated in Fig. 1, just above the sample tray was measured with the help of RTD sensor based digital temperature indicator of 0.1ºC resolution. In total 16 experiments performed at four velocities and four air temperatures ranges, the drying time for obtaining the raising was ranging in between 8 to 52 hrs.

Results and Discussion

The experimental drying conditions and elapsed drying time for each run is given in Table:1. The effect of drying process variables (temperature and velocity) on drying time is shown in Fig. 2 and Fig.3. It is clear from Fig.2 that the drying air temperature increases the dehydration rate of the Thompson seedless grapes, owing to the increase in vapour pressure of water and the permeability of the waxy cuticle. The effect of air velocity (keeping the temperature of air constant) is shown in Fig.: 3 it is observed that at a given temperature drying time decrease with increase in velocity of the air. The variation of the drying rate with moisture content at different temperatures and at given velocity (0.5 m/s) is shown in Fig.4. From Fig. 2-4, it is seen that the constant rate drying period generally observed in the initial drying stages of some agricultural products is absent in the case of pretreated grapes for the temperature range considered. From the initial stage itself the drying rate decreases continuously with the moisture content/time. This agrees with earlier studies of Alvarez and Legus, 1986; Riva and Peri , 1986; Tulasidas et. at, 1993. Initially the drying rate is higher because of as initially water for evaporation comes from the regions near the surface.

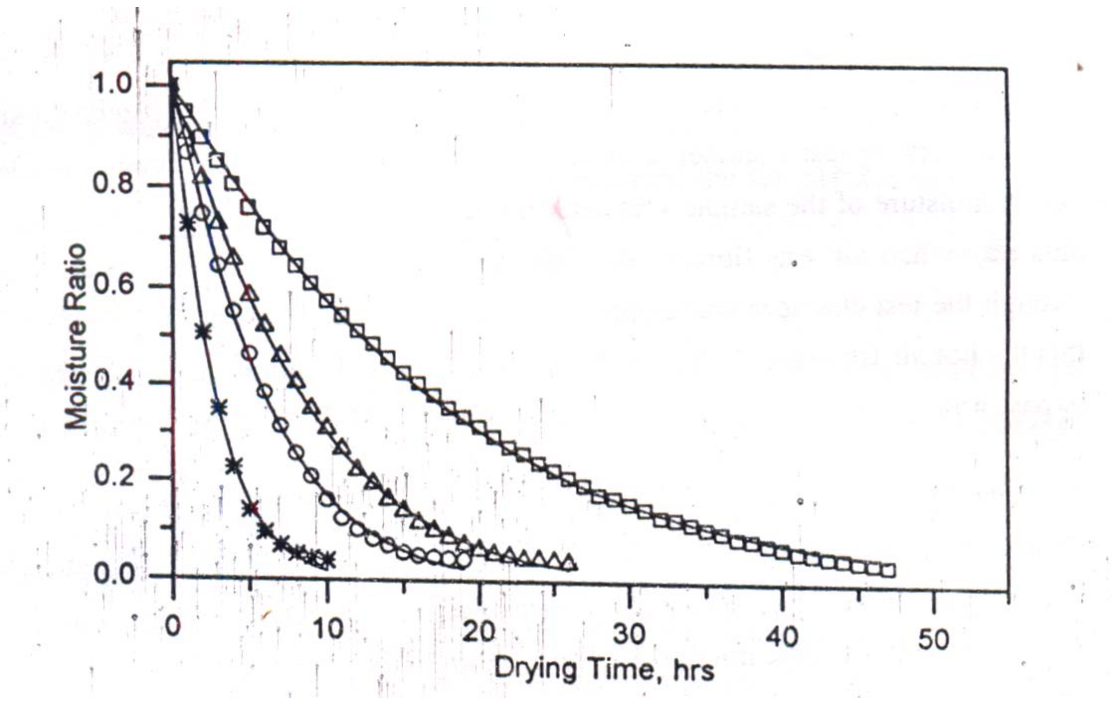

Figure: 2 Effect of air temperature on drying time of grapes at air velocity 0.5 m/s with air temperature □ 50ºC, △ 60ºC, ○ 70º C, ✱ 80ºC, - page predicted.

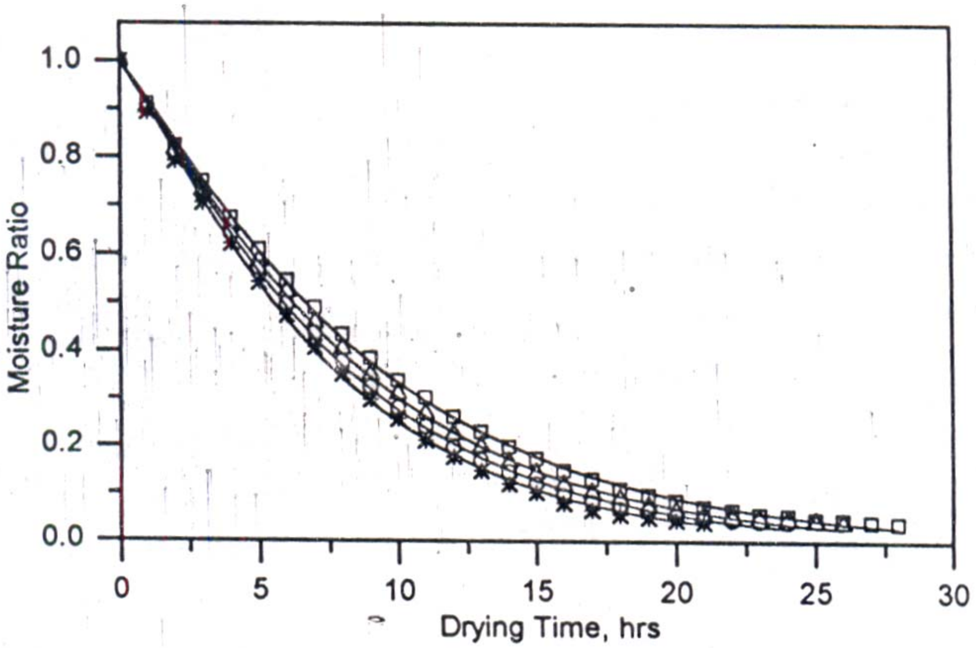

Figure: 3 Effect of air velocity on drying time of grapes at air temperature 60ºC with air velocities □ 0.25 m/s, Δ 0.5 m/s, ○ 0.75 m/s, ✱ 1.0 m/s- page predicted.

Table : 1

Experimental Drying Conditions and Drying Time to reach the Final Moisture Content (17-18%) of Thompson Seedless Grapes.

Run No.	T (ºC)	V (m/s)	R.H. (%)	Mo (% d.b.)	t (hrs)
1	50	0.25	12.00	414.07	52
2	50	0.50	12.50	415.74	47
3	50	0.75	13.00	417.12	44
4	50	1.00	13.00	419.32	41
5	60	0.25	8.00	411.70	28
6	60	0.50	8.50	414.49	26
7	60	0.75	9.00	415.55	24
8	60	1.00	8.50	414.45	21
9	70	0.25	4.50	406.90	20
10	70	0.50	5.00	408.51	19
11	70	0.75	5.50	411.38	16
12	70	1.00	5.00	412.11	15
13	80	0.25	3.50	409.94	11
14	80	0.50	3.50	410.21	10
15	80	0.75	3.00	418.71	09
16	80	1.00	4.00	401.07	08

As drying progresses the drying rate decreases with decrease of moisture content, as the water to the evaporated comes from parenchymal cells within the structure and must be transported to the surface. The falling rate region is indicative of an increased resistance to both heat and mass transfer through the inner cells and increased thickness of the crumpled and shrunken skin.

For drying conditions of each run the experimental data is fitted in equations (2), (3) and (4), the values of constant K_0 and A_0 of Eq. (2) : A_1, A_2 and K_1. K_2 of Eq. (3) and K and N of Eq. (4), were obtained and are given in Tables: 2, 3 and 4 respectively. The goodness fit of each model to the observed data is evaluated in terms of statistical parameters R^2 and X^2 and is also given in these tables.

Table : 2

The results of Nonlinear Regression Analysis of the individual drying curve at different air temperatures and velocities for Thompson Seedless grapes using single term exponential Eq. (2).

Run No.	Temp. (ºC)	Velocity (m/s)	A_0	K_0 ($x10^{-2}$ hrs^{-1})	R^2	Chi^2 ($x10^{-4}$)
1	50	0.25	1.03	5.52	0.997	2.27
2	50	0.50	1.03	6.07	0.997	2.18
3	50	0.75	1.03	6.52	0.996	3.14
4	50	1.00	1.03	7.07	0.995	3.95
5	60	0.25	1.03	11.49	0.996	3.20
6	60	0.50	1.04	12.48	0.995	4.05
7	60	0.75	1.04	13.28	0.994	4.84
8	60	1.00	1.04	14.14	0.994	5.24
9	70	0.25	1.04	15.47	0.995	4.52
10	70	0.50	1.04	17.36	0.995	4.64
11	70	0.75	1.04	19.56	0.995	4.62
12	70	1.00	1.04	21.48	0.994	5.19
13	80	0.25	1.02	33.81	0.998	2.17
14	80	0.50	1.02	36.50	0.996	2.71
15	80	0.75	1.02	39.84	0.997	3.53
16	80	1.00	1.02	45.72	0.996	4.42

It is evident from Tables: 2, 3, 4 and Fig. 5, that the Page's model (Eq.4) fits best with the experimental data for its better values of R^2 and Chi^2 compared to corresponding values for Eq.(2) and (3). Hence for further analysis only Page's model is considered.

The variation of Page's constant N with air velocity and temperature is shown in Table 4 and Fig. 6. It is seen that N increases with increase in air velocity but this increase is very marginal (about 1.4%).

Table: 3

The Results of Nonlinear Regression Analysis of the Individual Drying Curve at Different Air Temperature and Velocities for Thompson Seedless Grapes using Two Term Exponential Eq. (3).

Run No.	Temp. (ºC)	Velocity (m/s)	A_1	K_1 ($x10^{-2}$ hrs^{-1})	A_2	K_2 ($x10^{-2}$ hrs^{-1})	R^2	Chi^2 ($x10^{-4}$)
1	50	0.25	0.583	5.52	0.443	5.53	0.997	2.36
2	50	0.50	0.584	6.07	0.444	6.07	0.997	2.28
3	50	0.75	0.586	6.52	0.446	6.52	0.996	3.29
4	50	1.00	0.587	7.07	0.448	7.07	0.995	4.16

5	60	0.25	0.588	11.49	0.450	11.49	0.996	3.45
6	60	0.50	0.591	12.48	0.451	12.48	0.995	4.40
7	60	0.75	0.591	13.28	0.451	13.28	0.994	5.30
8	60	1.00	0.591	14.14	0.451	14.14	0.994	5.83
9	70	0.25	0.589	15.47	0.449	15.49	0.995	5.05
10	70	0.50	0.589	17.36	0.449	17.35	0.995	5.22
11	70	0.75	0.588	19.56	0.449	19.59	0.995	5.33
12	70	1.00	0.588	21.48	0.449	21.47	0.994	6.06
13	80	0.25	0.583	33.81	0.434	33.82	0.998	2.71
14	80	0.50	0.584	36.50	0.434	36.50	0.996	3.48
15	80	0.75	0.585	39.84	0.435	39.84	0.997	4.71
16	80	1.00	0.540	45.72	0.480	45.71	0.996	6.19

Also N increases with increase in air temperature between 50-70ºC while between 70-80ºC, it decreases with increasing air temperature. But this dependence of N on temperature is also very weak (only about 1-5%). The dependence of N on velocity and temperature of air was also modeled in the form of Arrhenius and Power Equations (Eqs. 5 and 6), but the obtained values of R^2 (= 0.23) indicate very poor fit. Hence for very small variations of N with air velocity and temperature it is tempting to ignore these variations and use the average value of N (=1.13) obtained for all velocities and temperature of the sixteen runs.

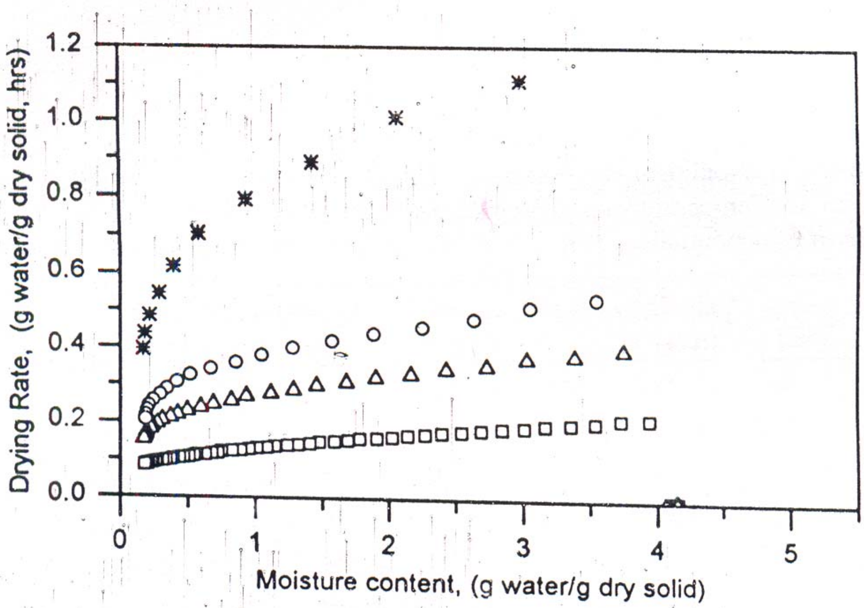

Figure 4: drying rate curves of grapes at air velocity of 0.5 m/s; with different air temperatures □ 50ºC, △ 60ºC, ○ 70º C, ✱ 80ºC.

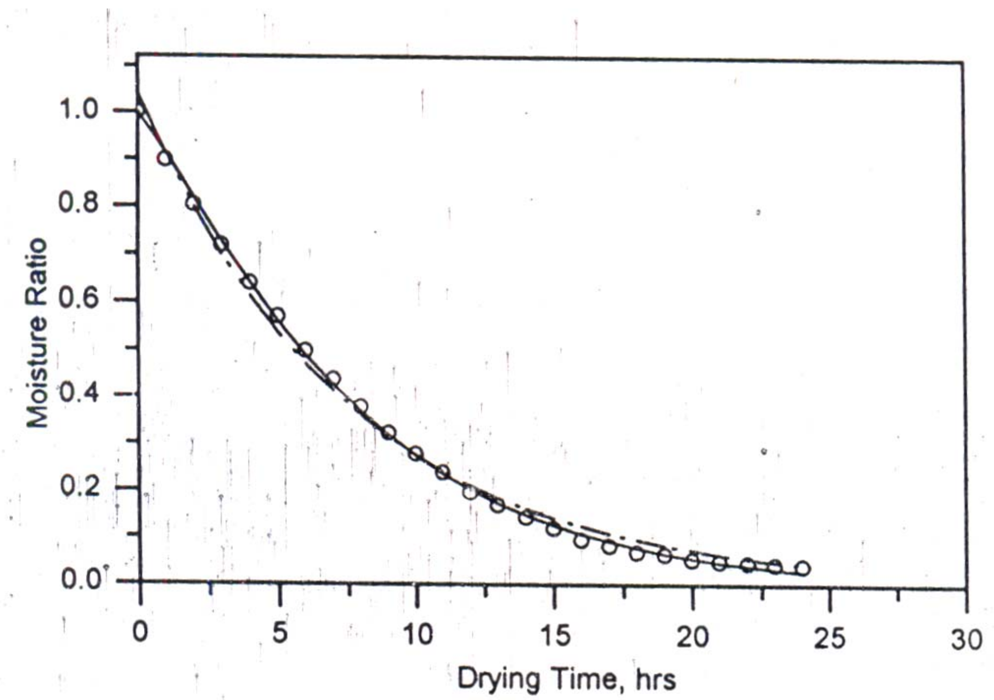

Figure: 5 Drying curves for goodness of fit, o experimental; - page equation, --------two terms and …….single term.

Table : 4

The results of nonlinear regression analysis of the individual drying curve at different air temperatures and velocities for Thompson seedless grape using Page's Eq/ (4).

Run No.	Temp. (ºC)	Velocity (m/s)	N	K (x10^{-2} hrs^{-1})	R^2	Chi^2 (x10^{-5})
1	50	0.25	1.10	4.02	0.999	7.59
2	50	0.50	1.10	4.37	0.999	5.24
3	50	0.75	1.12	4.46	0.998	8.36
4	50	1.00	1.13	4.67	0.998	0.10
5	60	0.25	1.13	8.08	0.999	4.71
6	60	0.50	1.15	8.52	0.999	6.08
7	60	0.75	1.16	8.90	0.999	7.67
8	60	1.00	1.17	9.49	0.999	6.46
9	70	0.25	1.15	10.87	0.999	6.40
10	70	0.50	1.15	12.46	0.998	0.10
11	70	0.75	1.15	14.26	0.999	6.49
12	70	1.00	1.16	15.69	0.999	8.16
13	80	0.25	1.08	30.13	0.998	0.12
14	80	0.50	1.09	32.01	0.998	0.12
15	80	0.75	1.12	34.16	0.999	9.31
16	80	1.00	1.14	38.87	0.999	5.75

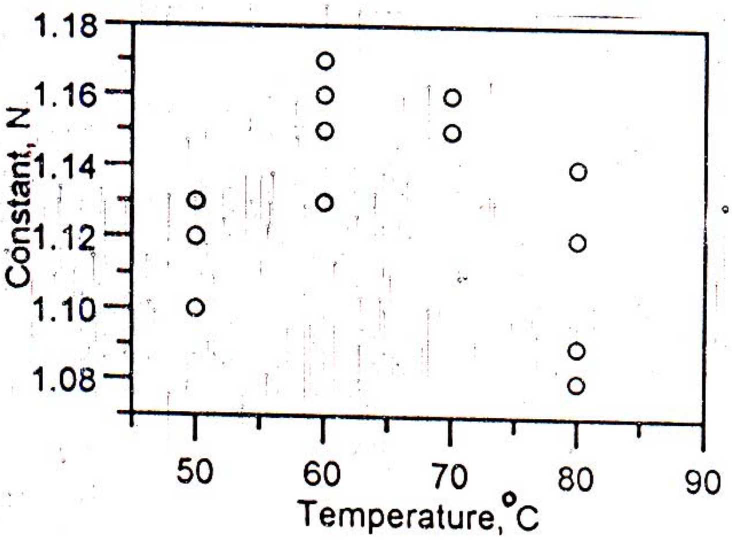

Figure : 6 Plot N against temperature

It is evident form Table : 4 that drying constant K increases with increase in air temperature and air velocity. The variation of K with drying air temperature at different velocities is shown in Fig. 7 From Fig. 7 it is observed that for the range of velocities considered the velocity effect on K is very small at lower values of the air temperatures (a variation of 16-17% between 50-60ºC). At higher temperature (70ºC) the dependence of K on velocity is stronger (a variation of 44% between 60 and 70ºC). At temperatures above 70ºC (maximum temperature recommended by Van Arsdel and Copley, 1964) the dependence of K on velocity becomes again weak (a variation of 29% between 70 and 80º). The increase in K with increase in temperature from 50-60ºC for all air velocities is significant (a variation of 95-103%), while between 60-70ºC this variation is only 35-65%. The dependence of K on air temperatures between 70-80ºC again becomes stronger (a variation of 140-177%) because of rupturing of the skin at these temperature. For the pretreated grapes in oil emulsion, the value of K determined in present study is in agreement with that obtained by Martin and Stott (1957) at air temperature of 50ºC.

The dependence of drying constants K and N on drying air velocity and temperature was obtained in the form of three parameter Arrhenius and Power Equations. The goodness of the fit for these two Equations is indicated Fig. 8 by better values of R^2 and Chi^2. From Table: 5 and Fig. 8, it can also be concluded that for its low values of chi square, the Arrhenius model is better than the power model. Hence of further discussions only Arrhenius Equation is used. The values of α_0, α and α_1 and α_2 for any given drying conditions can be used to calculate the value of drying constant K using Arrhenius equation. Along with the average values of N (=1.13), the value of K thus obtained can be used to ascertain the drying behaviour of the grapes for the given drying conditions of the drying air. To see that how far the drying behaviour predicted by this method matches with the observed experimental behaviour, the drying curves for the conditions of the drying air used in the present study were plotted and are shown in Fig. 9 and 10.

Table : 5

Results of nonlinear regression analysis of three parametric models for Thompson seedless Grapes for run no. 1 to 16 of process variables ranges:

T = 50-80ºC and V = 0.25-1.00 m/s.

Model	Parameters				
	α_0 (hrs^{-1})	**α_1**	**α_2**	**R^2**	**Chi^2**
Arrhenius	K 5.16 x 10^{10}	0.19	9059.59	0.97	325 x 10^4
	Parameters				
	β_0 (hrs^{-1})	**β_1**	**β_2**	**R^2**	**Chi^2**
Power	K 1.84 x 10^{-11}	0.19	5.41	0.96	4.27 x 10^{-4}

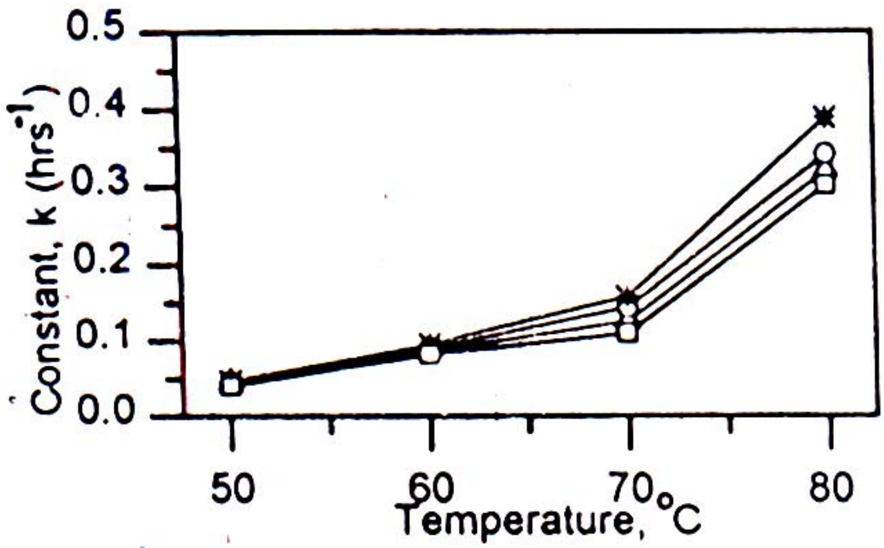

Figure: 7 Effect of air temperature on drying rate constant K at air velocities ✷ 1.00 m/s; . O 0.75 m/s; △ 0.50 m/s; □ 0.25 m/s

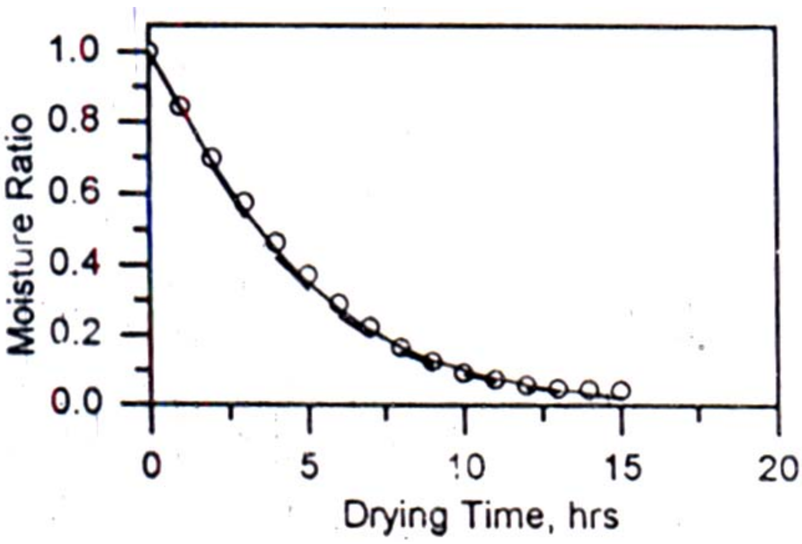

Figure:8 Drying curves for goodness of fit O experimental: - Arrhenius; ……………..Power.

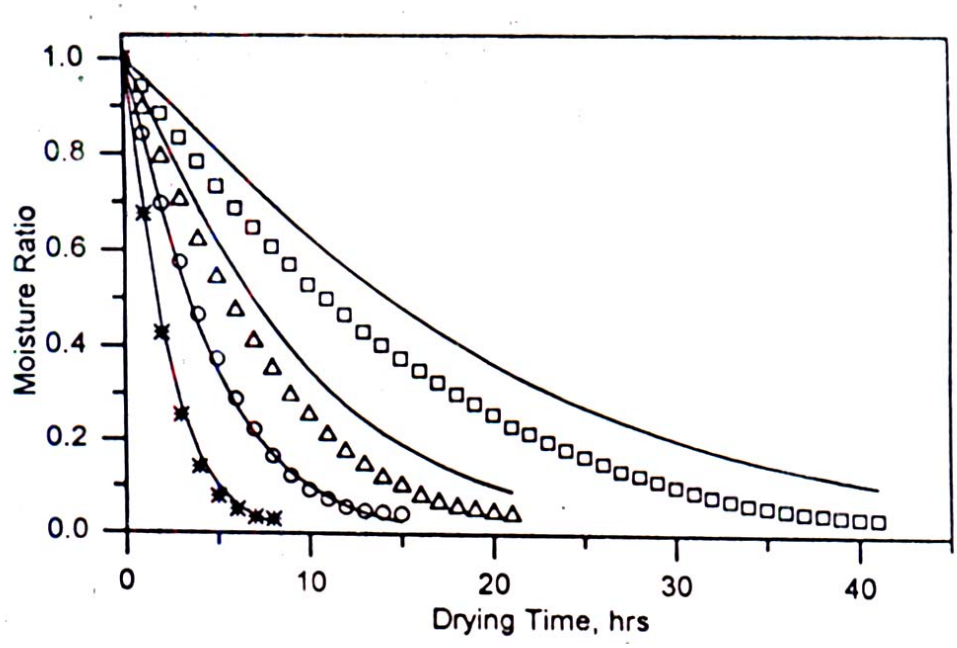

Figure: 9 Drying curves for goodness of fit with Arrhenius Eq. at different air temperatures for run No. □ 4, △ 8, ○ 12, ✱ 16.. – predicted.

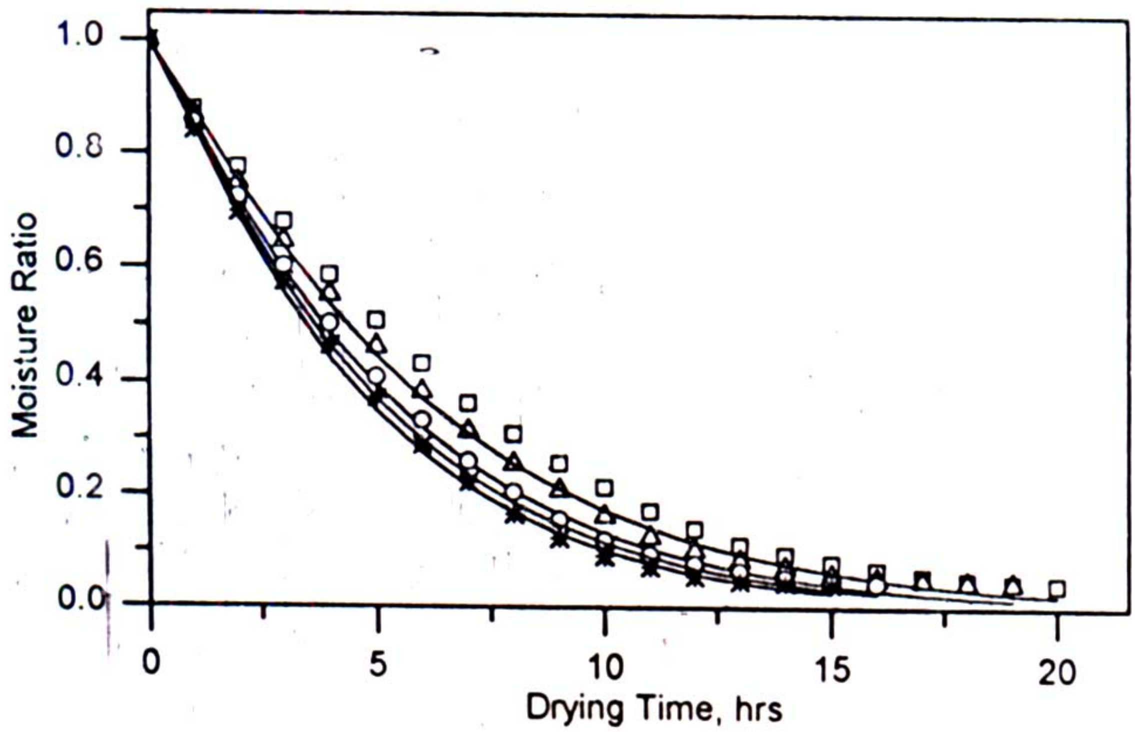

Figure: 10 Drying curves for goodness of fit with Arrhenius Eq. at different air velocities for run NO. □ 9, △ 10, ○ 11, ✱ 12..- predicted.

It is observed from Fig. 9 that thought the agreement between the predicted and observed values is good at air temperatures of 70 and 80ºC, the agreement at temperatures 60 and 50ºC is poor. Similarly Fig. 10 indicates that as higher velocities the predicted results matches well with the observed behaviour, but the agreement is not very good at lower air velocities.

As it has been pointed out that for the rupturing of the grapes skin above 70ºC, K and N constants show different behaviour in the temperature range of 70-80ºC. As the behaviour of drying process changes above 70ºC Fig. 7, it was decided to obtain the values of Arrhenius parameters separately in the temperature range of 50-70ºC. The new values of these parameters obtained for temperature range of 50-70ºC are given in Table: 6.

Table : 6

Modified results of nonlinear regression analysis of three parameter Arrhenius model for Thompson seedless grapes for run no. 1 to 12 of process variables Range: T = 50-70ºC and V = 0.25-1.00 m/s.

Model	**Parameters**				
	α_0 **(hrs^{-1})**	α_1	α_2	R^2	**Chi^2**
Arrhenius	K 2.91×10^6	0.22	5749.05	0.97	3.51×10^{-5}

For the values of drying constant K obtained with the use of new values α_0 , α_1 and α_2 the average value of N (=11.14), the drying curves were again drawn for different air temperatures and velocities and shown in Fig. 11 and 12 respectively. Comparing Fig. 11 with Fig. 9, it is seen from Fig. 9 that the Arrhenius Equation over predicts the moisture ratio values at different drying time, whereas in Fig. 11 it is under predicts the moisture ratio values at different drying time. Comparison with Fig. 12 with 10 shows that with the use of new values of α_0 , α_1 and α_2 Arrhenius Equation gives better agreement between the predicted and observed values at different velocities. Though the variation of N with air temperatures and velocities is small, it is obvious from Table: 4 that at different temperatures we can take different velocity average values of N. Choosing velocity

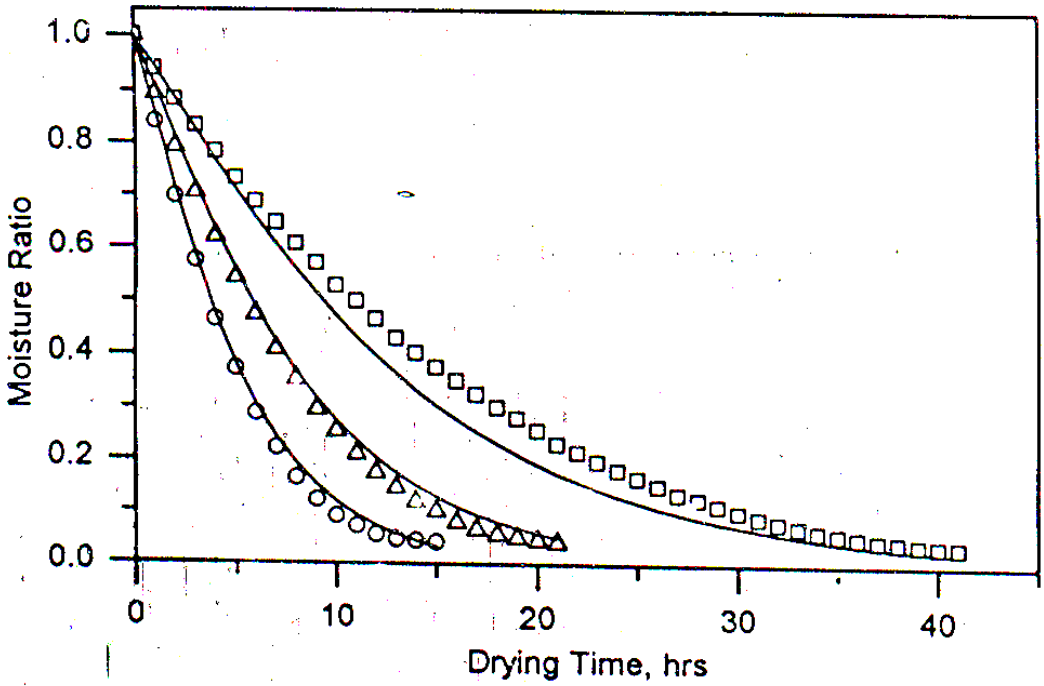

Figure: 11 Modified drying curves showing improved goodness of fit with Arrhenius Eq. at different air temperatures for run No. □ 4, Δ 8, ○ 12,.- predicted.

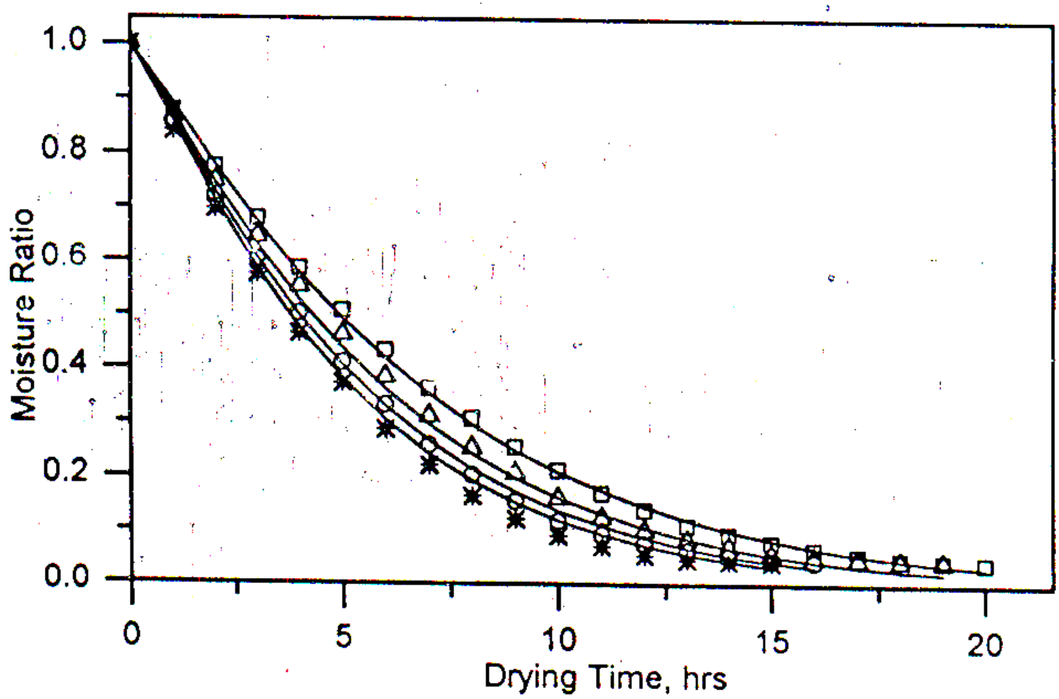

Figure: 12 Modified drying curves showing improved goodness of fit with Arrhenius Eq. at different air velocities for run No. □ 9, Δ 10, ○ 11, ✱ 12..- predicted.

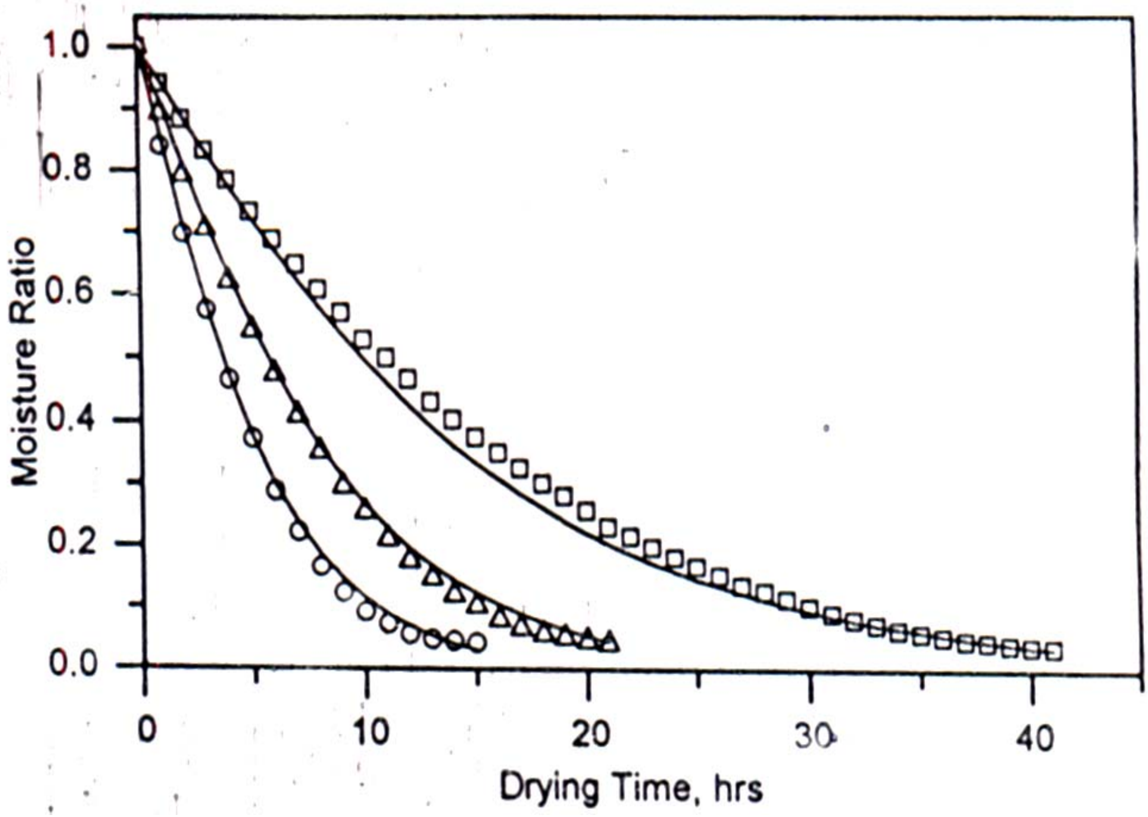

Figure: 13 Modified drying curves showing best it with Arrhenius Eq. at different air temperatures for run □ 4, △ 8, ○ 12,.- predicted..

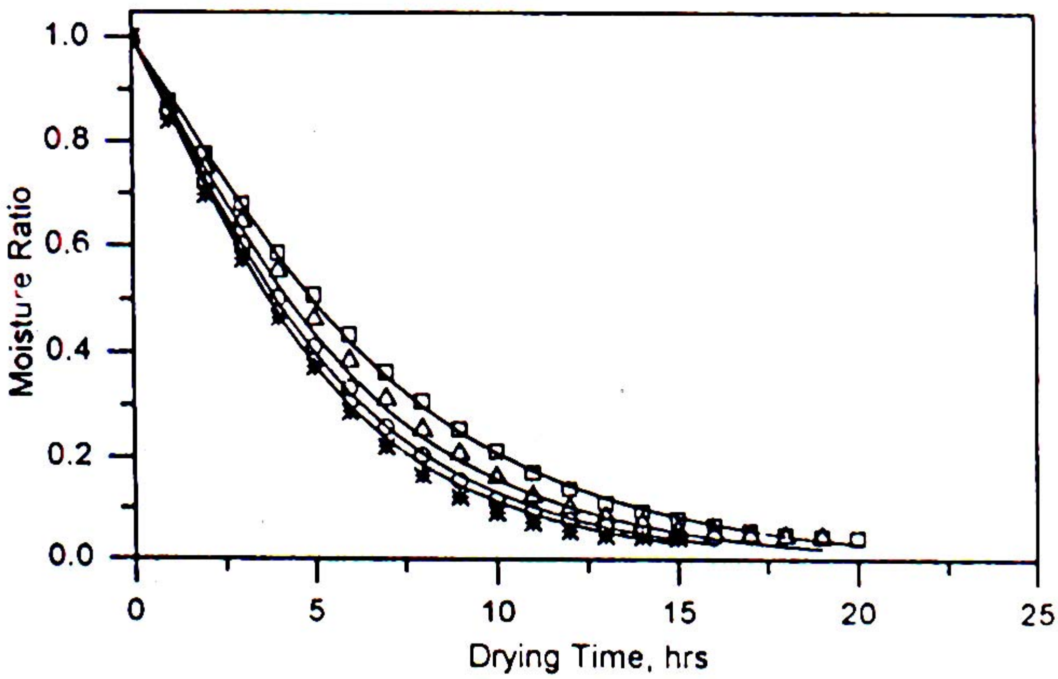

Figure: 14 Modified drying curves showing best it with Arrhenius Eq. at different air velocities for run No. □ 9, △ 10, ○ 11, ✷ 12..- predicted.

average value of N = 1.11 at air temperature 50ºC, N = 1m 15 at air temperatures 60 and 70ºC and with new value (Table 7) of α_0, α_1 and α_2, the drying curves were again plotted and are shown in Fig. 13 and Fig. 14. It is seen from these curves, that at different air temperature and velocity runs the predicted values are in very good agreement with the experimentally observed values. Inspite of very small variation of the N values at different temperatures and velocities of the drying air, it is not advisable to use its average value for all temperatures and velocities. For a given temperature conditions, it is more appropriate to use the velocity average value of N at that temperature.

Conclusions

Kinetic studies were carried for Thompson seedless grapes for all ranges of interest of process variables to determine drying constants. For predicting the variation of the moisture ratio with time, the Page's model is more suitable than the Single term and Two term exponential models. The dependence of drying constants K and N of the Page's model on process variables (velocity and temperature) was analyzed in terms of Arrhenius and power model. It is found that Arrhenius model gives better result compared to that of power model. The drying behaviour of the grape shows a change above 70ºC. which may be due to the rupturing of the skin at these temperatures.

Notation

exp	Exponential
K	Drying rate constant (hrs)
M	Moisture content (% dry basis)
MR	Moisture Ratio
N	Constant of equation (4)
R.H.	Relative humidity (%)
t	Time (hrs)
T	Air Temperature (ºC)
T_{ab}	Absolute temperature (K)
V	Air flow velocity (m/s)
α_0 , α_1 , α_2	Empirical constant of Eq. (5)
β_0 , β_1 , β_2	Empirical constant of Eq. (6)

Subscript

cal	Calculated
e	Equilibrium
exp	Experimental
f	Final
o	Initial

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