STUDIES ON
FLUIDISED BED DRYING OF ONION

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IN
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CERTIFICATE-I

This is to certify that the thesis entitled **"STUDIES ON FLUIDISED BED DRYING OF ONION"** submitted by **Jagannath Prasad Bebartta** in partial fulfillment for the award of the Degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING) IN POST HARVEST PROCESSING AND FOOD ENGINEERING** to the Orissa University of Agriculture and Technology, Bhubaneswar is a record of *bona fide* research work carried out by him under my supervision and guidance.

No part of the thesis has been submitted for any other Degree or Diploma. The help and sources of information as have been availed in course of this investigation have duly been acknowledged.

Sanjaya

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CERTIFICATE-II

This is to certify that the thesis entitled **"STUDIES ON FLUIDISED BED DRYING OF ONION"** submitted by **Jagannath Prasad Bebartta** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirement for the award of the Degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING) IN POST HARVEST PROCESSING AND FOOD ENGINEERING** has been approved by the student's advisory committee after an oral examination on the same in collaboration with the external examiner.

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CRAVINDRA NAIK)

I bow down my head before
LORD JAGANNATH,
the almighty, whose blessings as I
feel, have always been with me.

Whatever I claim to have done
so far is nothing but the output
of what He has initiated in
my mind and soul.

DEDICATED
TO
MY BELOVED
PARENTS

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ABSTRACT

Studies were carried out to investigate the feasibility of fluidised bed drying of onion with different combinations of air temperature (50°, 60°, 70° and 80°C), air velocity (1m/s, 2.5m/s and 4m/s) and slice thickness (2mm, 4mm and 6mm). The drying characteristics of onion under fluidised bed such as drying rate, moisture ratios and moisture diffusivities at different drying conditions were analysed. For determining the optimum parameters for drying, different quality aspects like rehydration characteristics, colour, ascorbic acid content and pungency of the dehydrated samples were considered along with the organoleptic attributes like taste, colour, flavour (pungency), texture and overall acceptability.

It was observed that the drying behaviour of onion was better represented by the Page's model as compared to the Exponential model. The moisture diffusivity values of onion ranged between 2.148×10^{-9} and 1.474×10^{-7} m^2/s. It was observed that all the quality parameters were important in deciding the optimum drying conditions. The maximum rehydration ratio of 4.144 was obtained for drying 2mm thick slices at air temperature of 70°C and air velocity of 4m/s, which was followed by 2mm thick slices dried with air temperature and velocity of 60°C and 4m/s, respectively. The amount of pyruvic acid content of dehydrated onion samples ranged between 90.40 μmole/g dry matter and 480.07 μmole/g dry matter. The enzymatically developed pyruvic acid content of fresh onion was estimated to be 768.10 μmole/g on dry weight basis. From the organoleptic point of view, the 2mm thick onion slices dehydrated at 60°C with air velocity of 4m/s was rated as the best. However, 2mm thick slices dried at 70°C and 4m/s air velocity and 1m/s air velocity were also acceptable at 5% level of significance. The organoleptic test of rehydrated samples also indicated that the 2 mm thick slices dried under fluidised bed at 60° and 70°C were acceptable. Considering all quality aspects, it is suggested to dry onion under fluidised bed with a slice thickness of 2 mm, air temperature of 60°C and air velocity of 4 m/s. In addition to giving a better quality product, it will also help to save in 60% drying time as compared to hot air convective drying at 60°C.

Key words: Onion, Fluidised bed drying, Exponential model, Page's model, Moisture diffusivity, Rehydration ratio, Pyruvic acid, Ascorbic acid, Surface colour, Organoleptic qualities

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
A	Constant
Agril.	Agricultural
B	Constant
C.A.E.T.	College of Agricultural Engineering and Technology
CD	Critical difference
cm	Centimeter
conc.	Concentration
d.b.	dry basis
D_{eff}	Effective moisture diffusivity
Dept.	department
E_a	Activation energy
Engg.	Engineering
Eq.	equation
et al.	And other people
etc.	Et cetra
exp	Exponent
Fig.	Figure
g	Gram
Govt.	Government
ha	hectare
Horti.	Horticulture
hr	Hour
i.e.	that is
K	degree Kelvin
kg	kilogram
kJ	Kilo Joules
k_p	Drying constant in Page's model
k_s	Drying constant in exponential model
L	Slab thickness
ln	Natural logarithm
m	Meter
M	moisture content at any time

m.c.	Moisture content
m/s	Meter per second
M_0	Initial moisture content
m^2	Square meter
m^2/s	Square meter per second
max	Maximum
M_e	Equilibrium moisture content
mg	milligram
min	Minute
ml	Milliliter
MR	Moisture ratio
MSAMB	Maharastra State Agricultural Marketing Board
n	Drying rate constant in the Page's model
No.	Number
^oC	Degree centigrade
OD	Optical density
OUAT	Orissa University of Agriculture and Technology
ppm	Parts per million parts
r^2	Square of correlation coefficient
RH	Relative humidity
RT	Room temperature
s	Second
TSS	Total soluble solid
vit.	vitamin
viz.	namely
vol.	volume
Vrs.	Versus
W	watt
w.b.	weight basis
W_1	weight of the empty moisture dish along with the cover
W_2	weight of the empty moisture dish along with the cover and sample
W_3	weight of the empty moisture dish along with the cover and dried sample
wt.	Weight

CHAPTER - I

Introduction

AUM

CHAPTER I
INTRODUCTION

Onion (Allium cepa L.) is one of the major bulb crops of the world and is the most important commercial vegetable crop grown in India. A large quantity of onion is used as fresh. The surplus quantity in the market is processed by dehydration for export and for armed forces (Pawar et al. 1988). India is the largest producer of onions in the world after China with a total production of 6034.25 thousand tonnes in 2005-06 (MSAMB, 2007).

Onion is highly valued for its flavour and nutritional qualities (Patil et al. 1991). Fresh onion contains about 86.8% moisture, 11.6% carbohydrates, 1.2% proteins, 0.2-0.5% calcium, 0.05% phosphorous, and traces of iron, thiamine, riboflavin and ascorbic acid (Raj et al. 2006). It also contains moderate amounts of other soluble vitamins and minerals (Gopalan et al. 1989).

The pungency in onion is due to a volatile oil known as allyl-propyl-disulphide. Onion pungency develops when the enzyme allinase hydrolyses the flavour precursors S-alk(en)yl L-cystein sulphoxides, during tissue bruising or maceration (Schwimmer 1971). The reaction products are pyruvate, ammonia and many volatile sulphur compounds, which are characteristic onion flavour and aroma (Schwimmer and Weston, 1961).

Generally, onion is available throughout the year and can be stored under ambient conditions on improvised racks under thatched roof with a free flow of air. Onion bulbs continuously loose water and dry matter under all storage conditions. Despite the fact that the world onion production is steadily increasing due to improved production technology and expansion of area under cultivation; the post-harvest losses due to sprouting, rotting, rooting and physiological loss in weight (PLW) account for 40-60% of annual production in India (Raj et al. 2006). Non-availability of sufficient storage space, transport and proper processing facilities at the production point aggravate the situations.

The preservation of vegetables by dehydration offers a unique opportunity and the use of artificial drying to preserve agricultural commodities is expanding, creating a need for more rapid drying techniques as well as less energy consumption for drying. Dried and processed vegetables constitute between 40-42% of total exports of processed products both by volume and by value, prominent among them being dehydrated onion flakes and powder (Chadha 1995). Dehydrated onions can be conveniently used by the consumer. Dehydration in addition to improving the shelf life, reduces the volume and weight, and thereby the cost of transportation. It can help to improve keeping quality and alleviate irregularity in price fluctuation during off-season. However, dehydrated onion has not gained wide consumer acceptance because after rehydration it does not match in flavour, texture and colour with the fresh onion (Sagar 2001).

Presently, there are some industries in India, which produce dehydrated onion flakes for export as well as for domestic consumption. But during commercial dehydration of white and red onion flakes, pink discolouration often adversely affects the quality of dried onion flakes. Control of pink discolouration is very important to attract the consumer and also to compete in the market (Rajkumar and Sreenarayanan 2001). New and innovative techniques that increase drying rates and enhance dried onion quality are receiving considerable attention (Mongpraneet et al. 2002).

Onion flavour and colour are generally perceived as important quality attributes. Quality changes during the drying process are influenced by drying temperatures. The volatile compounds responsible for the aroma and flavour of onions exhibit low boiling points, and accordingly, are often lost during high temperature drying. Maillard browning reactions induced by the drying process decrease nutritional value, change the colour and flavour and induce textural changes (Adam et al. 2000).

In some industrialized countries, onion is dried using high-temperature commercial dryers. Prepared onion is uniformly sliced to required thickness and the onion slices are dried in a thin layer at a temperature near 60°C to final moisture content of less than 9%. Extensive research has been carried out on onion drying by conventional hot-air methods (Sarsavadia et al. 1999). However, the major disadvantage associated

with hot air drying is the long drying time even at temperatures near 60°C, resulting in degradation of sliced onion quality (Praveen Kumar et al. 2005).

Among various drying methods, fluidised bed drying is a convenient method for heat sensitive food materials as it prevents them from overheating (Giner and Cavelo 1987). Fluidised bed drying is very effective for intensification of heat and mass transfer between drying gas (usually moist air) and food particulates being dried, which results in reduction of drying time. It facilitates very rapid equalisation of temperature of the drying medium in a whole volume of dried product, to the extent that the process practically takes place in a gradient free field of gas temperature. Studies have revealed that the drying of vegetables like carrot, peas, parsley roots, etc. in a fluidised bed produced final products of excellent quality in a shorter time than other types of dryers (Bobic et al. 2002). The method has also produced good quality products in less time for beans (Senadeera et al. 2005), garlic (Dhingra and Paul, 2006) and potato (Bakal, 2007).

Although considerable research work has been done on dehydration of onion round the globe, little information is available on the effect of various parameters on the quality characteristics of onion dehydrated in fluidised bed dryer. Therefore, it was proposed to study the fluidised bed drying of onion with the following objectives.

1. To study the drying characteristics of onion in fluidised bed dryer at different temperature and air flow conditions.
2. To compare the drying characteristics of onion in fluidised bed drying with that under normal convective drying.
3. To evaluate the product quality of onion obtained form fluidised bed and normal convective drying conditions to suggest suitable drying parameters.

CHAPTER - II

Review of Literature

CHAPTER II
REVIEW OF LITERATURE

This chapter in general deals with the review of research work done on dehydration of onions, fluidised bed drying and convective drying of vegetables in general and onion in particular, by various researchers in India and abroad.

Onion is an indispensable ingredient of food preparation and also has medicinal use (Viswanathan et al. 2003). Fresh as well as dehydrated onions are used in various culinary preparations. Dehydrated onions are of considerable importance in the world trade and single largest import item in Germany, the United States, the United Kingdom and the Netherlands (Sagar 2001, Sakhale et. al. 2001).

Because of the presence of several sulphur compounds, onion has antiseptic properties. Onion is said to possess stimulant, diuretic and expectorant properties and is considered useful in flatulence and dysentery. Freshly expressed onion juice has moderate bactericidal properties. Onions are used as salad, and are cooked in several ways in all types of curries. They are baked, fried and used in fresh or dehydrated or powder form in soups, pickles, sauces, etc. They are also eaten raw as salad which helps in lowering blood pressure and blood cholesterol (Pruthi 2001).

In the recent days consumption of dehydrated onion flakes is becoming popular. There are several dehydration units in India, which produce dehydrated onion flakes for export as well as for domestic consumption. But during commercial dehydration of white and red onion flakes, pink discolouration often adversely affects the quality of dried onion flakes. Control of pink discolouration is very much important to attract the consumer and also to compete in the market (Rajkumar and Sreenarayanan 2001). New and innovative techniques that increase drying rates and enhance dried onion quality are receiving considerable attention (Mongpraneet et al 2002).

2.1 Onion and its composition

Onion (*Allium cepa.* L) is an important vegetable bulb crop grown throughout the world. It belongs to the *Liliaceae* family in the plant kingdom. The crop has been known

and cultivated from the earliest period of history, for at least 5000 years. It has the origin from Asian countries- Northwestern India, Afghanistan, parts of former USSR and China. The cultivation of onion spread into Northern Europe in the middle ages (Ferguson et al. 1977).

Onion is grown in India mostly as a winter crop. In some regions with a moderate climate, onion can be grown in rainy season as well. In Orissa, onion is grown in both winter and rainy seasons depending on the cultivars being cultivated.

2.1.1 Types of onion

Six different types of onions viz. green onions, mild onions, pungent varieties, pearl onions or small onions, white and yellow onions and red and yellow onions, are generally popular in India.

There are more than 300 species of onion. Allium cepa or garden onion is probably the most widely cultivated species. This species is further divided into three types such as bulbing type or 'Common onion group' propagated by seed, multiplier type or 'Aggregatum group' propagated by branching at the base and top onion type or 'Proliferum group' forming bulbils in the inflorescence (Dhesi et al. 1972; Choudhury 1983). Of these, the bulbing type onion is mostly cultivated commercially in India and constitutes the most important commercial bulb crop of the country.

There are several varieties of onion available in the market. These are characterised by their colour, shape, size, pungency and keeping quality. Pruthi (2001) has reported that in India, the onion varieties could be divided into pungent and mild types and three distinct colours were recognized in each class, viz. red, white and yellow. However, for manufacturing dehydrated onion or onion powder etc; it is essential to have: (a) oblong shaped white onions instead of flat ones and (b) higher soluble/ total solids (more than 16%) as in Egyptian onions.

2.1.2 Composition

Onions are high in water content. They are low in calories, and have a generous amount of vitamins B_6, B_1, and Folic acid. Onions contain chemicals which help fight the free radicals in our bodies. Different varieties of onions differ slightly in their

compositions. Nutritionally fresh onions contain about 86.8% moisture, 11.6% carbohydrates, 1.2% proteins, 0.2-0.5% Ca, 0.05% P and traces of Fe, thiamine, riboflavin and ascorbic acid (Raj et al. 2006). The physico-chemical characteristics of some elite varieties of onions as found out by Sakhale et al. (2001) are given in Appendix- A.

According to studies conducted by Bajaj et al. (1979) on Chemical evaluation of five white and seven red varieties of onion (*Allium cepa* L.), percent dry matter varied from 10.66 to 14.80. Total water soluble sugars, reducing sugars and total phenols ranged from 41.50 to 74.00, 12.00 to 22.25, and 1.75 to 2.95 percent (on a dry wt basis), respectively. The lachrymatory factor and pyruvic acid content ranged from 8.00 to 27.25 mg/100g and 6.18 to 13.27 micro moles/g respectively on a fresh weight basis. Red varieties contained a higher phenolic content than white ones. Varieties with higher phenolic content also had a greater amount of coloring matter in the dehydrated onions. The variety Punjab-48 was considered to be most suitable for dehydration purposes. Composition of onion bulbs and onion powder as found out by Pruthi (2001) are given in the Tables2.1 and 2.2.

Table 2.1: Composition of onion bulbs

Parameters	Quantity present
Moisture, % (m/m)wet basis	86.80
Protein, %	1.20
Fat, %	0.10
Carbohydrates, %	11.60
Calcium, %	0.18
Phosphorous, %	0.05
Iron	0.70 mg/ 100g

The bulbs and fresh herb yield 0.005% of an essential oil (refractive index: 1.041: optical rotation: -5°), which has an acrid taste and unpleasant odour. The chief constituent of the crude oil is allyl-propyl disulphide, a sulphur compound responsible for tears.

Table 2.2: Composition of onion powder

Parameters	Quantity present
Moisture, % (m/m)wet basis	4.60
Protein, %	10.60
Fat, %	0.80
Fibre, %	8.40
Carbohydrates, %	74.10
Mineral matter (total ash), %	3.50
Calcium, %	0.30
Phosphorous, %	0.29
Sodium, %	0.04
Potassium, %	1.0
Iron, %	0.002
Vitamin A	175 IU/100g
Vitamin B_1, %	0.42
Vitamin B_2, %	0.06
Nicotinic acid, %	0.60
Vitamin C	14.70 mg/ 100 g
Calorific value	370 calories/ 100 g

The international quality standards (ISO) both for the dehydrated onion and onion powder are given in Table 2.3.

Table 2.3: International physico-chemical (ISO) quality specifications for dehydrated onion and onion powder

Physico-chemical characteristics	Dried slices, flakes, pieces and kibbled onions	Onion powder, grits
Moisture content, % (m/m), max.	8.0	6.0
Total ash, % (m/m) (dry basis), max.	5.5	5.5
Acid-insoluble ash, % (m/m) (dry basis), max.	0.5	0.5
Extraneous matter (rots, papery skin, etc.)	0.5	0.5

Source: ISO 5559-1983: International standard for dried onion/ onion powder.

2.2 Storage of fresh onions

Onion as a perishable product cannot be stored for long periods, due to various factors. The amount of losses is to the tune of 40% (Pandey 2000). Major deterioration problems that occur during onion storage are weight loss, sprouting, root growth, diseases, sugar accumulation, loss of pyruvic acid and ascorbic acid. Pyruvic acid is a trademark of onions and is the main factor why this vegetable is used in food industries throughout the world. Loss of ascorbic acid indicates loss in quality or loss in other nutrients components such as carbohydrate and protein. Sprouted bulbs cannot be used anymore, except for seedlings, while rooted and rotted bulbs by removing 2-3 outer skin layers of rotted bulbs and cutting or trimming rooted bulbs, onions can still be used for cooking. Loss of weight also results in unattractive appearance. More than 10 percent weight loss causes wilting, or even drying. Storage temperature and relative humidity are two important factors which must be considered if this product will be stored successfully. However, the shelf life also depends upon the cultivar. In general, storage temperature of 0°C and 30°C and relative humidity of 60 percent - 75 percent are an ideal condition for storing onions (Sentana 1998).

The objectives of onion storage are to extend the period of availability of crop, maintain optimum bulb quality and minimise losses from physical, physiological, and pathological agents. Bulbs selected for storage should be firm and the neck dry and thin. Thick-necked bulbs are discarded because they are most likely to have high moisture

content than optimum for storage, and therefore would have short storage life. Skin colour should be typical of the cultivar. Microbial infections such as *Aspergillus niger* occur during production of onions but these will only develop on the bulbs during storage where the storage environment is conducive for their growth. Prior to storage, crop must be cleaned and graded, and all damaged or diseased bulbs removed. Careful harvest and pre-storage treatments with minimal mechanical loads are important to achieve a long storage period. Several technology options are available for bulk storage of onions, including low-temperate storage, high-temperature storage, 'direct harvest' storage and the use of controlled atmosphere (CA) stores. (Thompson 1982, Thompson et al. 1972, Stow 1975, Smittle 1989, Sealand 1991 and Hardenburg et al. 1990).

2.3 Drying and dehydration of onions

Dehydration of onion is one of the major processing operations, which reduces the volume, and thereby transportation cost and increases the storage life of onion. Dehydration of onion would help to improve keeping quality and alleviate irregularity in price fluctuation during off-season (Nandasana et al. 1998). However, dehydrated onions have not found popular acceptance because they do not match in flavour, texture and colour to the fresh onion after rehydration (Sagar 2001).

Onions are dehydrated without blanching or sulphiting in order to protect the enzyme system which develops onion flavour when onion cells are cut or broken. When the cells are broken, the onion enzyme alliinase is free to contact certain onion compounds which reacts to form numerous volatiles; responsible for the characteristic onion flavour (Pruthi 2001). Different drying methods have been suggested for onion.

2.3.1 Convective drying of onions

In industrialized countries, onions are dried using high-temperature commercial dryers such as conveyor belt dryers or fluidised bed dryers. Prepared onions are uniformly sliced to required thickness and the onion slices are dried in a thin layer at a temperature near 60°C to a final moisture content less than 9%. However, the major disadvantage associated with hot air drying is the long drying time even at temperatures near 60°C, resulting in degradation of sliced onion quality (Praveen Kumar et al. 2005). Extensive research works have been carried out for drying of onion by conventional hot-

air methods (Sarsavadia et al.1999). Elustondo et al. (1996) developed a simple model for the dehydration of onion pieces.

The drying of onion takes place in falling rate period and is governed by moisture diffusion. The total drying time for onion decreases with increase in drying air temperature due to increase in drying rate at higher temperature (Singh and Sodhi 2000). It was also observed that the dehydrated product should be stored below 40% RH.

In the process of drying fruits and vegetables the choice of temperature to be used is the result of a compromise between the efficiency of the process, energy cost and product quality.

2.3.2 Fluidised bed drying

Among various drying methods, fluidised bed drying is a convenient method for heat sensitive food materials as it prevents overheating (Giner and Cavelo 1987). The fluidization process had been known for long time, because of its hydrodynamics (Geldart 1973); and because of the transfer of heat and mass between gas and solid body particles in it (Denloy 1978).

Giner and Cavelo (1987) studied drying behaviour of wheat in a batch fluid bed dryer with drying air temperatures ranging from 40°C to 70°C. The drying operation in fluid bed was modeled by assuming perfect mixing of solids. They concluded that fluid bed drying was a convenient method for heat sensitive food materials.

Piotrowski and Lenart (1997) studied the drying time of apples under constant and variable conditions. The experiments carried out showed a larger influence of air temperature than air flow velocity on the drying curves and on the time required to obtain specific levels of water content. The influence of constant or variable air velocity could not be neglected, even though its importance decreased with processing time. Either higher air temperature or velocity gave shorter drying time.

Bobic et al. (2002) studied the rehydration ratio of fluidised bed-dried vegetables such as potato, parsley roots, celery roots and carrot. The results showed that fluidized bed drying produced products of excellent quality in a much shorter time than that in continuous belt-dryers. Depending on the pre-treatment applied, rehydration times were

up to 30% less in fluidised bed drying than the continuous belt dryer. The quality was also very uniform. Further it was concluded that substantial energy saving was possible in fluid bed drying as lower drying temperature could be used.

Sutar and Prasad (2005) investigated the drying characteristics of osmotically dehydrated onion in a vertical column fluidized bed dryer and observed that the drying air temperature of 70°C was found most appropriate.

Senadeera et al. (2005) experimented on the effect of shape on fluidised bed drying. Three particular geometrical shapes as parallelepiped, cylinder and sphere were taken from cut beans (length: diameter = 1:1, 2:1 and 3:1) and potatoes (aspect ratio = 1:1, 2:1 and 3:1) and peas, respectively. The dimensional shrinkage behaviour was also studied in a batch fluidised bed at three drying temperatures of 30°C, 40°C and 50°C with RH 15%.

Dhingra and Paul (2006) studied on drying kinetics of fluidised bed drying of garlic slices. They observed that the slice thickness and temperature of drying air were significant factors affecting drying.

Bakal (2007) studied on the effect of shapes on kinetics of fluidised bed drying of potato. He observed that the drying rate decreased with decrease in the moisture content of potato at different drying air temperatures for both cuboidal and cylindrical shapes of the sample.

Singh et al. (2007) studied on drying kinetics of button mushroom in fluidised bed dryer. Result of the study showed that in the fluidised bed dehydration of button mushroom, Exponential model was more accurate than Page's model and the rate constant followed Arrehenius relationship.

To summerise, fluidised bed drying is very effective for intensification of heat and mass transfer for drying gas (usually moist air) and food particulates being dried, which results in reduction in drying time. It facilitates very rapid equalization of temperature of the drying medium in a whole volume of dried product, to the extent that the process practically takes place in a gradient free field of gas temperature.

2.4 Quality analysis of dehydrated product

Singh and Kumar (1984) studied the loss of pungency and the discolouration in selected cultivars of onions during hot-air drying. Water is an important contributor to the organoleptic quality of foods. A loss of water from high moisture content foods or gain in water by low moisture content foods can lead to reduction in organoleptic quality and acceptability of said foods (Brennan et al. 1990).

Onion flavour and colour are generally perceived as important quality attributes. Quality changes during the drying process are influenced by drying temperatures. The volatile compounds responsible for the aroma and flavour of onions exhibit low boiling points and, accordingly, are often lost during high temperature drying. Maillard browning reactions induced by the drying process decrease nutritional values, changes the colour and flavour and induces textural changes (Adam et al. 2000).

In the processing of dehydrated onions, it is desirable that the final product retains many of the flavour characteristics of the fresh onions; and hence severe heat treatments are avoided to protect the sensory quality of the dehydrated product. Although blanching prior to drying substantially reduces enzymatic activity, onion and garlic are dried without prior blanching. Garcia et al. (2002) has reported that typical drying temperatures and treatment duration used in the drying process of onion and garlic spices did not lead to complete enzyme inactivation.

Rajkumar and Sreenarayanan (2001) studied on dehydration and pre-treatment level to control browning and storage of onion flakes. They observed that retention of ascorbic acid in the dehydrated onion sample was comparatively higher when dried at 50°C with 0.4% KMS treatment.

Hatamipour and Mowla (2003) studied on Shrinkage of carrots during drying in an inert medium fluidized bed. It was found that the shrinkage of root vegetables during drying in a fluidized bed could be well correlated with moisture content of the sample during drying. Air velocity, temperature and presence of inerts did not show significant effects on shrinkage in this system.

Baysal et al. (2003) studied on the effects of microwave and infrared drying on the quality of carrot and garlic. They concluded that in the garlic dehydration process, no significant difference was found between fluidised bed drying, infrared drying and microwave drying except colour. They recommended that where colour is an important parameter, hot-air or microwave drying instead of infrared drying should be used.

Raj et al. (2006) studied on the effect of pre-treatments on the quality characteristics of dehydrated onion rings during storage. They observed that varieties having higher TSS, dry matter content and lower reducing sugars to non-reducing sugars ratio resulted in very less browning discolouration of dehydrated onion rings.

Drying of foods is aimed at producing high density product, which when properly packaged has considerably long shelf life after which the food can be rapidly and simply reconstituted without substantial loss of flavour, taste, texture, colour and aroma. Most of the time, cost of the dehydrated product depends on the drying process. Hence, it is highly desirable to dehydrate the product with the least of the energy, cost and time involved for better acceptability among the processors and consumers.

2.5 Drying kinetics

The drying of food materials in general and fruits and vegetables in particular normally occurs in falling rate period. The moisture and/ or vapour migration during this period is controlled by diffusion (Bakker et al. 1978). The diffusion may include molecular diffusion, liquid diffusion through solid pores, Knudsen flow and all other factors which affect drying characteristics. Since it is difficult to separate individual mechanism, the rate of moisture movement is described by an effective diffusivity; a lumped value. In most situations, Fick's second law of diffusion as given in Equation 2.1 was used to describe a moisture diffusion process (Crank 1975). The solution of this equation depended on the shape of the food materials, with certain specific assumptions.

$$dm/dt = D_{eff} \nabla^2 m \qquad \ldots(2.1$$

In drying, the diffusion coefficient is used to indicate the flow of moisture or mass out of the material being dried. The diffusion coefficient of the food material varies with its moisture content and is estimated by analyzing data. Many researchers have tried to correlate the coefficient with temperature and changing moisture content.

Ronald et al. (1992) studied on the Influence of process variables on the drying of potato slices. As per the investigation of the effects of varying air velocity, slice thickness, and pre-treatment with sodium chloride solutions and surface active agents on drying potato slices they observed that the drying occurred entirely in the falling rate period and was controlled by the mechanism of liquid diffusion. The rate of drying, and therefore the diffusion coefficients, increased with the addition of sodium chloride and surface active agents. They concluded that diffusion coefficients were influenced by air velocity and slice thickness, indicating that the rate of drying of potato slices is controlled by a combination of internal and external resistances.

Naverri and Andrew (1993) described the combined drying (convective and infrared) of aqueous coated films under high infrared densities. Two main properties were deduced from the drying experiments: (i) the mean absorptivity as a function of the mean moisture content, and (ii) the apparent diffusivity as a function of the temperature and moisture content.

Lazarides et al. (1995) attributed the quick water loss of the beginning of the osmo-dehydration process to the driving force between the diluted solution within the onion and the hypertonic surrounding solution. Even in dilute solutions, however, the rapid water removal rate decreased after an hour of processing. This seems to be related to a solid barrier formed on the surface of the product by salt uptake.

Magee and Bransburg (1995) determined the thermal diffusivity of three food products, Pentland Dell potato, malt bread and wheat flour, using a thermal diffusivity tube under transient heat transfer conditions by two different methods; the log method and the slope method, both based on the solutions of the Fourier equation. Both methods gave similar results for potato, flour but different results for bread.

Madamba et al. (1996) studied the thin-layer drying characteristics of garlic slices (2-4 mm for a temperature range 50-90°C, at RH ranging from 8-24%, with air flow range 0.5-1m/s). An analysis of variance (ANOVA) revealed that the temperature and slice thickness significantly affected the drying rate while relative humidity and air flow rate were insignificant factors during drying. Effective diffusivity of water varied from 2 to 4.2 X 10^{-10} m^2/s in the temperature range studied, with activation energy of 989kJ/kg.

Phetdasada (1997) investigated on the parameters affecting the operating of chopped spring onion drying and to develop a mathematical model for predicting its drying rate in the fluidized bed dryer. Drying air used in this experiment was set at temperature of 75-105 °C and specific air flow rate of 0.787-1.704 kg/s per kg dry matter. Initial moisture content of chopped spring onion was 93-94% wet-basis. Experimental result showed that the minimum air velocity of fluidization was approximately 1.36, 1.2, 0.95, 0.62 m/s at initial moisture content of 95%, 71%, 56%, 5% wet-basis with air temperature of 32 °C respectively. Air temperature before entering the bed and specific air flow rate were parameters affected to drying rate. Comparing among five drying application models, Page's model showed the predicted value closest to the experimental data. The drying air temperature before entering the bed should not exceed 75 °C to maintain the acceptable green colour of the product.

Afzal and Abe (1998) investigated on the effect of radiation intensity and thickness of slab on moisture diffusion characteristics of potato during far infrared drying. The diffusivity was found to vary with radiation intensity. It was further observed that the diffusivity also increased with increase in thickness of slab at constant radiation intensity level. They also reported that decrease in energy of activation caused an increase in the drying rate.

McMinn et al. (1999) studied about the effect of surfactant, blanching and osmotic pretreatments on the convective drying of potatoes. The drying behaviour of potato was monitored within an experimental air tunnel dryer, with the mechanism of internal moisture migration being identified as diffusion. This was subsequently evaluated on the basis of the liquid diffusion theory. Experimental data revealed osmotic concentration as a favorable process. A 29±2% reduction in diffusion coefficient was observed following osmotic dehydration with a salt/sugar solution; however, this provided a 63±3% reduction in drying time. Structural modifications were induced by blanching, with this rendering a 10±1 and 27±2% lowering of the moisture transfer rate during drying at 30 and 60°C, respectively.

Baroni and Hubinger (1999) studied the kinetics of the Dehydration of Onion by Immersion. They observed that the reductions of water content and salt penetration were

strongly affected by the solution concentration and temperature. In general, the higher the concentration and temperature, the greater was the removal of water and the higher the salt content in the onion. Thus solute concentration seemed to have a more pronounced effect on the processing parameters than did temperature. They concluded that square onion pieces can be partially dehydrated by soaking in sodium chloride solution. High moisture removal and salt impregnation rates were observed at the beginning of the process. Effective diffusion coefficients were obtained successfully using Crank's plane sheet geometry solution of Fick's diffusion law, bi-dimensional mass transfer because of the product skin. The results showed that the higher the temperature and salt concentration, the higher the effective diffusion coefficient.

Debnath et al. (2004) studied the rehydration characteristics of osmotic pretreated and dried onion. The effect of osmotic pretreatments (10% sodium chloride for 1 h or 50% sucrose for 3 h treatment) on rehydration kinetics of dried onion was studied over a range of temperatures (25–65°C) and compared with an untreated (control) sample. The effective diffusion coefficients for water and solute were determined by considering the rehydration process to be governed by Fickian diffusion. They observed that the diffusion coefficients for water absorption and solute infusion were found to be in the range 1.96×10^{-9} to 8.04×10^{-9} and 2.94×10^{-9} to 5.53×10^{-9} m^2 s^{-1}, respectively. Osmotic pretreatment resulted in a decrease in the diffusion coefficient of water as well as an increase in the diffusion coefficient of solute during rehydration. Decrease in the diffusion coefficient of water was due to an increase in the proportion of ruptured and shrunken cells caused by osmotic treatments, which in turn resulted in reduced ability of dried onion tissue to absorb water. They concluded that the increase in diffusion coefficient for solid during rehydration was higher in the case of osmotic pre-treated material, some of the solids absorbed during osmotic dehydration were not retained in the cell matrix and dissolve faster than the constitutive onion dry matter.

Odilio et al. (2004) studied about physical properties of food products undergoing a combined sublimation and evaporation process. Pieces of vegetables and potatoes were dried in a heat pump fluidised bed dryer at combined modes with temperatures below freezing point in the beginning and a final drying step at temperatures above the freezing point. Samples of products were tested at different moisture contents with respect to

physical properties. The average effective mass diffusivity for 5 mm slabs of leek was 0.5 X 10^{-11} m^2/s for the sublimation stage and 2.2 X 10^{-11} m^2/s for the evaporation stage.

Sharma et al. (2005) studied on thin-layer infrared radiation drying of onion slices. They carried out the investigation in Single layer drying of onion slices 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 1.0, 1.25 and 1.5 m/s. They observed that the drying time was reduced by about 2.25 times on increasing infrared power from 300 to 500 W, air temperature 35–45 °C and air velocity from 1.0 to 1.5 m/s. Effective moisture diffusivity varied from 0.21×10^{-10} to 1.57×10^{-10} m^2/s and was significantly influenced by infrared power and air temperature. The rehydration ratio of dehydrated onion slices was found to be in the range of 4.5 and 5.3.

Jaruk and Roberts (2006) determined the moisture transfer of hygroscopic non-porous materials such as potato, carrot core and carrot cortex during drying. Drying curves and temperature profiles were obtained from cylindrical samples under convective hot air drying (40, 50, 60 and 70°C and 1.5 and 3 m/s air velocity). Temperature dependence of the effective moisture diffusivity was found to follow the Arrhenius type relationship.

Dhingra and Paul (2006) studied the drying kinetics of fluidised bed drying of garlic slices. They observed that the slice thickness and temperature of drying were significant factors affecting drying. The influence of air velocity and concentration of sodium meta-bisulphite (with in the range studied) was statistically insignificant.

2.6 Modelling of drying parameters

Drying of food materials is a vital component in the post harvest process. It is the removal of excess moisture from the products to a predetermined level for safe storage. During drying, the moisture from solid gets vapourised and diffused in dilute environment. Review of some of the relevant literatures on modeling of drying data is given below.

Noomborn et al. (1986) examined non linear regression technique to model drying data of foods. Data of moisture content and time were collected for long grain rough rice

representing on-farm and commercial drying conditions. Four different drying models were evaluated for single layer rice drying data. The first two were based on the solution of diffusion equation and others were empirical. The two term exponential form of diffusion model and second empirical model were determined to be the best. A generalized form was developed with the aid of non linear regression technique. For commercial drying conditions, the second empirical model proved to be the best for generalized model.

Pathak et al. (1991) developed mathematical model of thin layer drying of rapeseed in the form of Page's model. Eight levels of drying air temperature, four in conventional drying temperature range of 50-60°C and four at the elevated temperatures upto 200°C were selected. The model predicted the moisture ratios well at conventional as well as elevated drying temperature.

Rossello et al. (1992) developed simple mathematical model to describe the convective drying kinetics of potato cubes. The influence of both drying air temperature and air flow rate on the drying of 1 cm potato cubes was studied. They observed that the critical value above which the air flow rates have no effect on drying rates was approximately 800kg/h m^2. The agreement between calculated and experimental average moisture content was satisfactory.

Markowski and Zielonka (1996) investigated on heat transfer coefficient during the air drying of onion. The weight losses in 5 mm thick onion slices were determined during the drying at 40, 45, 50, 55, 60 and 65°C and 0.7, 0.9 and 1.1 m/s air flow rates. Each experiment lasted 2 h. They calculated heat transfer coefficient based on the empirical results and a mathematical model for the constant drying rate period of the forced air drying of solid materials. They found no functional relationship between the air temperature and heat transfer coefficient for onion slices under the forced convection drying conditions. They observed that the heat transfer coefficient ranged from 16.3 to 21.0 W/(m^2.K), and it increased with the air flow rate.

Abe and Afzal (1997) studied four mathematical models to describe the thin layer infrared drying characteristics of rough rice. The models considered were exponential model, Page's model, diffusion model based on spherical grain shape and an

approximation of the diffusion model. Tests were conducted using four levels of radiation intensity, three levels of inlet air velocities and three levels of grain initial moisture content. The Page's model was reported to be the most adequate one in describing thin layer infrared drying of rough rice.

Pandey et al. (2000) studied about hot air drying characteristics of osmosed button mushroom (Agaricus bisporous) slices. They observed that changes in DM/MO and MR were higher during initial drying periods. One variable and two variable power law models, Exponential model and Page's model very well fitted the experimental data of hot air drying. However, Page's model and Exponential model gave better results as compared to power law models. The predicted values of Page's model were very much close to observed values.

Wang (2002) studied three mathematical models to describe thin layer far infrared drying characteristics of onion. He used exponential model, Page's model and approximation of the diffusion model. It was observed that Page's model gave the best result in describing single layer far infrared radiation drying of onion.

Viswanathan et al (2003) studied the thin layer drying characteristics of shredded onion (white variety) at drying air temperatures of 30, 40 and 50°C and RH ranges of 15, 35 and 45%. The drying data fitted well to both Lewis' and Page's equations with high level of regression coefficient. They observed that the 'k' in the Lewis' equation ranged from 0.486 to 1.11 and for the Page's equation, the 'k' and 'n' value ranged from 0.383 to 1.112 and 0.993 to 1.1306 respectively.

Sogi et al. (2004) studied the drying characteristics of tomato seeds dried in cabinet/ fluidised bed dryers at 50, 70 and 90°C using tray load of 4, 8 and 12 kg/m^2. Sorption isotherms were obtained at 30, 40, 50, 60 and 70°C by the static method using saturated salt solutions. They concluded that drying rates in the drying of tomato seeds took place under the falling rate period and the drying behaviour was well described by Page's model.

Veli et al. (2004) investigated about the influence of drying air velocity (0.64, 1.00, 1.50, 2.00, 2.50 and 2.75 m/s) on the kinetics of convective drying of Jonagold apple. Kinetic equations were estimated by using an Exponential mathematical model.

The results of calculations corresponded well with experimental data. Two well defined falling rate periods and a very short constant rate period at lower air velocities were observed. They concluded heat transfer coefficient and effective diffusion coefficient increased with increase in the drying air velocity.

Demir et al. (2004) studied drying of Bay leaves (Laurus nobilis L.) at 40, 50 and 60°C air temperatures with air velocity 1.5m/s and 5, 10 and 15% RH. The data obtained from the drying tests were applied to various well-known semi-empirical mathematical models. Five well known models with drying rate constant as a function of air temperature and both temperature and relative humidity were tested for goodness of fit. The Page's model satisfactorily described the kinetics of convective drying of bay leaves.

Praveen Kumar et al. (2005) studied the Infrared and hot-air drying of onions slices and studied the effects of processing conditions such as drying temperature, slice thickness, air temperature and velocity on onion slice characteristics. The onion slice quality was evaluated on the basis of the colour and the pyruvic acid content. Drying of thin slices of onion (2 mm) at low temperature (60°C) with a moderate air velocity (2 m/s) and air temperature (40°C) retained greater flavour and colour. An empirical equation developed to correlate the drying process variables and the onion slice moisture with the drying time provided a good fit ($R^2 = 0.92$). They concluded that combination drying resulted in shorter drying process time and in better onion slice quality as compared to IR and hot-air drying applied individually.

From the foregoing paragraphs, it is well evident that onion in particular is a heat sensitive food material susceptible to quality losses if not handled properly during the dehydration process. Selection of drying parameters for the process of dehydration is crucial to fulfill the objectives of the proposed experiment. Different researchers have suggested different drying conditions for onions (either arbitrarily or based on specific varieties) and one has to be judicious and cautious to pick up one or the other parameters suitable for the purpose of investigation. It is thus highly essential to design the experimental plan suitably and adopt materials and methods for the experiments with the utmost degree of precision.

CHAPTER - III

Materials and Methods

CHAPTER III
MATERIALS AND METHODS

This chapter deals with the materials used and procedure adopted to achieve the objectives of the present investigations. This includes the description of raw materials used, determination of moisture content, experimental set up and methodology used for the investigation and analysis of drying data. The proposed study is aimed at exploring the feasibility of fluidised bed drying for production of dehydrated onion. Different stages of the experiment were as described below.

1. To study the drying kinetics of sliced onion under fluidised bed drying conditions. Onion rings of three thicknesses, viz. 2mm, 4mm and 6mm were dried in the vertical column fluidised bed dryer at three different air velocities across the bed viz. 1m/s, 2.5m/s and 4m/s. The drying air temperatures were kept at four levels, viz. 50, 60, 70 and 80°C. The effects on moisture loss and drying rates were compared amongst the various parameters selected.

2. The final product characteristics of the dried onion were studied in terms of physical parameters as rehydration properties, surface colour, and organoleptic properties and chemical parameters such as changes in ascorbic acid content and pungency in terms of pyruvic acid content.

3.1 Raw material

Well graded onions (Cv. Nasik red) were procured from the local market. Care was taken to select onions of uniform size and colour without any visible mechanical damage, rotting, rooting, sprouting and microbial infestation. The weight of the selected onions was 85-95 g. The other physico-chemical characteristics of the fresh onion such as skin colour, shape index, dressing losses, TSS, acidity, ascorbic acid, pyruvic acid, reducing and non-reducing sugar, etc. were studied.

The onions were peeled manually and the non-edible portions like the neck and stem disc were removed with the help of sharp stainless steel knives. These were then cut

longitudinally into two equal halves and then foils of desired thicknesses were cut out transversely with utmost precision. Prior to using each lot of onions for the experiment, initial moisture content was determined which was used to determine the moisture loss and for studying the dehydration characteristics.

3.2 Experimental setup

A laboratory model table top vertical column type fluidised bed dryer (Make: Retsch, model: TG 200, Germany) was used for the experiments of the proposed study. Photograph of the dryer is presented in Plate 3.1. The specifications of the dryer have been given in Appendix B. Figure 3.1 below shows the schematic diagram of the process of fluidised bed drying.

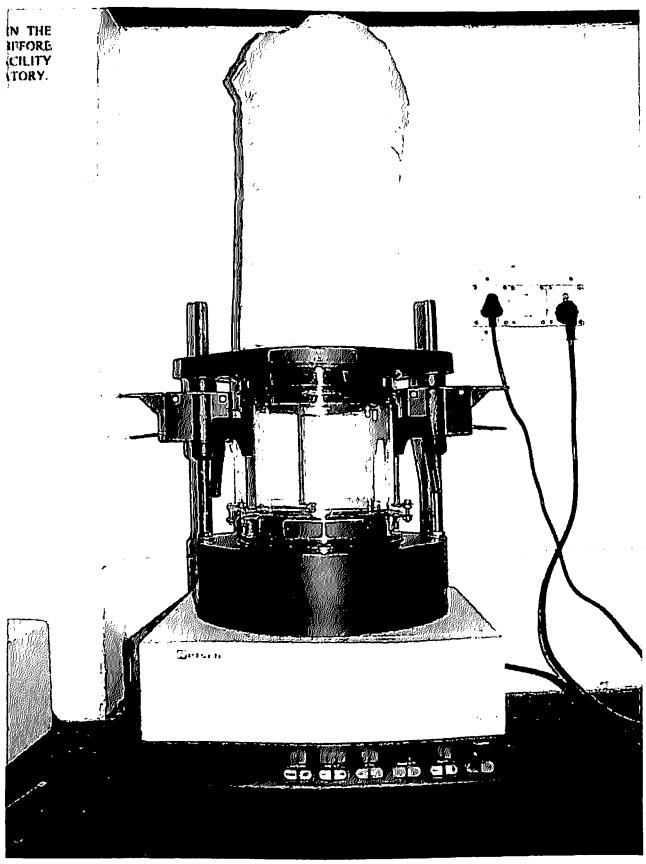


Plate 3.1 Table top vertical column fluidised bed dryer

The dryer had provisions for varying drying air temperatures from 0 to 150°C and air flow rates ranging from 10% (1m/s) to 99% (4m/s). The system contained an air

distribution system and an electronic control panel. An axial fan forced air through the perforated stainless steel floor of the drying vessel. The air was heated by a 2kW electrical heater placed in between. The drying vessel is made of high quality glass supported by stainless steel frames. A nylon fabric filter bag fitted at the top of the assembly helped to trap any particles tending to be expelled from the fluidised bed during the drying operations.

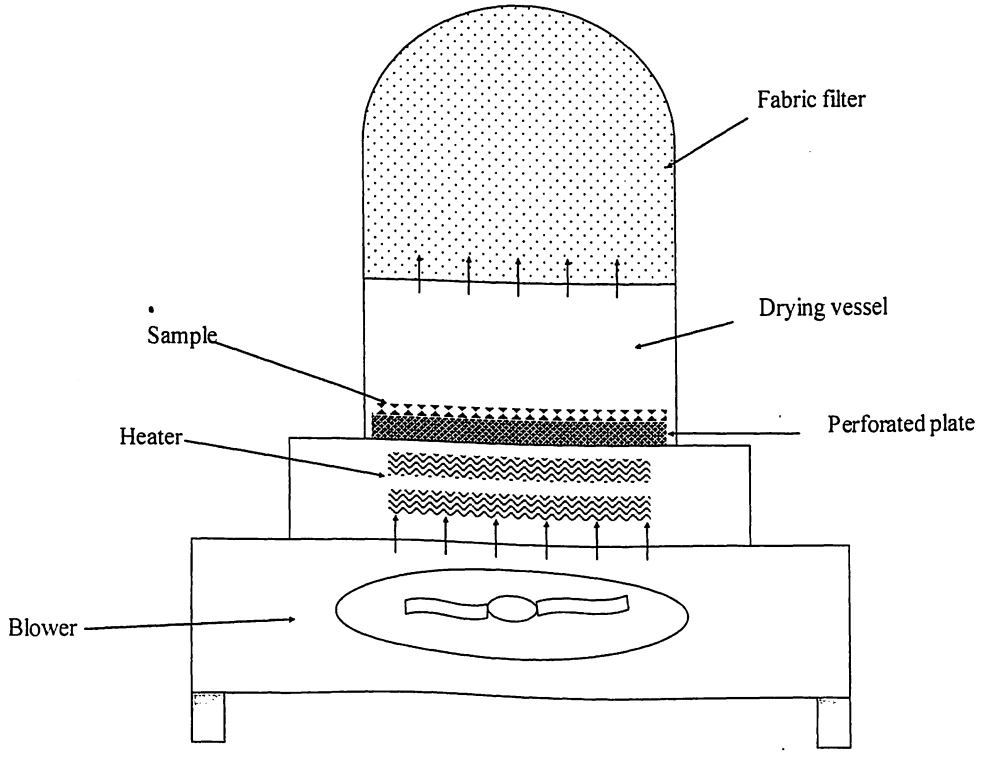


Fig. 3.1. Schematic representation of table top vertical column fluidised bed dryer.

Prior to the commencement of each drying experiment, the fluidised bed dryer was run idle for a period of 15 minutes to stabilise drying air parameters like the temperature and air velocity. Three replications were taken for each experiment and the sample size for each replication was kept at approximately 350 g (on fresh weight basis). Weight of the sample during the drying process was taken in every 15 minutes by using a

top-pan electronic balance (Sartorius, Resolution ±0.01g). The drying characteristics were studied till the weight of the sample became constant for four consecutive readings.

3.3 Determination of initial moisture content

The moisture content of onion was determined by Oven drying method (ASTA, 1985; Ranganna, 1986). The raw samples kept in the oven were observed to come to equilibrium condition after 72 hours at 70°C. Hence, 20-30 g of sliced samples (in three replications) was kept in the oven for 72 hours at 70°C for determination of moisture content,. The initial moisture content of the sample was calculated using the following formula.

$$\text{Moisture content, \% (w.b.)} = 100X\frac{(W_2 - W_3)}{(W_2 - W_1)} \qquad (3.1$$

$$\text{Moisture content, \% (d.b.)} = 100X\frac{(W_2 - W_3)}{(W_3 - W_1)} \qquad (3.2$$

The symbols have been defined in the list of symbols.

The initial moisture content of onion samples was found to be ranging from 680 to 780% (d.b.).

3.4 Study of drying characteristics

Preliminary studies indicated that the onion slices dried at 80°C under both static and fluidised bed drying conditions gave burnt flavour and dark colour, which was not acceptable from the consumers' point of view. Similarly due to longer drying time in case of 6mm thick samples, more discolouration was noticed in the dehydrated product. Therefore, it was decided to restrict the air temperature during drying to 70°C and the slice thickness to 4mm for the studies on final product quality. However, higher temperatures and higher thicknesses could be used for removal of product moisture content to a predetermined level in the first stage in multistage dehydration processes (Dash and Bhatnagar, 1991). Hence for study of drying characteristics, 80°C air temperature and 6mm slice thickness were considered.

Similarly, the fluidised bed dryer used for the experiment had the capability to maintain maximum air velocity of 4m/s across the drying tray. The condition gave adequate fluidization of the onion samples being dried. Therefore, to study the effects of fluidization on the qualities of the dried products, the air velocity of 4m/s was compared with that of 1m/s. The air velocity of 1m/s represented pure convective drying with static bed. However, to study the effect of air velocity on the drying characteristics, an intermediate air velocity of 2.5m/s was included in the experimental plan.

Thus, to study the drying characteristics of onion in the fluidised bed dryer, the independent and dependent parameters were decided as follows.

3.4.1 Independent parameters

1. Foil thickness-2mm, 4mm and 6mm
2. Temperatures- 50°C, 60°C, 70°C and 80°C
3. Air flow rates- 1m/s, 2.5m/s, 4m/s

3.4.2 Dependent parameters

1. Moisture loss
2. Moisture ratio
3. Drying rate
4. Drying constants
5. Moisture diffusivity
6. Drying time

The change in weight, i.e. the moisture loss of the onion samples with respect to time i.e. the drying data recorded during the fluidised bed drying process were analysed to study the drying kinetics.

3.4.3 Moisture ratio and drying rate

In order to estimate the moisture ratio (MR) of onion during drying, the final moisture content of the dried product was taken as the equilibrium moisture content (EMC). Moisture ratio at any time was calculated using the following equation.

$$MR = \left[\frac{M - M_e}{M_0 - M_e}\right] \qquad (3.3$$

The symbols have been defined in the list of symbols.

The rate of drying was estimated from the moisture loss data; and expressed in term of g water/ g dry matter-h.

3.4.4 Effective moisture diffusivity

In drying of vegetables, moisture diffusivity is used to indicate the transfer of moisture from the commodity. In the falling rate period of drying, moisture migration takes place mainly in the form of molecular diffusion. Diffusivity is influenced by shrinkage, case hardening, moisture content and temperature of the material.

Generally during drying of agricultural produce with slab geometry, Fick's diffusion equation is used for calculation of effective moisture diffusivity (Maskan et al., 2002). As the onion samples were sliced before drying, the shape of the commodity in the present study could be taken as a slab.. The diffusivity equation is expressed as:

$$MR = \frac{8}{\pi^2}\exp\left(\frac{-\pi^2 D_{eff} t}{L^2}\right), \qquad (3.4$$

where, MR is the dimensionless moisture ratio, D_{eff} the effective moisture diffusivity in m^2/s, t the time of drying in seconds and L is the slab thickness in metres.

In a generalized form, Eq. (3.4) can be written in a semi-log form as follows:

$$\ln(MR) = A - Bt, \qquad (3.5$$

where, $A = \ln\left[\frac{8}{\pi^2}\right]$ and $B = \left[\frac{\pi^2}{L^2}\right]D_{eff}$

Curves were plotted taking ln(MR) versus drying time according to Eq. 3.5. The slope B was calculated from the curve and the effective moisture diffusivity was derived from the slope.

3.4.5 Modelling of drying behaviour of onion

Knowledge of drying kinetics is an important tool for design, simulation and optimization of drying process. Normally drying curves are modeled by defining drying rate constants based on first order kinetics. The basic model is popularly known as the Exponential model, as follows.

$$MR = \exp(-k_s t) \qquad (3.6$$

This model is able to predict the drying behaviour of the food material in the early stages of drying. To overcome the shortcomings of the Exponential model, the Page's model was used with an empirical modification to the time component by introducing an exponent 'n'.

$$MR = \exp(-k_p t^n) \qquad (3.7$$

All the experimental data for drying of onion were initially fitted to both Exponential model and Page's model. For estimating the model constants and correlation coefficient, r^2, nonlinear regression was performed.

3.5 Quality analysis of dehydrated onion

As mentioned in the previous section, for the quality analysis of the dehydrated product and to decide the best combinations of air temperature and velocity for onion dehydration, the air temperatures of 50°, 60° and 70°C, air velocity of 1 and 4 m/s and slice thickness of 2 and 4 mm were used. The dried onion samples were then kept in air tight PET jars in dark for quality evaluation studies. The moisture content of the dehydrated product was moderated to 6-9% for the quality analysis. The following product characteristics were studied.

1. Rehydration ratio
2. Surface colour
3. Ascorbic acid content
4. Pungency
5. Organoleptic quality, viz. colour, flavour (pungency), taste, texture and overall acceptability

3.5.1 Rehydration characteristics

The rehydration characteristics of the dehydrated products were studied in terms of the rehydration ratio and the coefficient of restoration (Dash and Bhatnagar, 1991).

$$\text{Rehydration ratio (R.R)} = {}^{C}\!/_{D} \qquad (3.9$$

$$\text{Coefficient of restoration of weight (C.R)} = \frac{C(100-A)}{(D-BD)X100} \qquad (3.10$$

$$\%\text{ of water in rehydrated sample} = \frac{C-(D-BD)}{C}X100 \qquad (3.11$$

Here, A is the percentage of water in original sample on wet basis and B is the moisture content in decimal (wet basis) in the dehydrated sample. C is the drained weight of rehydrated sample and D is weight of dry sample.

The time of soaking was initially standardised by soaking 2 g of dehydrated onion slices in 100 ml distilled water maintained at 31± 0.5°C. After every 15 minutes, the sample was taken out and put in buchner funnel which was fitted with a coarsely porous Whatman No. 4 filter paper. A gentle suction was applied to drain the excess water. Any trace of surface moisture was then removed with the help of a tissue paper and then the samples were weighed. The process was continued until a constant reading was obtained. It was observed that the weight of samples equilibrated after 3 hours, and the same time was maintained for the rehydration studies.

3.5.2 Surface colour

Colour is one of the major aspects of quality and acceptability of any food product. The HunterLab colorimeter, model: 45/0 was used to measure the colour of the product. The dehydrated onion samples were put in the sample cup and compressed and colour measurement was done in terms of L, a and b values. Values of L (lightness) vary from 0 to 100 for black to perfect white. 'a' measures redness when positive, gray when zero, and greenness when negative. Similarly 'b' measures yellowness when positive, gray when zero, and blueness when negative. The value 'a/b' was taken as the colour index (Sharma, 2006). Higher values of 'a/b' indicated more redness of the products.

3.5.3 Determination of ascorbic acid

Ascorbic acid is a major constituent of most of the fruits and vegetables. It is a well known fact that the ascorbic acid content in agricultural produce depletes significantly during dehydration and storage. Ascorbic acid content of the fresh as well as dehydrated onion products was estimated using standard procedure suggested by

Ranganna (1986) based on the reduction of 2, 6- dichlorophenol indophenol dye by ascorbic acid.

3.5.4 Determination of Pungency

Pungency in onions is derived from a number of volatile sulphur compounds. These compounds are produced when the onion cell is mechanically disrupted, bringing the enzyme alliinase present in the cell cytoplasm into contact with the flavour precursors, S-alk(en)yl-L-cystein sulphoxides. In addition to producing volatile sulphur compounds, the enzymatic breakdown of the S-alk(en)yl-L-cystein sulphoxides also produces stoichiometric amounts of ammonia and pyruvic acid. The amount of pyruvic acid generated enzymatically upon homogenization of onion in a blender is thus a good measure of the action of the alliinase on the flavour precursors and has been shown to be correlated with perceived onion pungency (Schwimmer and Weston, 1961). This enzymatically produced pyruvic acid is the commonly accepted measure of onion pungency. It is, however, only an indicator of pungency as pyruvate does not directly contribute to onion flavour. In order to determine the amount of enzymatically derived pyruvic acid, a correction for the endogenous, non-enzymatically derived pyruvic acid should be made. This is done by inactivating the alliinase enzyme either by heating prior to homogenization or by homogenizing in trichloroacetic acid. The level of pyruvic acid in this treated sample is then determined and subtracted from the total pyruvic acid. The pyruvic acid level in an onion homogenate can be measured by several methods. The most commonly used method involves the reaction of pyruvic acid with 2, 4-dinitrophenylhydrazine (DNPH) to form a coloured product. The amount of pyruvic acid is then estimated by measuring the absorbance of the pyruvic acid-DNPH adduct at 420nm in a spectrophotometer.

Amount of enzymatically produced Pyruvic acid was estimated by the modified Schwimmer and Weston method as prescribed by Anthon and Barret (2003). In the modified method, the amount of pyruvic acid was estimated by measuring the absorbance of the pyruvic acid-DNPH adduct at 515nm in the spectrophotometer. The UV-VIS spectrophotometer (Make: Elico, Model: SL164, double beam) was used for the study.

3.5.5 Organoleptic evaluations

The organoleptic evaluation of the dehydrated onion products was done on the basis of a 9-point Hedonic scale recommended by the Bureau of Indian Standards (IS: 6273, 1971) with a consumer test panel comprising of 12 members. Besides, as dehydrated onion is also to be used in cooked form, the sensory analysis of rehydrated onion samples was also conducted. The sensory attributes included taste, colour, flavour (pungency), texture (crispness) and overall acceptability of the dehydrated onion foils as well as the rehydrated samples. The evaluation sheet used for the sensory analysis has been given in Appendix C. The data were statistically analysed to find out the acceptable quality attributes.

CHAPTER - IV

Results & Discussion

CHAPTER IV
RESULTS AND DISCUSSION

As presented in the previous chapter, fresh onion samples were subjected to fluidised bed dehydration with various drying air conditions and slice thicknesses. This chapter deals with the results obtained from the investigations.

4.1 Physico-chemical characteristics of raw material

The initial moisture content of the onion samples used for the study varied between 87.2 and 88.6% (w.b.) i.e. 680 to 780% (d.b.) during the period of study. The physico-chemical characteristics of fresh onions used for the study are given in Table 4.1.

Table 4.1. Physico-chemical characteristics of onion samples taken for the study.

Parameters	Values*
Skin colour	Red
Bulb size, cm	5.2 X 4.9
Weight of bulbs, g	91.2
Shape of bulb	Globe
Shape index	0.92
Dressing losses, %	12.4
Moisture, % (w.b.)	88
Total soluble solids, °Brix	12.6
Acidity, %	0.37
Ascorbic acid, mg/100g dry matter	58.275
Endogenous pyruvic acid, µmoles/ g dry matter	4.56
Enzymatic pyruvic acid, µmoles/ g dry matter	768.10
Reducing sugars, %	3.8
Non-reducing sugars, %	5.6
Total sugars, %	9.4
Reducing sugars: Non-reducing sugars	0.68
Dry matter, %	12.0

* Average of 10 bulbs.

4.2 Drying characteristics of onion

4.2.1 Effect of drying air temperature

Different combinations of drying air temperature, air velocity and slice thickness were taken, as discussed in the previous chapter, to study their effects on the drying characteristics. The changes in the moisture content of onion with time at various air temperatures with air velocity kept at 1m/s are shown in Fig.4.1. It was observed that the moisture content of onion decreased exponentially with time at all air temperatures of 50°, 60°, 70° and 80°C for all slice thicknesses. The rate of moisture removal increased as the drying air temperature was increased from 50° to 80°C. Similar trends in the moisture loss were observed for 2.5 and 4m/s air velocities (Fig. 4.2 – 4.3).

4.2.2 Effect of air velocity

A comparison of the moisture loss from onion slices at drying air temperatures of 50°, 60°, 70° and 80°C and air velocities of 1, 2.5 and 4m/s has been presented in Figs.4.4-4.6. It was observed that higher drying air velocities resulted in increase in the rate of moisture removal from onion as compared to that with lower air velocities. It was mainly because higher air velocity helped in quick removal of moisture vapour from the vicinity of drying surface, thus increasing vapour pressure differential for moisture removal and by increasing the area of heat and mass transfer due to fluidisation.

Besides, the rate of heat transfer on a surface by convection has been found to be directly proportional to air velocity across the surface (Dash and Chandra, 2001). As the air velocity across the product was increased, it had a direct effect on the surface heat transfer coefficient of onion slices. This, along with the above phenomenon was responsible for the increased rate of drying of onion.

The same trend was noticed for all slice thicknesses and drying air temperatures used in the study. However, the effect of variation in the drying air velocity was found to be less prominent at higher drying temperatures as compared to lower temperatures. It was observed that by increasing the air velocity from 1 to 4m/s, net saving in the drying time ranged between 35-70%.

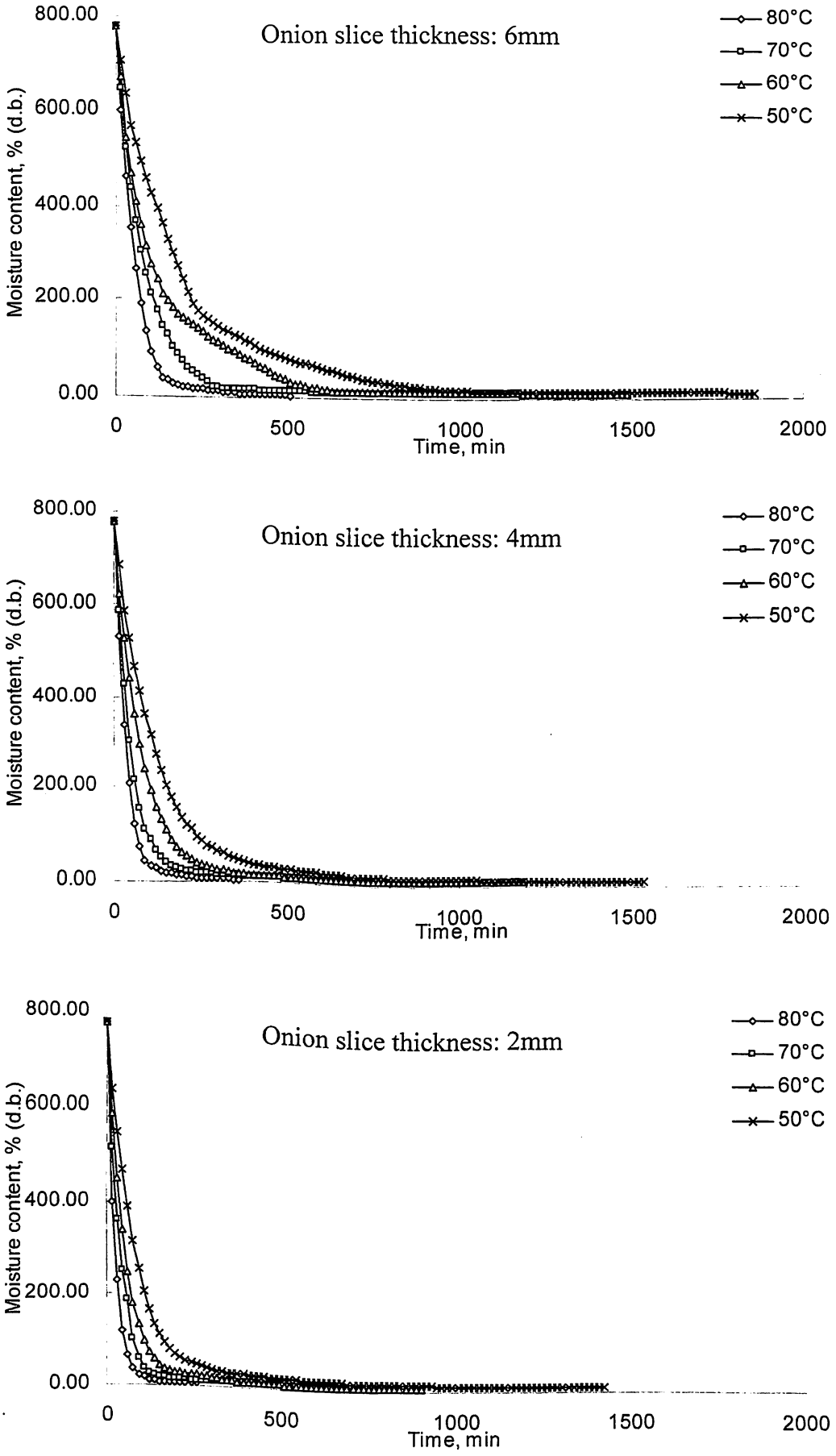


Fig 4.1: Effect of drying air temperature on moisture loss at 1m/s air velocity

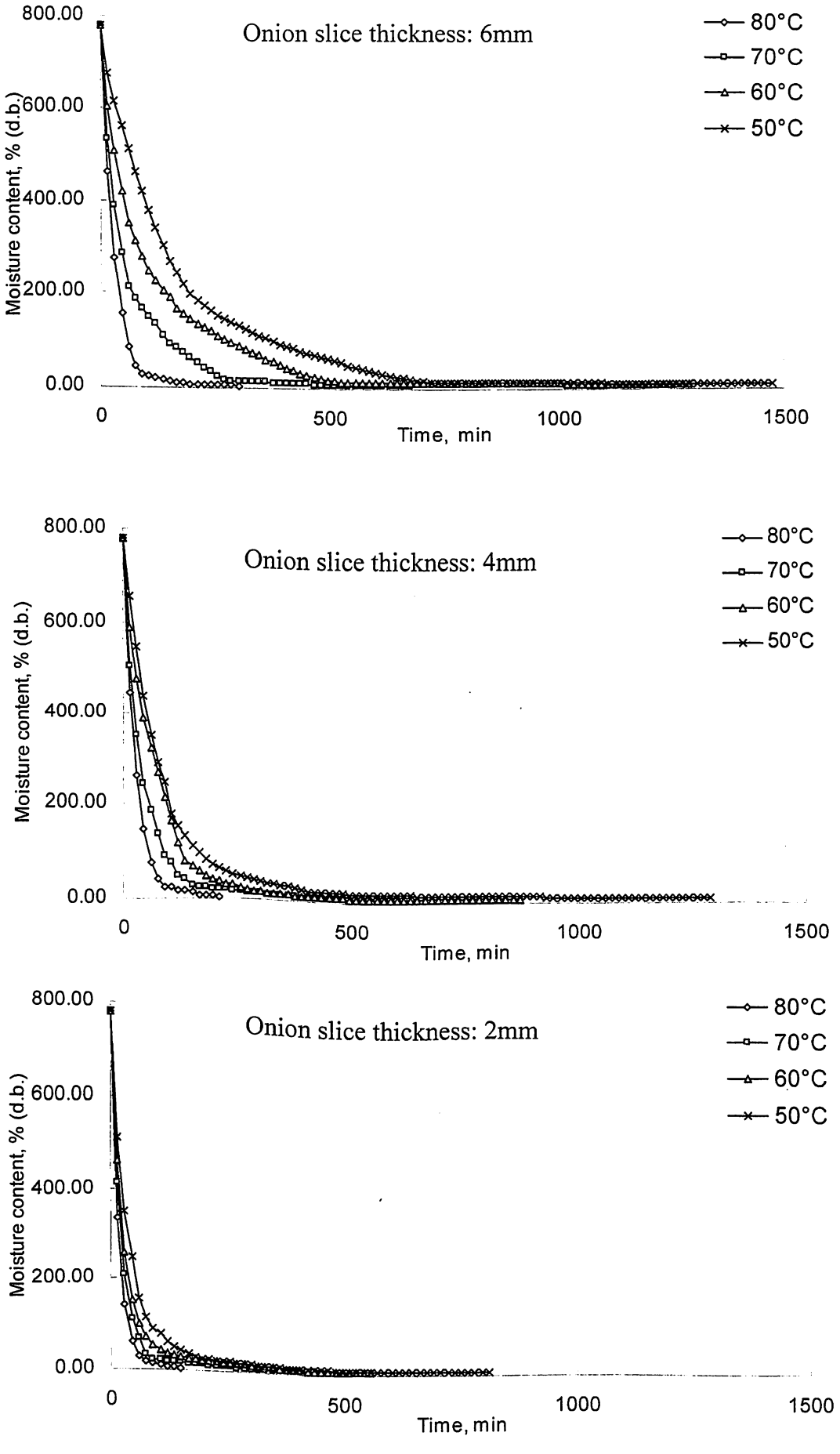


Fig 4.2: Effect of drying air temperature on moisture loss at 2.5m/s air velocity

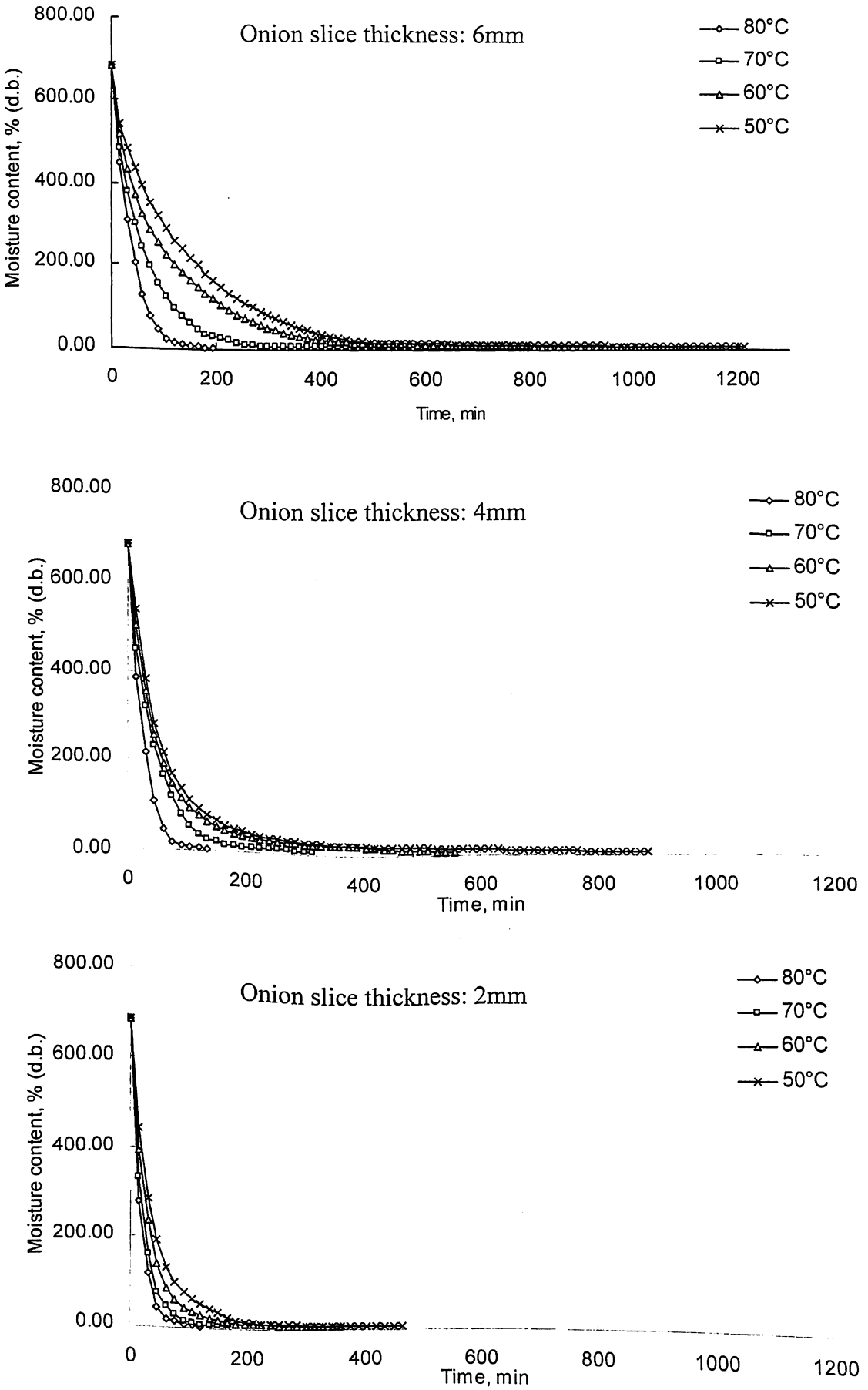


Fig 4.3: Effect of drying air temperature on moisture loss at 4m/s air velocity.

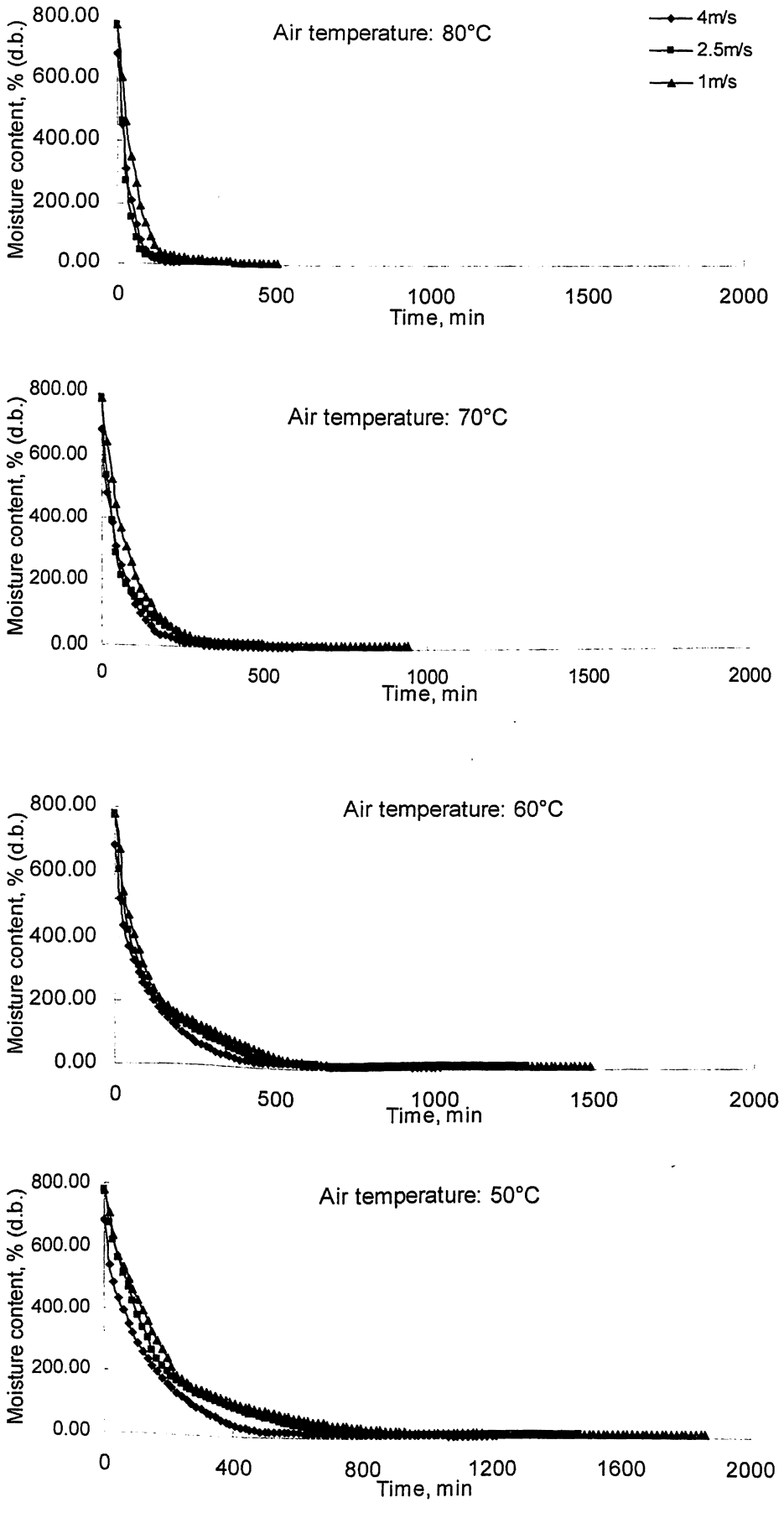


Fig 4.4: Effect of drying air velocity on moisture loss of 6mm onion foils

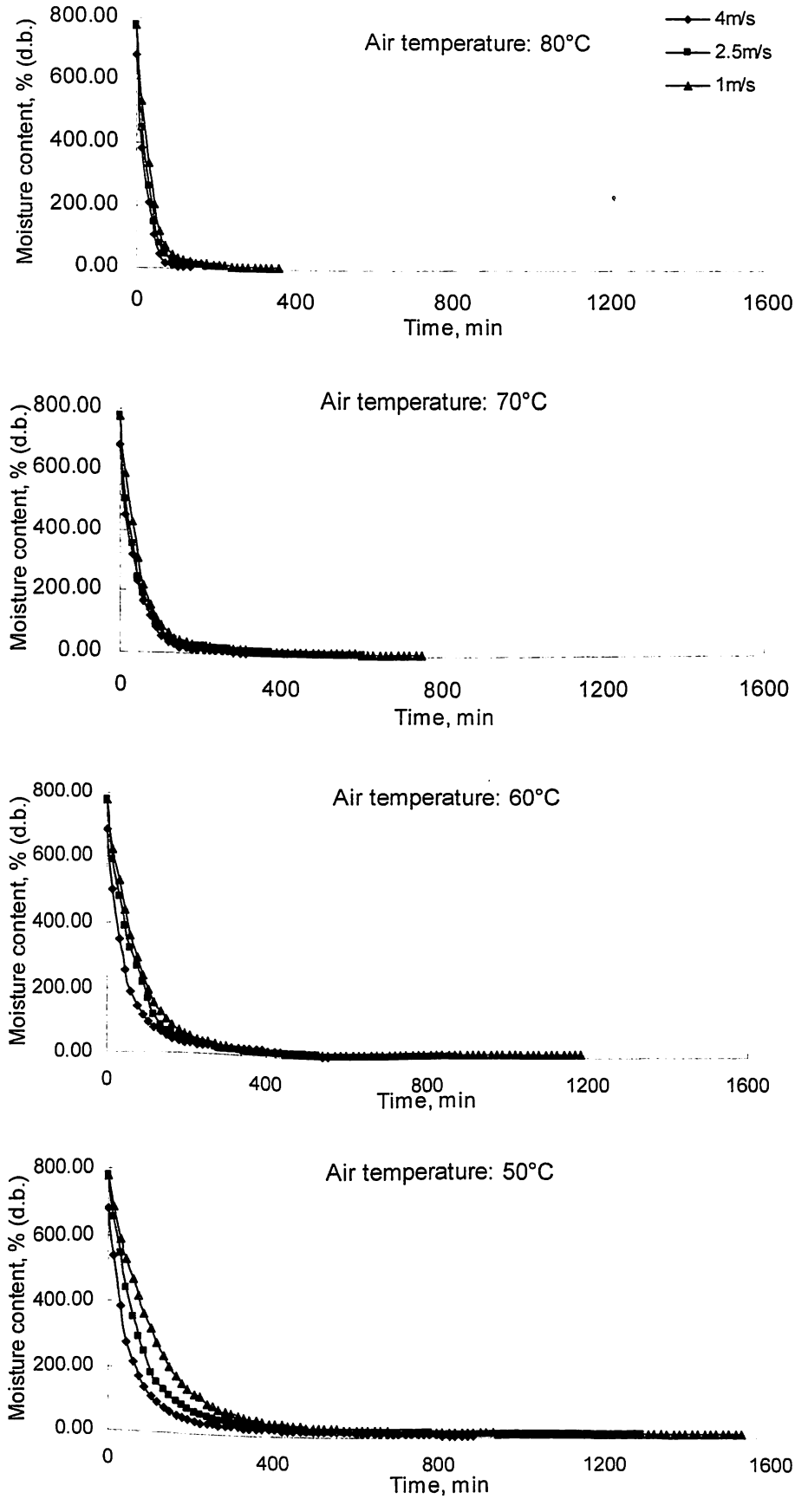


Fig 4.5: Effect of drying air velocity on moisture loss of 4mm onion foils.

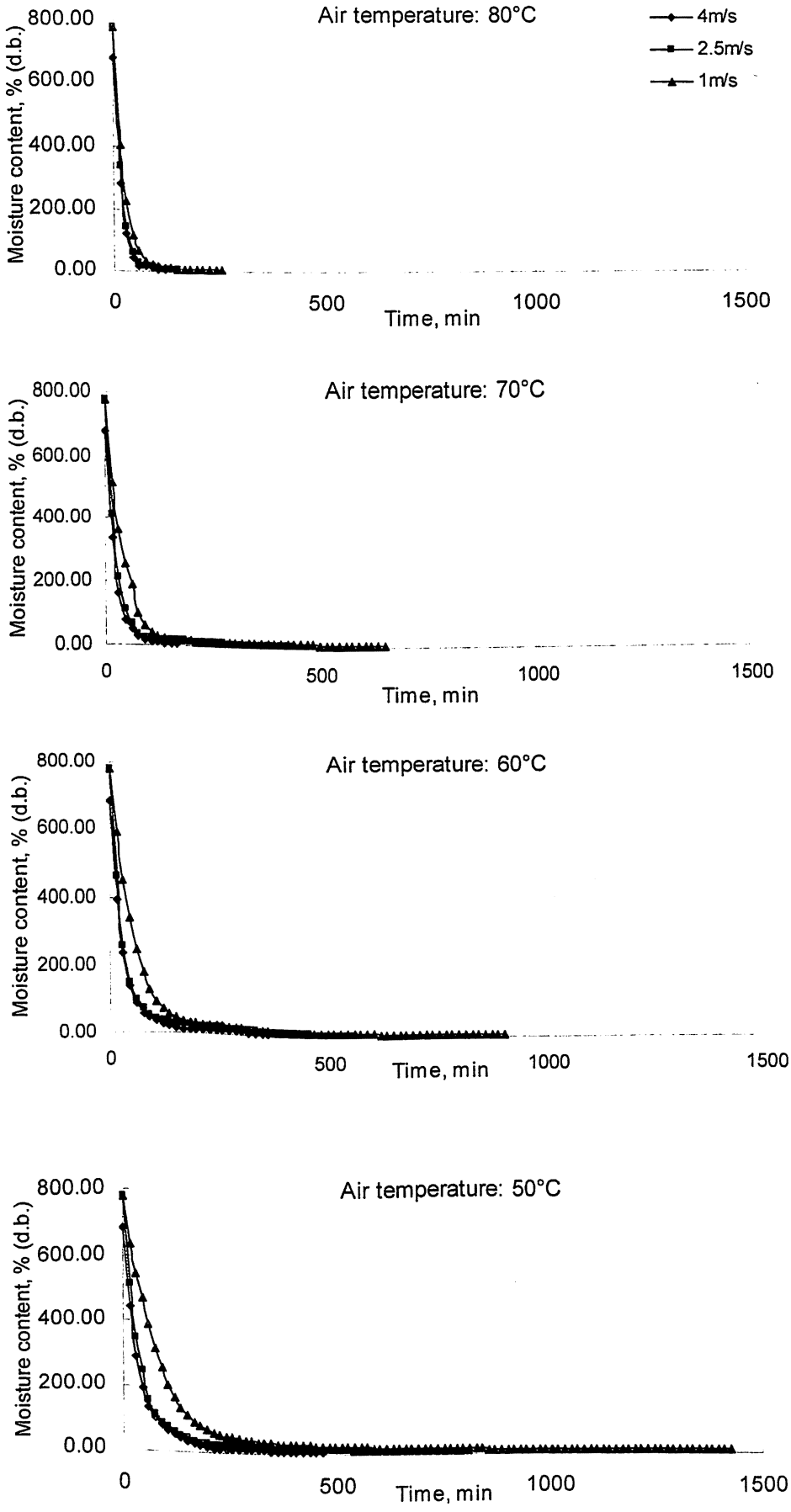


Fig 4.6: Effect of drying air velocity on the moisture loss of 2mm onion foils.

4.2.3 Effect of foil thickness

The onion foil is covered by a thin film like structure on both the surfaces. This film acts as a barrier for mass transfer. Hence, onion can be stored for longer periods without much moisture loss under normal ambient conditions as compared to other high moisture agricultural commodities. In other words, moisture transfer during any type of dehydration process for onion takes place mostly through the edges. The effect of changes in onion slice thickness on the rate of drying and drying time has been shown in Figs. 4.7-4.9. It was observed that the rate of moisture removal increased as the slice thickness was reduced. A 33.33% decrease in slice thickness (from 6mm to 4mm) decreased the drying time by 45.6% when the drying air temperature and velocity were 60°C and 4m/s respectively. Similarly at the same air temperature and velocity, 66.66% reduction in slice thickness (from 6mm to 2mm) resulted in reduction of 64.7% drying time. Similar trends were observed for other combinations of drying air temperatures and velocities.

The increase in rate of drying as a result of reduction in onion slice thickness was mainly due to increase in mass transfer surface area. Thus, by reducing size, more area was available for moisture evaporation to the surroundings. Also, reduction in the thickness of onion slices resulted in small individual pieces having less mass as compared to thicker slices helping in better fluidisation during drying.

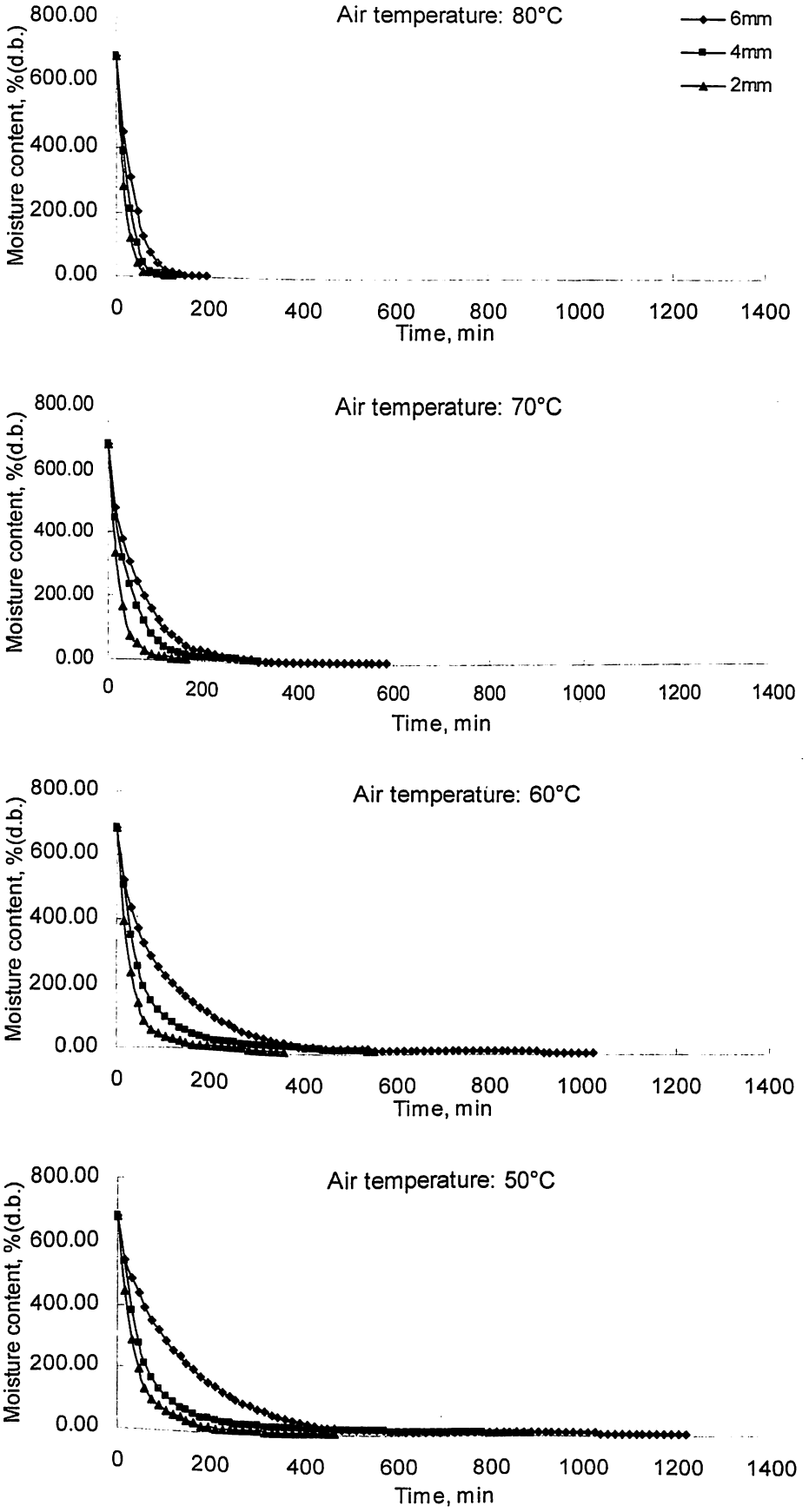


Fig 4.7: Effect of foil thickness on moisture loss at 4m/s air velocity.

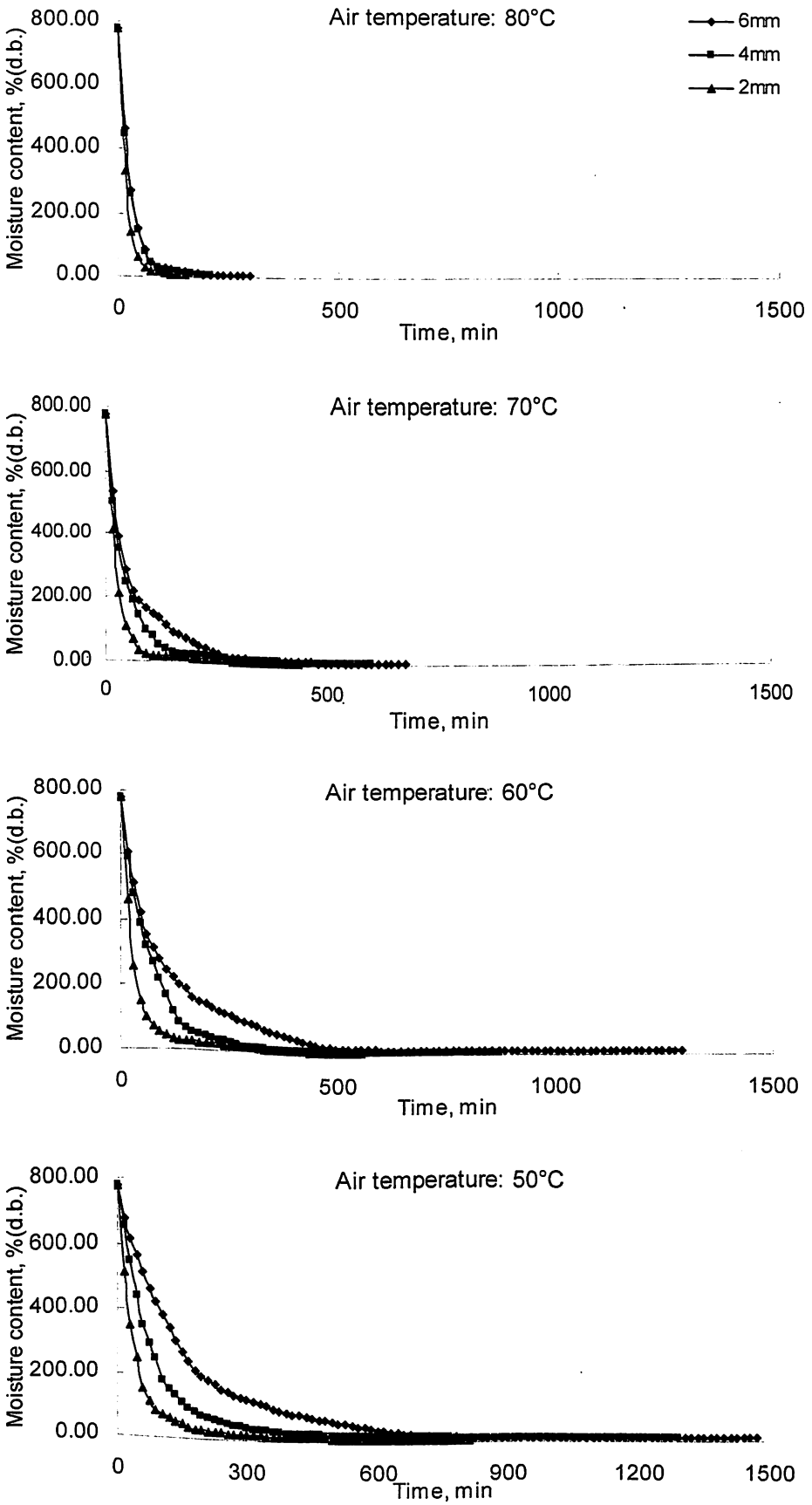


Fig 4.8: Effect of foil thickness on moisture loss at 2.5m/s air velocity.

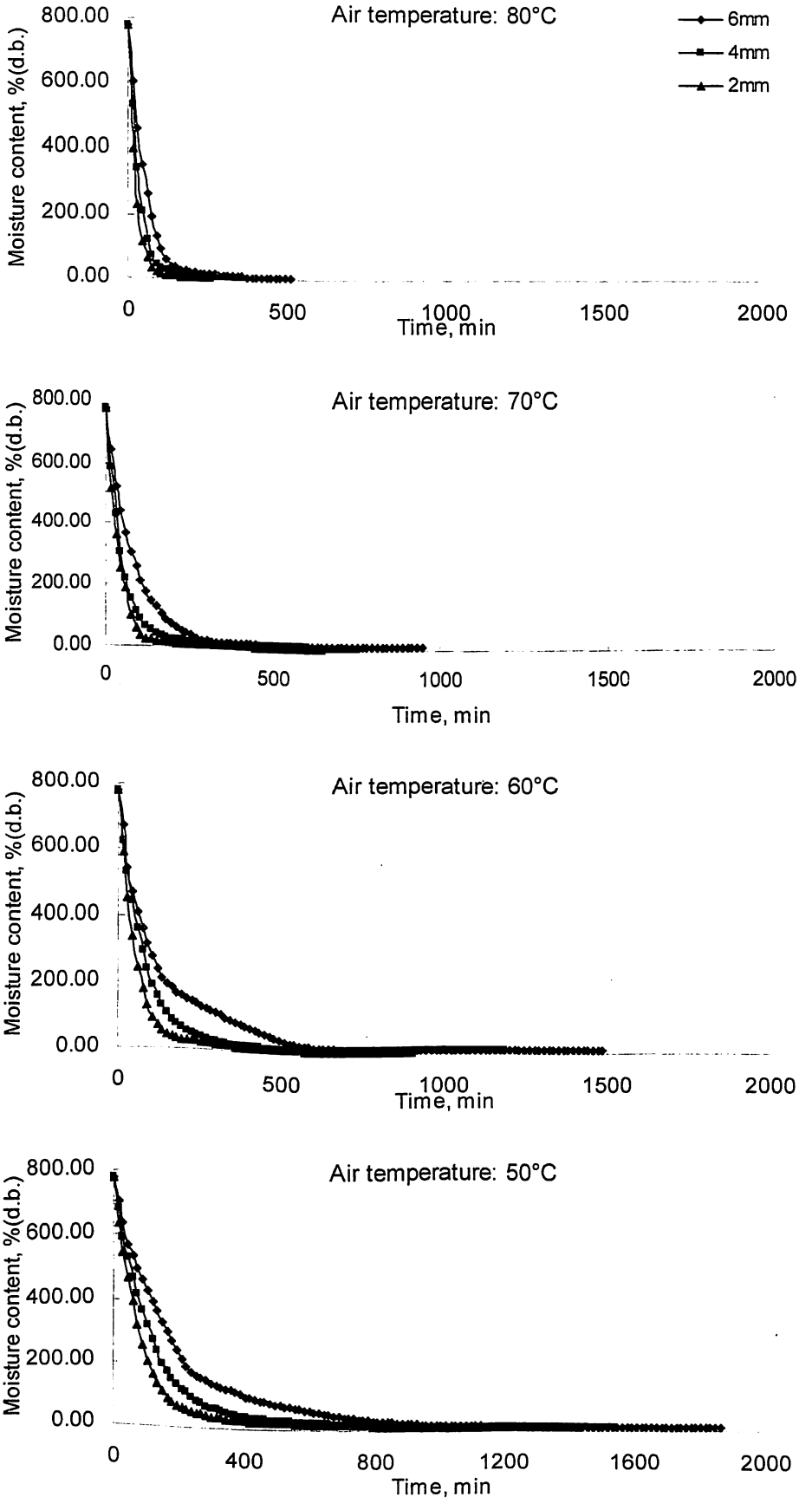


Fig 4.9: Effect of foil thickness on moisture loss at 1m/s air velocity.

4.2.4 Drying time

The time of drying required to bring down the moisture content of onion foils to the desired level is given in Fig.4.10 and Appendix D. It may be observed that the drying times increased with decrease in air temperature and air velocity and increase in foil thickness, as was expected.

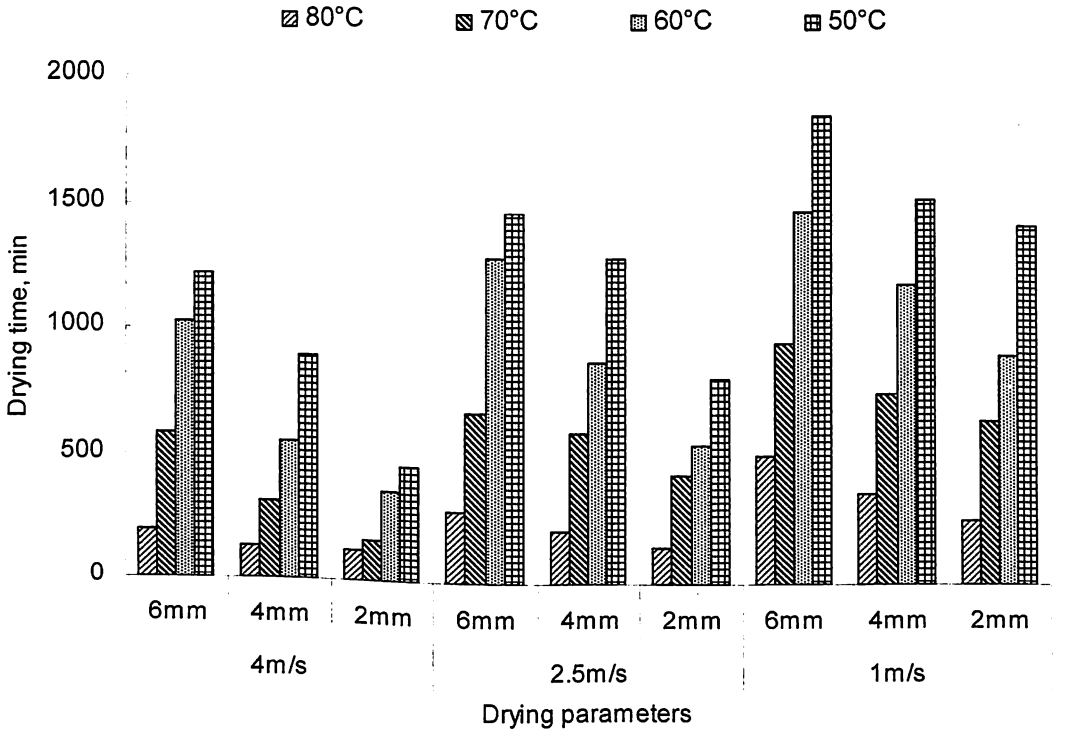


Fig 4.10: Comparison of drying time for onion samples dried under different drying conditions

4.2.5 Drying rates and moisture diffusivity under different conditions

The moisture loss data for onion dehydration under various drying conditions have been presented in Appendix E. The drying rates of onion slices for those conditions have been presented in Appendix F. The drying rate curves have been shown in Figs.4.11-4.13.

From the drying curves; it was observed that for all the conditions under study, the drying took place in falling rate period and the drying rates decreased with time associated with the decrease in moisture content. The drying rates were higher for higher air temperatures as well as for higher air velocities. Initially, at higher moisture contents there was a remarkable variation in the drying rates. However, as the moisture content reduced with time, the difference in drying rates phased out. In

general, the drying rates were higher for 2mm thick slices as compared to 4mm and 6mm thick slices, thus supporting the basic findings that less slice thickness would be advantageous in reducing the drying time.

The moisture loss data obtained during drying of onion samples were analysed and moisture ratio after each 15 minutes interval was calculated. The values of moisture ratios with respect to drying time have been presented in Appendix G. The variations in moisture ratio (MR) with respect to drying time under different drying conditions have been presented in Figs.4.14-.4.16 on semi-logarithmic scale. The changes in ln(MR) with respect to time were found to be linear with a negative slope. As the drying temperature was increased from 50°C to 80°C, the slope became steeper indicating that increase in drying temperature caused an increase in the drying rate and thus a faster depletion in moisture ratio. Moisture diffusivities were calculated from the slopes of these lines using equation 3.4. The r^2 values of the linear relationship and the moisture diffusivities estimated for various process conditions are given in Table 4.2.

Moisture diffusivity values of onion slices dried under different drying conditions in ranged between 2.148×10^{-9} and 1.474×10^{-7} m^2/s. Similar values of moisture diffusivities have been reported by different researchers for drying of various food products (Madamba et al. 1996; Pinthus et al. 1997; Senadeera et al. 1997; McMinn et al. 2003; Odilio et al. 2004; Charles et al. 2005, Bakal 2007; Kingsly et. al. 2007).

For all onion slice thicknesses under study, the moisture diffusivity increased with increase in drying air temperature. For example, for 6mm thick onion slices and for air velocity of 4m/s, the moisture diffusivity increased from 2.190×10^{-8} to 1.474×10^{-7} m^2/s when the drying air temperature was increased from 50°C to 80°C. This is because the product temperature increases with increase in the drying air temperature and moisture diffusion, being an internal process, mostly depends on product temperature (Singh and Heldman, 2004).

Similarly increase in moisture diffusivity values were observed for all slice thicknesses when the air velocity was increased. For 6mm thick onion slices dried at 80°C, the moisture diffusivity increased from 5.438×10^{-8} to 1.474×10^{-7} m^2/s when the air velocity was increased from 1m/s to 4m/s. This is because the increase in air velocity induced higher vapour pressure gradient between the materials being dried

and the drying atmosphere resulting in higher moisture gradient inside the material. Higher air velocity also increased the heat transfer coefficient on the surface of commodity. It increased moisture diffusion in the onion tissue.

For onion slices dried at 80°C temperature and 4m/s air velocity, the moisture diffusivity value decreased from 1.474×10^{-7} to 2.278×10^{-8} m^2/s when the thickness was reduced from 6mm to 2mm. This declining trend of moisture diffusivity by decreasing onion slice thickness was similar for all other drying conditions. This is because moisture diffusivity of food commodities is a function of cubic meter of moisture transferred per square meter of cross section per meter thickness per second. This is synonymous as saying that moisture diffusivity is directly proportional to the square of the length of moisture transfer which is nothing but the slice thickness in a uni-dimensional moisture transport phenomenon.

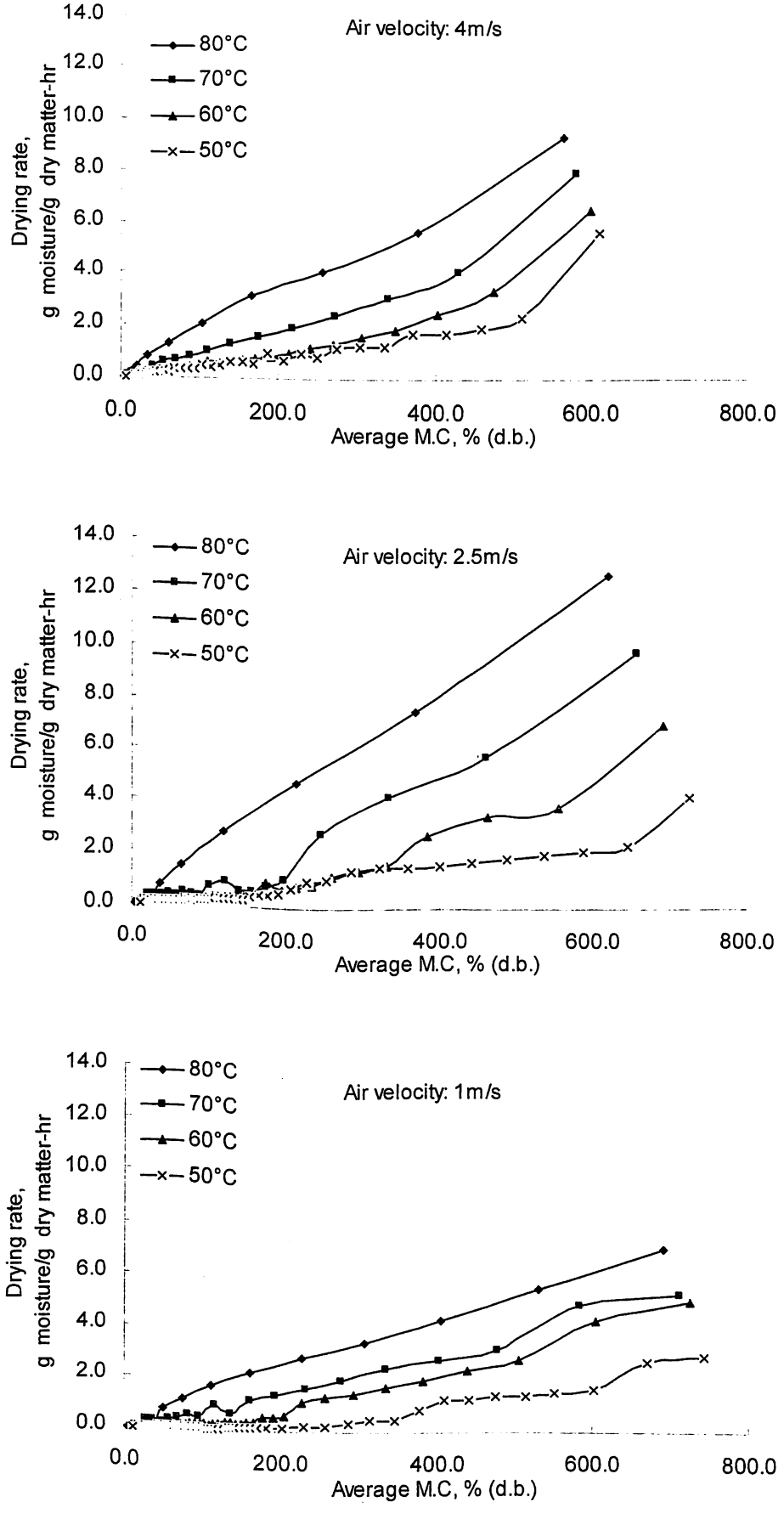


Fig. 4.11: Variation of drying rate with moisture content of 6mm thick onion foils.

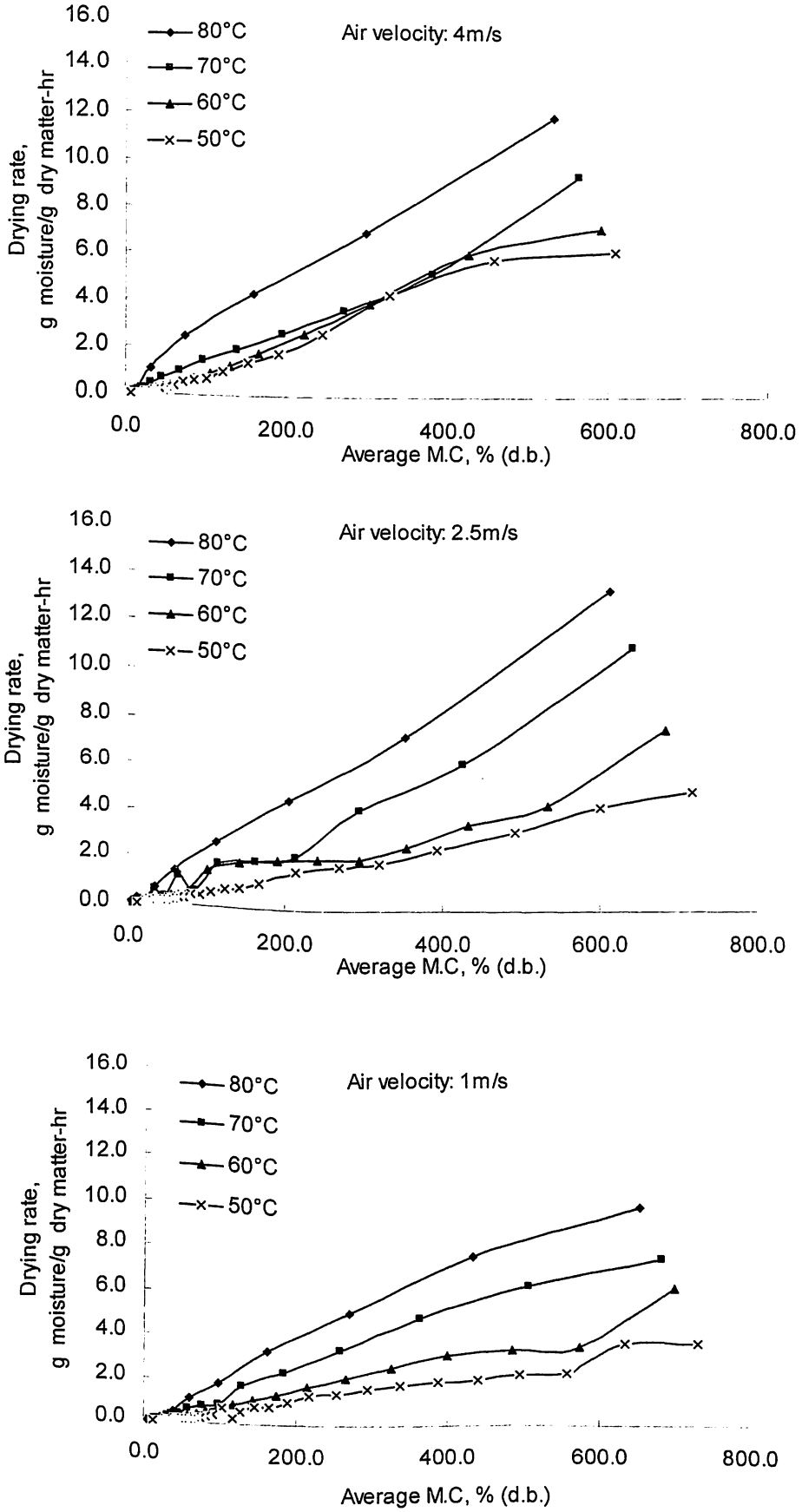
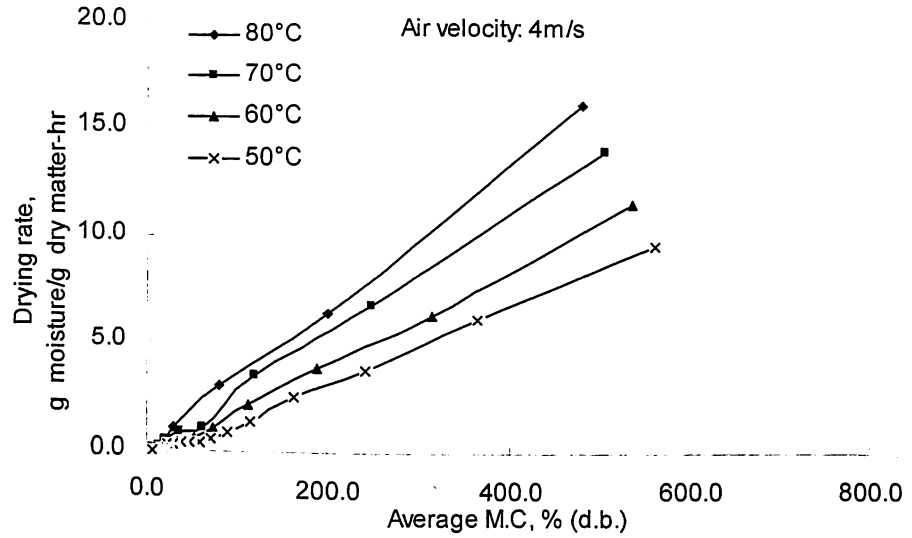
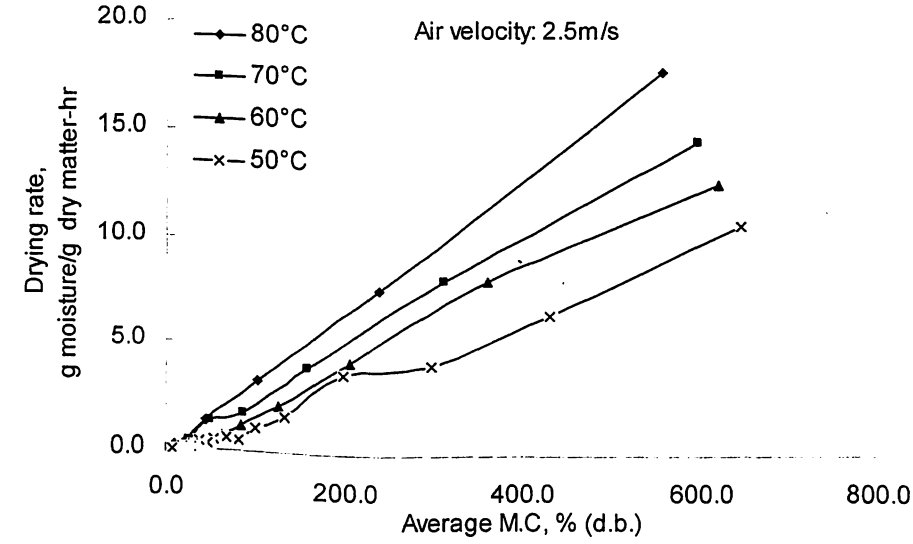


Fig. 4.12: Variation of drying rate with moisture content of 4mm thick onion foils.





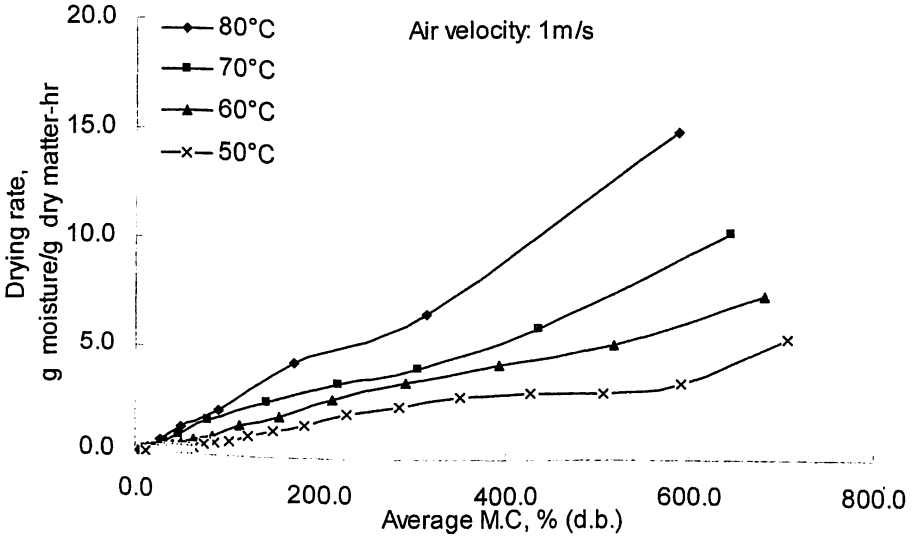


Fig. 4.13: Variation of drying rate with moisture content of 2mm thick onion foils.

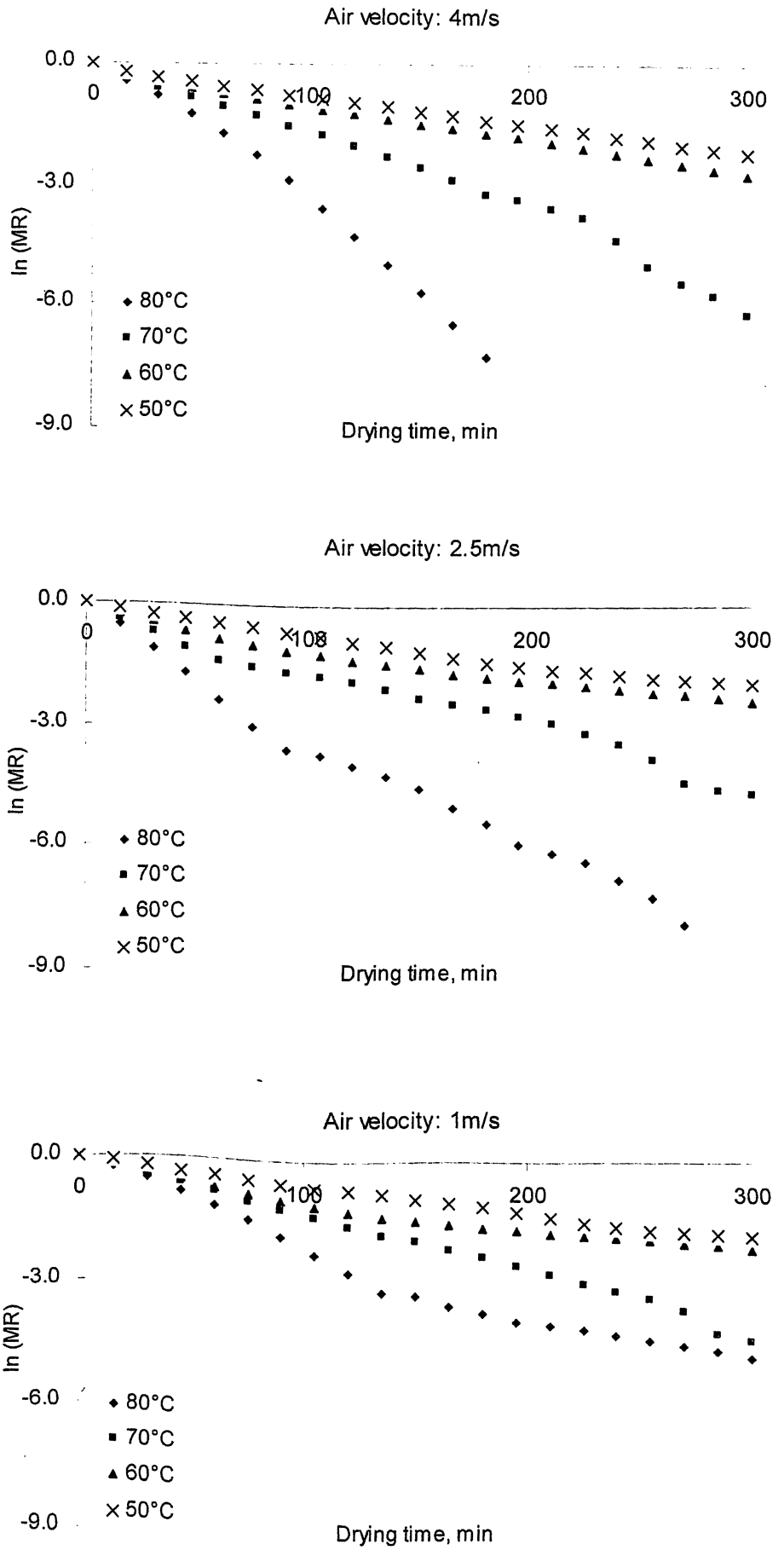


Fig.4.14: ln (MR) versus drying time for 6mm thick onion foils.

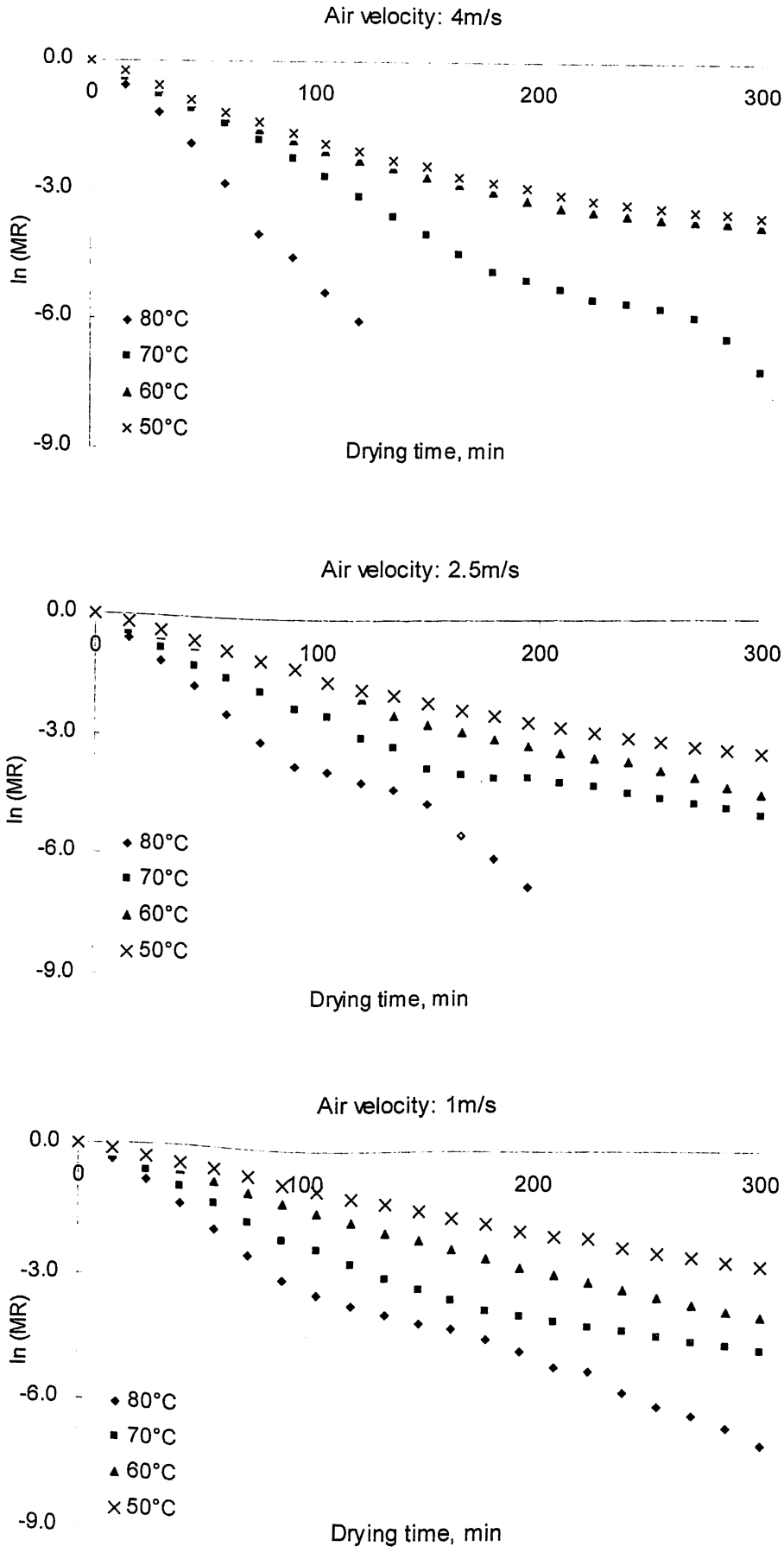


Fig.4.15: ln (MR) versus drying time for 4mm thick onion foils.

Th. 4300

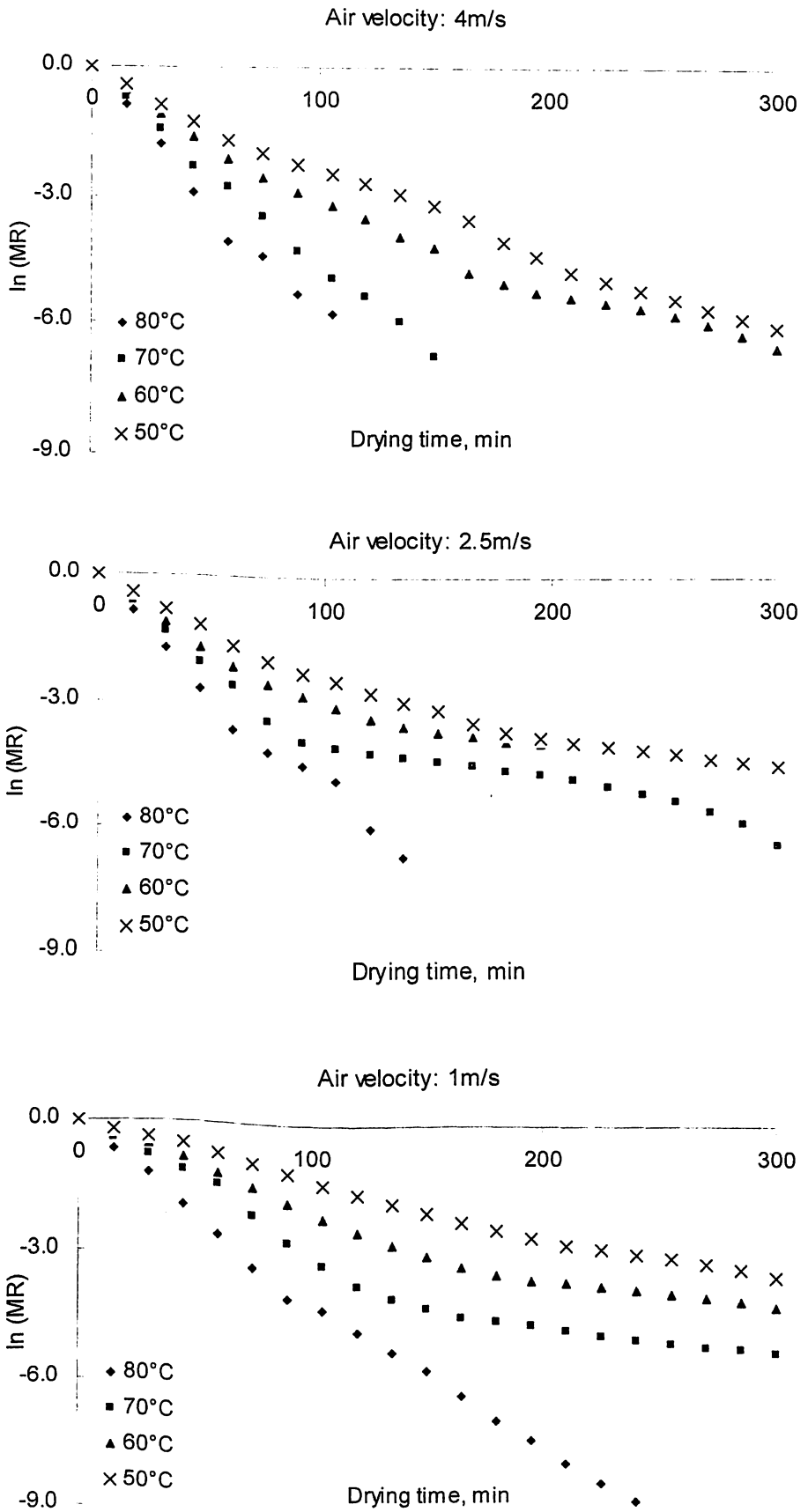


Fig.4.16: ln (MR) versus drying time for 2mm thick onion foils.

Table 4.2: Effective diffusivity values of onion slices at different drying conditions

Slice thickness (mm)	Air velocity (m/s)	Temperature (°C)	Regression equation	Moisture diffusivity (m^2/s)	r^2
6	4	80	y = -0.0404x + 0.4645	1.474×10^{-7}	0.987
		70	y = -0.0168x - 0.2696	6.131×10^{-8}	0.969
		60	y = -0.0068x - 0.5796	2.482×10^{-8}	0.967
		50	y = -0.0060x - 0.4774	2.190×10^{-8}	0.959
	2.5	80	y = -0.0268x - 0.4934	9.781×10^{-8}	0.986
		70	y = -0.0136x - 0.1854	4.964×10^{-8}	0.985
		60	y = -0.0068x - 0.6999	2.482×10^{-8}	0.954
		50	y = -0.0069x + 0.1413	2.518×10^{-8}	0.985
	1	80	y = -0.0149x - 0.4392	5.438×10^{-8}	0.968
		70	y = -0.0088x - 0.7402	3.212×10^{-8}	0.967
		60	y = -0.0061x - 0.5847	2.226×10^{-8}	0.955
		50	y = -0.0047x - 0.1874	1.715×10^{-8}	0.987
4	4	80	y = -0.0525x + 0.2147	8.509×10^{-8}	0.994
		70	y = -0.0230x - 0.2195	3.728×10^{-8}	0.985
		60	y = -0.0093x - 0.8662	1.507×10^{-8}	0.933
		50	y = -0.0066x - 1.1128	1.070×10^{-8}	0.915
	2.5	80	y = -0.0316x - 0.2607	5.122×10^{-8}	0.981
		70	y = -0.0143x - 0.7275	2.318×10^{-8}	0.979
		60	y = -0.0105x - 0.7671	1.702×10^{-8}	0.975
		50	y = -0.0061x - 1.1061	9.887×10^{-9}	0.967
	1	80	y = -0.0225x - 0.4193	3.647×10^{-8}	0.980
		70	y = -0.0097x - 1.262	1.572×10^{-8}	0.951
		60	y = -0.0069x - 1.3562	1.118×10^{-8}	0.939
		50	y = -0.0054x - 0.7273	8.752×10^{-9}	0.971
2	4	80	y = -0.0562x - 0.1665	2.278×10^{-8}	0.985
		70	y = -0.0439x - 0.1338	1.780×10^{-8}	0.997
		60	y = -0.0208x - 0.7647	8.431×10^{-9}	0.972
		50	y = -0.0187x - 0.4509	7.580×10^{-9}	0.994
	2.5	80	y = -0.0470x - 0.2931	1.905×10^{-8}	0.983
		70	y = -0.0198x - 1.0032	8.026×10^{-9}	0.943
		60	y = -0.0115x - 1.2290	4.662×10^{-9}	0.923
		50	y = -0.0103x - 1.2088	4.175×10^{-9}	0.980
	1	80	y = -0.0358x - 0.3297	1.451×10^{-8}	0.996
		70	y = -0.0102x - 1.7066	4.135×10^{-9}	0.882
		60	y = -0.0086x - 1.3198	3.486×10^{-9}	0.969
		50	y = -0.0053x - 1.2569	2.148×10^{-9}	0.960

y=ln (MR), dimensionless; x= drying air temperature, °C

4.2.6 Modelling of drying behaviour of onion slices

All the experimental data on drying of onion slices were fitted to Exponential model and Page's model as discussed in the previous chapter. The non-dimensional moisture ratio was used to model the drying curves with respect to time in minutes. Initial moisture content of the onion samples was used as critical moisture content as there was no constant rate drying period (Karthanos, 1993). Equilibrium moisture content M_e at different drying conditions was taken as the final moisture content in each drying operation. The goodness of fit of the model was determined by estimating the r^2 value by using non-linear regression analysis (Madamba et al., 1996; Noomborn and Verma 1986; Palipane and Driscoll, 1994).

The estimated parameters of Exponential as well as Page's model are given in Table 4.3 for all drying conditions along with the corresponding values of r^2.

Comparison of two models revealed that Page's model gave better fit than the Exponential model. The analysis yielded higher values of r^2 in the Page's model than those of Exponential model. As evident from the Table 4.4, the rate constant 'k_s' depended on air temperature; air velocity and onion foil thickness. The values of rate constant 'k_s' increased with increase in the drying air temperature signifying that higher drying rates were achieved at higher drying air temperatures. Similarly keeping the drying air temperature and velocity constant, decrease in onion slice thickness resulted in higher values of rate constant 'k_s' indicating higher rates of moisture loss for less thick slices. Further, as the drying air velocity was increased keeping the temperature and foil thickness constant, an increase in the drying rate constant 'k_s' was observed indicating increased rate of outside film heat transfer coefficient, thus increasing the effective moisture diffusivity.

No specific explanation could be given for variation in the value of empirical drying constant 'n' with various drying parameters.

Table 4.3: Drying constants of drying models under different drying conditions.

Slice thickness (mm)	Air velocity (m/s)	Temperature (°C)	Exponential model		Page's model		
			k_s (min^{-1})	r^2	n	k_p (min^{-1})	r^2
6	4	80	0.0404	0.987	1.1724	0.0153	0.994
		70	0.0168	0.969	0.9679	0.0214	0.988
		60	0.0068	0.967	0.7964	0.0290	0.992
		50	0.0060	0.959	0.8498	0.0182	0.987
	2.5	80	0.0268	0.986	0.8835	0.0557	0.988
		70	0.0136	0.985	0.8383	0.0367	0.986
		60	0.0068	0.954	0.8261	0.0248	0.981
		50	0.0069	0.985	0.9731	0.0079	0.988
	1	80	0.0149	0.968	0.9203	0.0265	0.980
		70	0.0088	0.967	0.8761	0.0230	0.986
		60	0.0061	0.955	0.8622	0.0175	0.981
		50	0.0047	0.987	0.9079	0.0093	0.994
4	4	80	0.0525	0.994	1.1645	0.0238	0.996
		70	0.0230	0.985	0.9553	0.0310	0.995
		60	0.0093	0.933	0.7157	0.0650	0.966
		50	0.0066	0.915	0.6703	0.0720	0.950
	2.5	80	0.0316	0.981	0.9210	0.0502	0.989
		70	0.0143	0.979	0.7808	0.0680	0.989
		60	0.0105	0.975	0.8555	0.0304	0.990
		50	0.0061	0.967	0.7640	0.0379	0.977
	1	80	0.0225	0.980	0.9033	0.0421	0.983
		70	0.0097	0.951	0.7507	0.0606	0.965
		60	0.0069	0.939	0.7932	0.0362	0.973
		50	0.0054	0.971	0.8331	0.0199	0.987
2	4	80	0.0562	0.985	0.9720	0.0671	0.990
		70	0.0439	0.997	0.9571	0.0571	0.998
		60	0.0208	0.972	0.7941	0.0761	0.990
		50	0.0187	0.994	0.8527	0.0474	0.997
	2.5	80	0.0470	0.983	0.9020	0.0797	0.989
		70	0.0198	0.943	0.6976	0.1296	0.949
		60	0.0115	0.923	0.6121	0.1498	0.946
		50	0.0103	0.980	0.6969	0.0862	0.987
	1	80	0.0358	0.996	0.9197	0.0577	0.997
		70	0.0102	0.882	0.6824	0.1033	0.926
		60	0.0086	0.969	0.7411	0.0591	0.974
		50	0.0053	0.96	0.7257	0.0451	0.968

4.3 Quality analysis of dehydrated onion

As discussed in article 3.5, the onion samples dried at temperatures of 50°, 60° and 70°C; air velocities of 1 m/s and 4 m/s and slice thicknesses of 2 mm and 4 mm were used for the study for finding the best parameters for producing dehydrated onion and to assess the suitability of fluidisation on the final product quality.

The dehydrated onion samples obtained from various drying conditions of the present investigation have been presented in Plate 4.1.

4.3.1 Rehydration characteristics

The rehydration characteristics of the dehydrated onion slices were studied in terms of rehydration ratio, coefficient of restoration and percentage of water in the rehydrated sample. The values of the rehydration ratio for the samples dried under different process conditions have been presented in Fig. 4.17. It was observed that the maximum rehydration ratio of 4.144 was obtained for drying 2mm thick slices at air temperature of 70°C and air velocity of 4m/s. It was followed by 2mm thick slice dried with air temperature and velocity of 60°C and 4m/s, respectively. The minimum rehydration ratio was 3.173 for 4mm thick slice dried at 70°C and 4m/s air velocity.

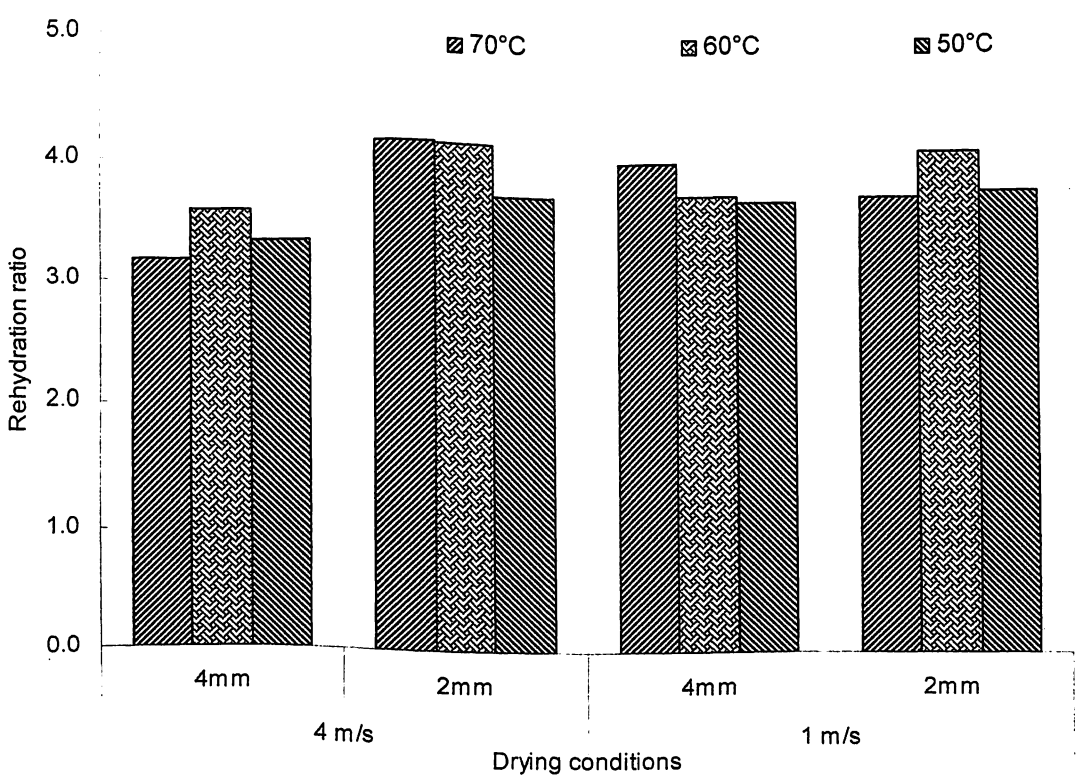


Fig.4.17: Effect of various drying parameters on rehydration ratio of dried onion.

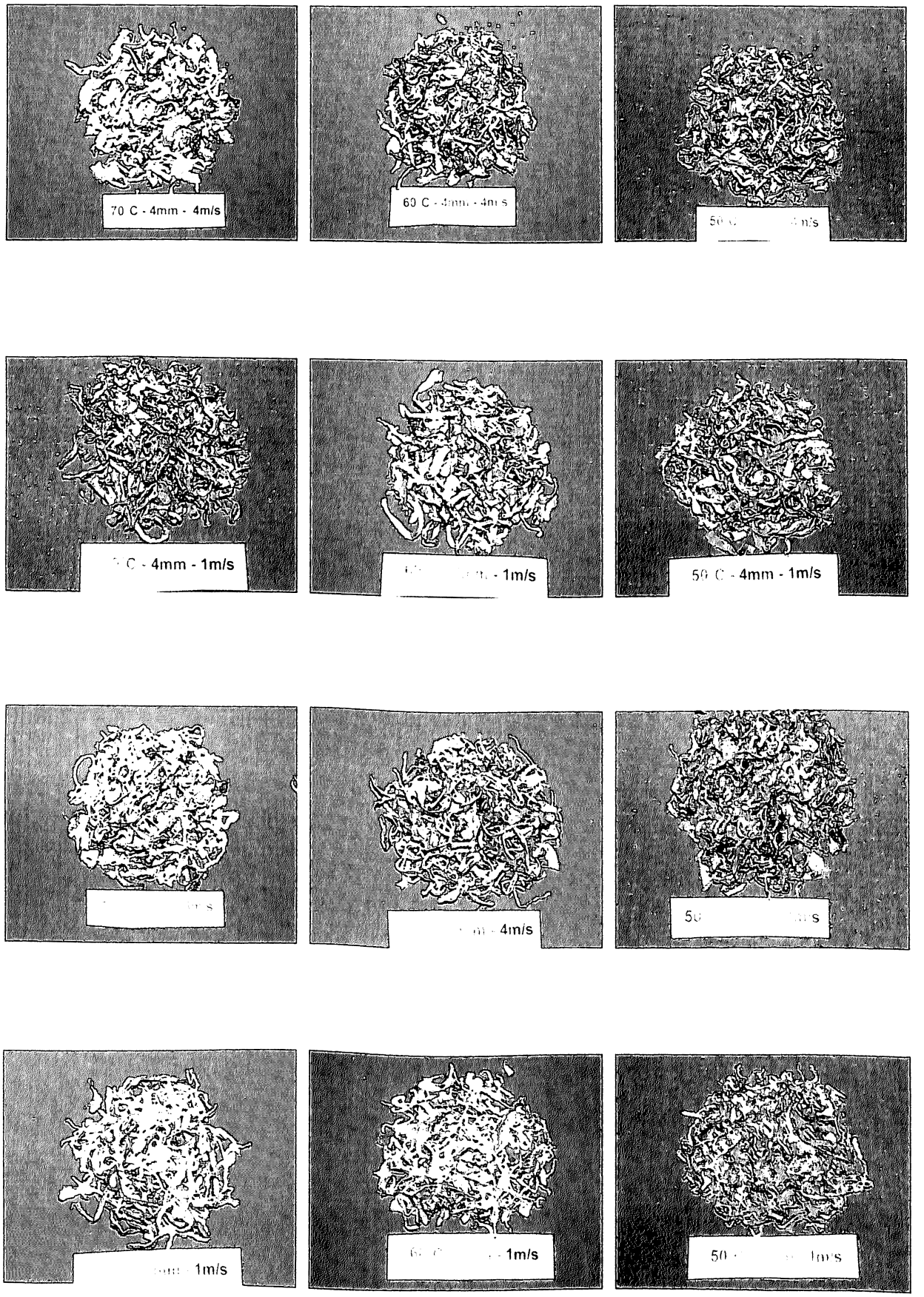


Plate 4.1 Onion slices obtained from different drying conditions

The values of the coefficient of restoration were between 0.44 and 0.57 whereas the percent of water in the rehydrated samples ranged between 70.61 and 77.37. Considering the critical difference for rehydration ratio at 5% level of significance to be 0.04, the acceptable process conditions in terms of rehydration characteristics are given in Table 4.4.

Table 4.4: Acceptable process parameters for onion dehydration in terms of rehydration characteristics

Drying air temperature (°C)	Air velocity (m/s)	Slice thickness (mm)	Rehydration ratio	Coefficient of restoration	% moisture after rehydration
70	4	4	3.173	0.44	70.61
		2	**4.144**	**0.56**	**77.09**
	1	4	3.986	0.49	76.74
		2	3.711	0.45	74.71
60	4	4	3.583	0.49	73.97
		2	**4.137**	**0.57**	**77.37**
	1	4	3.715	0.46	75.47
		2	4.094	0.50	77.08
50	4	4	3.341	0.46	72.10
		2	3.711	0.51	74.86
	1	4	3.673	0.46	75.49
		2	3.764	0.47	75.93

4.3.2 Surface colour

The colour ratio (a/b) of the dehydrated onion samples varied from 0.28 to 0.50. The effects of various drying parameters on the colour ratio of dehydrated onion samples have been presented in Fig. 4.18.

As already discussed in the previous chapter, the colour ratio 'a/b' represents comparative colourant strength of the sample in terms of red colour over yellow colour. More colour ratio value is an indication of more redness of the sample being examined. From consumers' preference point of view, neither very dark nor very light coloured products would be accepted. From Fig. 4.18, it was observed that 2mm thick onion slices dehydrated with air velocity of 4m/s at 70° and 60°C temperatures showed moderate values of colour ratio and thus the surface colour of these two particular samples may be considered to be acceptable, which was also confirmed by the consumer panel during organoleptic evaluation.

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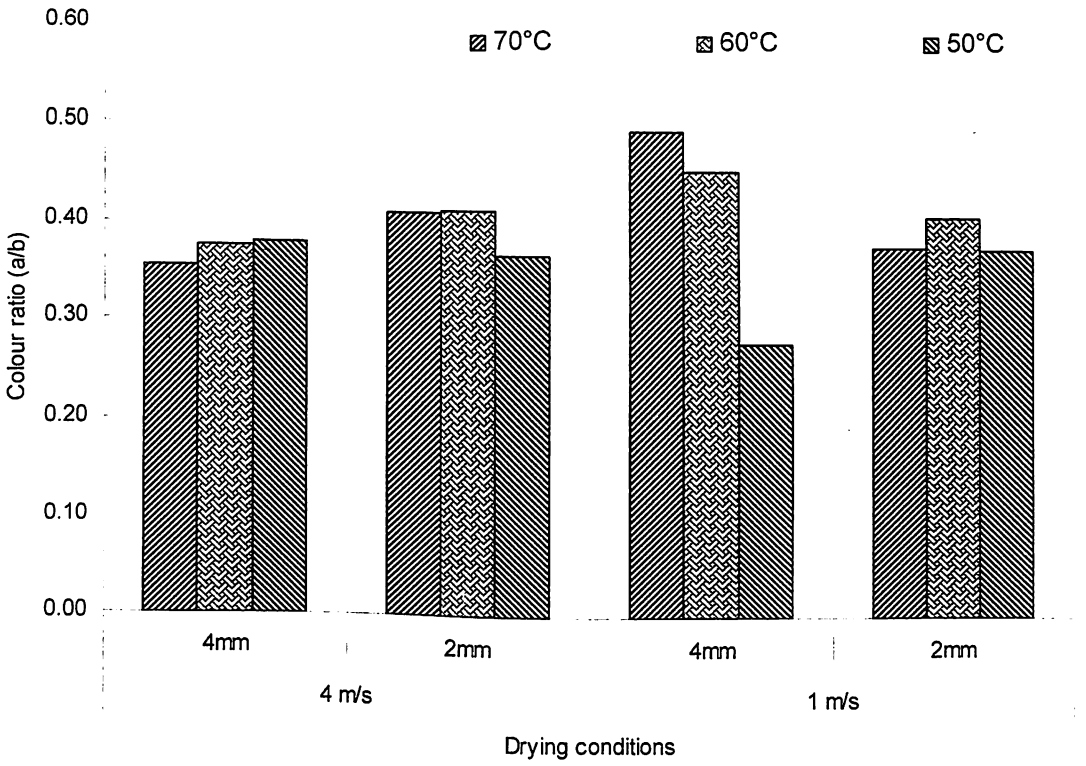

Fig.4.18: Effect of various drying parameters on the value of colour ratio.

4.3.3 Pungency

As discussed in article 3.5.4, amount of enzymatically produced pyruvic acid, as an indicator of onion pungency, was estimated by the modified Schwimmer and Weston method. The enzymatically developed pyruvic acid content of fresh onion was estimated to be 768.10 μmole/g on dry weight basis. Amount of pyruvic acid content of dehydrated onion samples ranged between 90.40 μmole/g dry matter and 480.07 μmole/g dry matter. Effect of various drying conditions on the pyruvic acid contents of dehydrated onion samples has been presented in Fig. 4.19. The analysis of the observations indicated that CD value at 5% level of significance was 10.63%.

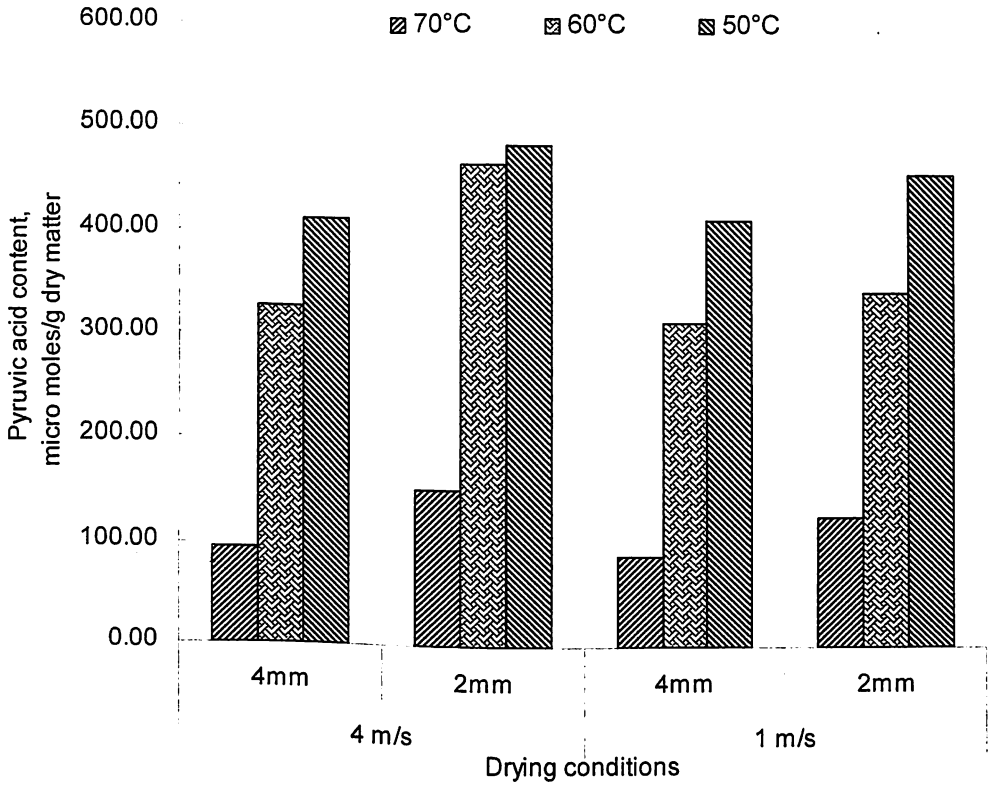

Fig.4.19: Effect of drying parameters on enzymatically produced pyruvic acid content of dehydrated onion.

It is observed that the amount of enzymatically produced pyruvic acid in the dehydrated onion samples was affected by all the drying parameters. Drying at 70°C resulted in less scores of pyruvic acid content, which was attributed to the enzyme inactivation at such a high temperature. Lower drying air temperatures caused more retention of enzymatic activities and thus higher pyruvic acid contents.

Samples dried at 1m/s air velocity exhibited higher loss of pyruvic acid as compared to that at 4m/s. This was because drying time at higher air velocity was relatively low resulting in less time exposure of the samples to heating, which might otherwise have caused enzyme inactivation.

Selection of onion slice thickness for dehydration has also effect on enzymatic development of pyruvic acid. It was observed that pyruvic acid content in 2mm thick onion foils was more than that in 4mm thick onion foils. This was attributed to the relatively lower drying time in case of less thick slices. Considering the critical difference to be 10.63, the samples of 2mm thickness dried at 50°C and 60°C with the air velocity of 4m/s were considered acceptable in view of retention of pyruvic acid.

4.3.4 Ascorbic acid

Ascorbic acid content of fresh onion was estimated to be 58.275 mg/100g of dry matter which was reduced to 19.843 mg/ 100g of dry matter when the onion slices were dried at 70°C at an air velocity of 4m/s. Values of ascorbic acid content of dehydrated onion samples ranged from 19.325 mg/100g dry matter and 21.721 mg/ 100g dry matter. Such massive reduction in the ascorbic acid content in onion during drying was due to long time exposure to heat and air flow. Ascorbic acid contents of dehydrated onion samples dried under various temperatures are presented in Fig. 4.20.

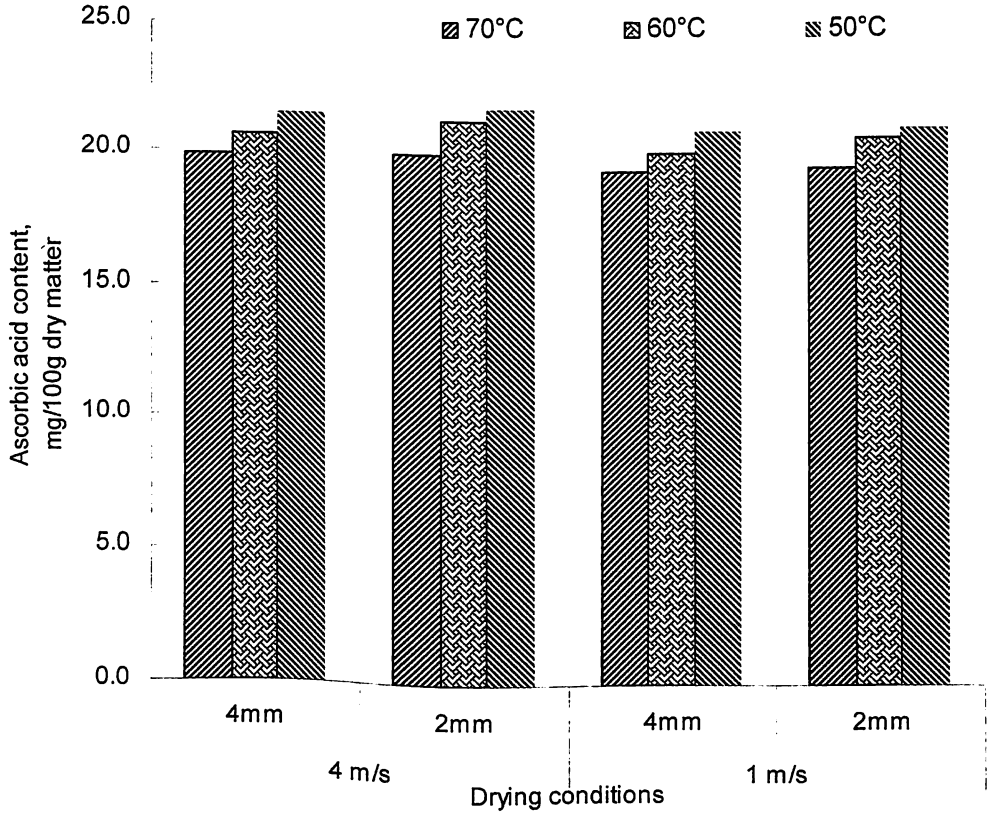

Fig.4.20: Effect of drying parameters on ascorbic acid content of dehydrated onion samples.

It was observed that decrease in drying air temperature from 70°C to 50°C resulted in retention of more ascorbic acid in the dehydrated samples. But the amount of ascorbic acid retained in the dehydrated sample was nominal as compared to that in the fresh sample irrespective of the drying air temperatures, velocities and onion slice thicknesses chosen for the experiment. Although, it is an accepted fact that depletion in ascorbic acid content of vegetables during any processing operation is an indication of its quality degradation in terms of other vitamins and nutritive values, onion being

a typical vegetable which is valued primarily in terms of its pungency; effect of ascorbic acid depletion during drying operation could be ignored.

4.3.5 Organoleptic evaluation

The mean scores for the different sensory parameters obtained from the consumer panel for the dehydrated and rehydrated samples have been given in Tables 4.5 and 4.6 along with the critical differences at 5% level of significance.

The maximum scores of dehydrated products for taste, colour, flavour, texture and overall acceptability were obtained for 2mm thick onion slices dried at 60°C with air velocity of 4m/s. However 2mm thick slices dried at 70°C and 4m/s air velocity and 1m/s air velocity were also acceptable at 5% level of significance.

Table 4.5: Mean scores for the sensory qualities obtained from the consumer panel for dehydrated onion samples

Slice thickness (mm)	Air velocity (m/s)	Air temperature (°C)	Taste	Colour	Flavour (pungency)	texture	Overall acceptability*
4	4	70	5.00	5.67	5.00	4.83	5.17
		60	5.58	4.25	**5.33**	4.92	5.25
		50	5.58	4.75	4.75	4.67	4.67
	1	70	5.67	5.08	5.08	**5.58**	5.08
		60	**6.17**	5.17	**5.42**	**5.75**	5.50
		50	**6.08**	5.17	**6.08**	**5.42**	**6.17**
2	4	70	**6.92**	**6.50**	**6.33**	**6.33**	**6.42**
		60	**7.08**	**7.25**	**6.50**	**6.33**	**6.67**
		50	**5.75**	4.08	5.17	**5.17**	4.92
	1	70	**6.00**	**6.08**	**6.00**	**5.92**	**6.17**
		60	**6.08**	5.67	**5.92**	**5.83**	**5.75**
		50	**6.25**	4.33	**6.33**	**6.17**	**5.75**
CD at 5% level of significance			1.333	1.26	1.32	1.35	1.13

*Figures in bold indicate that the product is acceptable in terms of the specific attribute.

Table 4.6: Mean scores for the sensory qualities obtained from the consumer panel for dehydrated onion samples after rehydration

Slice thickness (mm)	Air velocity (m/s)	Air temperature (°C)	Taste	Colour	Flavour (pungency)	texture	Overall acceptability*
4	4	70	6.00	5.33	6.25	5.58	6.08
		60	**6.58**	4.25	6.08	**6.00**	5.92
		50	5.50	5.75	5.08	5.58	5.42
	1	70	**6.50**	5.33	5.83	**5.83**	6.00
		60	6.33	5.17	5.75	**5.92**	5.83
		50	**7.00**	**6.67**	**6.83**	**6.83**	**6.83**
2	4	70	**6.92**	**6.42**	**7.00**	**6.67**	**6.84**
		60	**7.50**	**7.25**	**7.33**	**6.75**	**7.27**
		50	5.42	3.50	5.33	5.58	5.08
	1	70	**6.75**	6.17	**6.42**	**6.50**	**6.42**
		60	**6.50**	**7.08**	**6.42**	**6.58**	**6.58**
		50	**6.67**	5.25	5.67	**6.25**	5.83
CD at 5% level of significance			1.07	1.02	1.02	1.15	0.9

*Figures in bold indicate that the product is acceptable in terms of the specific attribute.

The maximum scores in terms of taste, colour, flavour and overall acceptability for dehydrated onion samples after rehydration were obtained for 2mm- 4m/s- 60°C. The best texture score was obtained for onion sample 4mm- 1m/s- 50°C. However, considering the critical difference at 5% level of significance as indicated against each quality parameter, the 4mm thick samples dried at 50°C with 1m/s air velocity and 2mm thick samples dried at 60°C and 70°C with air velocity 4m/s and dried at 60°C with air velocity 1m/s were also acceptable.

4.3.6 Optimisation of process parameters

As per the discussions in the foregoing sections, the following observations are made in general.

In terms of rehydration quality, the 2mm thick onion slices dried at 60°C and 70°C with air velocity of 4m/s were found to be acceptable.

In terms of surface colour, the onion foils of 2mm thickness dried at 70°C and 60°C with air velocity of 4m/s were acceptable. In terms of pyruvic acid content, 2mm thick onion slices dried at 60°C and 50°C with 4m/s air velocity were acceptable. These were also confirmed by the scores obtained from the organoleptic test. The ascorbic acid loss was similar in all the cases, the minor differences being very insignificant to determine the acceptance by consumers.

The drying conditions producing acceptable quality products as per the organoleptic evaluation have been presented in Table 4.7.

Table 4.7. Summary of acceptable parameters for drying in terms of organoleptic evaluation

	Slice thickness	Air temperature	Air velocity
Dehydrated Product			
	2 mm	60°C	4 m/s
		70°C	4 m/s
		70°C	1 m/s
Rehydrated Product			
	2 mm	60°C	4 m/s
		70°C	4 m/s
		60°C	1 m/s
	4 mm	50°C	1 m/s

Thus, considering all the quality parameters used for the study, it is recommended that in order to get an acceptable quality product, onion should be dried in the form of 2mm thick slices under fluidised bed (air velocity of 4m/s) at drying air temperature of 60°C. Drying at 60°C air temperature and at an air velocity of 4 m/s, i.e. under fluidised bed would help in saving of 60% in drying time as compared to normal convective drying (air velocity:1 m/s) for 2 mm thick onion slices.

CHAPTER - V

Summary & Conclusion

CHAPTER V
SUMMARY AND CONCLUSION

Onion (*Allium cepa* L.) is one of the major bulb crops of the world and is the most important commercial vegetable crop grown in India. Fresh onion is highly perishable owing to its high moisture content, usually more than 85%, and suitable dehydration techniques could be employed to reduce losses and extend its shelf life. Several methods have been tried to dehydrate onion such as hot air drying, infrared drying, freeze drying, vacuum drying, etc. Each of these methods has its own limitations and efforts are still continuing to find out the most suitable dehydration technology for onion.

Fluidised bed dehydration is a novel method being tried now a days to dehydrate fruits and vegetables with better cost effectiveness and less compromise with the final product quality as compared to other commercial methods. Fluidised bed drying has been successfully employed for dehydration of wide range of food commodities starting from food grains to varieties of fruits and vegetables like apples, peaches, grapes, potato, carrot, peas, beans, etc. and some spices like garlic, bay leaves, pepper seeds, etc. In all these cases the dehydration with fluidised bed has yielded better final product quality and substantial saving in drying time. A very little information was available on the fluidised bed drying of onion. The development of successful fluidised bed drying method for onion could help in providing a low cost alternative to Indian farmers to preserve this important commodity.

Keeping this in view, it was planned to study the feasibility of fluidised bed drying for onion. The study was planned with the following objectives.

1. To study the drying characteristics of onion in fluidised bed dryer at different temperature and air flow conditions.
2. To compare the drying characteristics of onion in fluidised bed with that under normal convective drying.

3. To evaluate the product quality of onion obtained form fluidised bed and normal convective drying conditions to suggest suitable drying parameters.

A laboratory model table top vertical column type fluidised bed dryer (Make: Retsch, Germany; model: TG 200) was used for the experiments. The dryer had provisions for varying drying air temperatures from 0 to 150°C and air flow rates ranging from 10% (1m/s) to 99% (4m/s). The equipment contained an air distribution system and an electronic control panel. Air was drawn in through the perforated stainless steel base of the drying vessel and was blown by the axial fan over an inbuilt 2kW electrical heater. The drying vessel was made of good quality glass supported on stainless steel frames. A fabric filter bag fitted at the top of the assembly helped to arrest particles tending to escape away with the drying air.

Well graded onions (Cv. Nasik red) were procured from the local market. Care was taken to select onions of uniform size and colour without any visible mechanical damage, rotting, rooting, sprouting and microbial infestation. Weight of the selected onions was 85-95 g. The onions were peeled manually and the non-edible portions like the neck and stem disc were removed with the help of sharp stainless steel knives. These were then cut longitudinally into two equal halves and then foils of desired thicknesses were cut out transversely. Prior to the dehydration experiment, initial moisture content of the sample was determined, which was used to determine the moisture loss and for studying the dehydration characteristics.

Different combinations of air temperature (50°, 60°, 70° and 80°C), air velocity (1m/s, 2.5m/s and 4m/s) and slice thickness (2mm, 4mm and 6mm) were used to study the drying characteristics of onion. The drying operations carried out at 1m/s air velocity was essentially the normal convective drying. The parameters studied under drying characteristics were the change in drying rate, moisture ratio and moisture diffusivity with time at different drying conditions. The drying data were also fitted to Exponential and Page's model. To assess the feasibility of using fluidised bed drying for onion and for determining the optimum parameters for drying, three drying air temperatures, viz. 50°, 60° and 70°C, two air velocities, viz. 1 m/s (convective drying with static bed) and 4 m/s

(convective drying with fluidised bed), and two slice thicknesses, viz. 2 mm and 4 mm were used for the study. The different quality aspects of the dehydrated samples such as rehydration characteristics, colour, ascorbic acid content and pyruvic acid content were considered along with the organoleptic attributes like taste, colour, flavour (pungency), texture and overall acceptability.

Based on the experimental findings, the following conclusions were drawn.

1. The moisture content of onion decreased exponentially with time at all air temperatures and air velocities, the drying rates being higher at higher drying air temperatures and air velocities and with less slice thicknesses.
2. Higher drying air velocities resulted in increase in the rate of moisture removal from onion as compared to that with lower air velocities. This was mainly because higher air velocity helped in quick removal of moisture vapour from the vicinity of drying surface, thus increasing vapour pressure differential for moisture removal and by increasing the area of heat and mass transfer due to fluidisation.
3. The rate of moisture removal from onion samples increased as the slice thickness was reduced. A 33.33% decrease in slice thickness (from 6mm to 4mm) decreased the drying time by 45.6% when the drying air temperature and velocity were 60°C and 4m/s respectively. Similarly at the same air temperature and velocity, 66.66% reduction in slice thickness (from 6mm to 2mm) resulted in reduction of 64.7% drying time.
4. The onion foil is covered by a thin film like structure on both the surfaces. This film acts as a barrier for mass transfer. Thus, moisture transfer during any type of dehydration process for onion takes place mostly through the edges only.
5. Drying of onion took place in falling rate period for all the drying conditions under study. The drying rates decreased with decrease in the moisture content and with time during the process of drying. There was a remarkable variation in the drying rates in the initial periods of drying, i.e. at higher moisture contents. However, as the moisture content reduced with drying time, the difference in drying rates phased out.

6. Moisture diffusivity values of onion slices dried under different drying conditions in the present investigation ranged between 2.148×10^{-9} and 1.474×10^{-7} m^2/s. For all onion slice thicknesses under study, the moisture diffusivity increased with increase in drying air temperature. Similarly increase in moisture diffusivity values were observed for all slice thicknesses when the air velocity was increased.

7. Keeping the drying air temperature and velocity unchanged, reduction in the onion slice thickness decreased the value of moisture diffusivity. It was attributed to the basic assumption taken in deriving the equation that moisture transport took place in a single dimension. The moisture diffusivity of food commodities is a function of cubic meter of moisture transferred per square meter of cross section per meter thickness per second. This is synonymous as saying that moisture diffusivity is directly proportional to the square of the length of moisture transfer which is nothing but the slice thickness in a uni-dimensional moisture transport phenomenon.

8. The drying data was fitted to two commonly used models, namely the Exponential model and Page's model. Comparison of two models revealed that Page's model gave better fit than the Exponential model. The analysis yielded higher values of r^2 in the Page's model than those of Exponential model.

9. The maximum rehydration ratio of 4.144 was obtained for drying 2mm thick slices at air temperature of 70°C and air velocity of 4m/s. It was followed by 2mm thick slices dried with air temperature and velocity of 60°C and 4m/s, respectively. The minimum rehydration ratio was 3.173 for 4mm thick slice dried at 70°C and 4m/s air velocity. The values of the coefficient of restoration were between 0.44 and 0.57.

10. The colour ratio (a/b) of the dehydrated onion samples varied from 0.28 to 0.50. It was observed that onion samples of 2mm slice thickness dehydrated with air velocity of 4m/s at 70° and 60°C temperatures showed moderate values of colour ratio and thus the surface colour of these two particular samples may be considered to be acceptable, which was also confirmed by the consumer panel during organoleptic evaluation.

11. The enzymatically developed pyruvic acid content of fresh onion was estimated to be 768.10 μmole/g on dry weight basis. Amount of pyruvic acid content of dehydrated onion samples ranged between 90.40 μmole/g dry matter and 480.07 μmole/ g dry matter. Considering the critical difference to be 10.63, the samples of 2mm thickness dried at 50°C and 60°C with the air velocity of 4m/s were considered acceptable in view of retention of pyruvic acid.

12. Ascorbic acid content of fresh onion was estimated to be 58.275 mg/ 100g of dry matter, which was reduced to 19.843 mg/ 100g of dry matter when the onion slices were dried at 70°C at an air velocity of 4m/s. Values of ascorbic acid content of dehydrated onion samples ranged from 19.325 mg/100g dry matter and 21.721mg/ 100g dry matter. Such high reduction in ascorbic acid content in onion was due to long time exposure to heat and air flow during drying. Although, it is an accepted fact that depletion in ascorbic acid content of vegetables during any processing operation is an indication of its quality degradation in terms of other vitamins and nutritive values, onion being a typical vegetable which is valued primarily in terms of its pungency; effect of ascorbic acid depletion during drying operation could be ignored.

13. From the organoleptic point of view, the 2mm thick onion slices dehydrated at 60°C with air velocity of 4m/s was rated as the best. However, 2mm thick slices dried at 70°C and 4m/s air velocity and 1m/s air velocity were also acceptable at 5% level of significance. The organoleptic test of rehydrated samples also indicated that the 2 mm thick slices dried under fluidised bed at 60° and 70°C were acceptable.

14. With reference to the above analysis, it is suggested to dry onion under fluidised bed with a slice thickness of 2 mm, air temperature of 60°C and air velocity of 4 m/s. In addition to giving a better quality product, it will also help to save in 60% drying time as compared to hot air convective drying at 60°C.

CHAPTER - VI

Suggestions for Future work

CHAPTER VI
SUGGESTIONS FOR FUTURE WORK

On the basis of the present study, the following suggestions are put forth for future works.

1. More investigations may be carried out on using different air velocities to find their effect on dehydrated product quality.
2. A prototype fluidised bed dryer suitable for onion dehydration may be developed and its economic feasibility be studied.
3. Storage study of dehydrated onion foils and powder in different storage and packaging conditions may be conducted.
4. More extensive studies on proximate composition changes in the onion obtained from fluidised bed drying may be carried out to explore its possibility for use in medicines.

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Appendices

Appendix A

Physico-chemical characteristics of onion cultivars

Parameters	Cultivars							
	Jalgaon White	**Phule White**	**Decco**	**Pusa Selection**	**Tadola Local**	**Parbhani Local**	**Red Creole**	**CD at 5%**
Skin colour	White	White	White	White	White	Light red	Red	
Avg. bulb weight, g	95.50	91.90	83.40	79.80	73.20	48.90	73.50	16.300
Avg. bulb size, L X B* cm	4.84 x 6.08	5.11 x 6.16	8.39 x 4.67	4.69 x 5.75	4.99 x 5.32	4.73 x 5.04	5.16 x 5.54	
Shape index	0.80	0.84	1.89	0.81	0.93	0.94	0.93	0.198
Bulb neck	Closed	Closed	Open	Closed	Closed	Closed	Closed	
Moisture, %	85.50	85.70	82.90	86.30	87.10	86.50	82.30	0.840
TSS, °Brix	12.50	11.60	15.10	12.60	12.20	12.40	15.20	0.670
Total solids, %	14.46	14.28	16.94	13.66	13.06	13.46	17.72	0.840
Total ash, %	0.57	0.63	0.64	0.54	0.64	0.44	0.72	0.012
*L= Length (cm), B= Breadth (cm)								
Each figure is the average of 10 bulbs of each cultivar								

Source: Sakhale et al. 2001

Appendix B

Specifications of the table top vertical column fluidised bed dryer

Make/ Year of production	Retsch/ 2007
Model/ Sl. No.	TG200/ 127100412
Manufacturer	Retsch GmbH, Germany (www.retsch.com)
Power requirement	2740VA at 220V (50-60Hz), 15A. External fuse-20A
Machine dimensions	1000mm X 400mm X 480mm, 21kg without drying vessel
Floor space	400mm wide X 540mm depth with 100mm back clearance
Ambient temperature	5°C to 40°C
Atmospheric humidity	Max. RH 80% at 31°C, linear decrease up to 50% RH at 40°C
Heater	2 X 1000 W
Fan type and capacity	Axial flow, 185 m^3/hr at no-load condition
Fan power	2740 VA at 220 V A/C supply
Air velocity range	1.00 – 4.00 m/s
Drying vessel size and material	6 litres, glass with stainless steel frame support
Filter bag	Nylon fabric
Heating temperature range	0 to 150°C

Appendix C

Evaluation Card for Hedonic Rating Test

Name:---------- Date:

Product: Dehydrated onion Time:

1. Please test this sample according to your preference.
2. Use the appropriate scale to show your attitude by checking at the point that best describes your feeling about the sample.
3. Remember you are the only one who can tell what you like.
4. An honest expression of your personal feeling will help us.

Scale:

Like extremely-9	Like very much-8	Like moderately-7
Like slightly-6	Neither like nor dislike-5	Dislike slightly-4
Dislike moderately-3	Dislike very much-2	Dislike extremely-1

Sample Code	Taste	Colour	Flavour (pungency)	Texture	Overall acceptability

Signature

Appendix D

Data on drying time of onion samples under various drying conditions

Onion slice thickness (mm)	Air velocity (m/s)	Air temperature (°C)	Drying time (min)	Onion slice thickness (mm)	Air velocity (m/s)	Air temperature (°C)	Drying time (min)
6	4	80	195	4	2.5	60	870
		70	585			50	1290
		60	1020		1	80	360
		50	1215			70	750
	2.5	80	285			60	1185
		70	675			50	1530
		60	1290	2	4	80	120
		50	1470			70	165
	1	80	510			60	360
		70	945			50	465
		60	1485		2.5	80	150
		50	1860			70	435
4	4	80	135			60	555
		70	315			50	810
		60	555		1	80	255
		50	885			70	645
	2.5	80	210			60	900
		70	600			50	1425

Appendix E

Experimental data on moisture loss of onion under different drying conditions

Air velocity-4m/s

	Slice thickness- 6mm				Slice thickness- 4mm				Slice thickness- 2mm			
Time, min	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db
0	680.82	680.81	680.83	680.81	680.82	680.83	680.82	680.82	680.83	680.82	680.83	680.81
15	448.53	481.45	517.20	540.36	384.73	446.98	501.54	536.82	279.72	331.87	392.98	441.32
30	308.03	379.49	433.38	482.72	211.96	316.85	351.40	381.72	119.17	161.58	235.06	286.92
45	205.75	302.85	372.58	434.84	105.85	228.24	254.15	276.00	43.52	74.66	138.78	193.55
60	128.14	243.38	326.16	392.69	44.47	164.23	188.81	211.99	17.04	48.07	86.39	132.20
75	77.36	195.69	287.72	350.38	17.58	115.69	145.64	168.64	13.85	27.29	59.11	99.21
90	44.75	156.35	254.84	320.32	12.27	78.89	115.53	134.81	8.70	15.09	44.12	77.88
105	24.81	124.45	226.05	289.88	8.23	53.74	93.56	109.19	7.39	10.39	34.54	64.16
120	14.89	98.33	202.00	260.67	6.65	36.94	77.06	92.83	5.20	8.67	27.96	53.90
135	10.03	77.44	181.00	240.61	5.02	26.30	64.56	76.73		7.21	20.33	43.88
150	7.57	60.49	162.67	216.98		19.85	54.62	67.67		6.19	17.14	34.60
165	6.29	46.03	146.27	199.58		15.10	47.12	55.25		5.36	12.63	26.65
180	5.68	35.36	131.81	176.22		12.57	40.64	48.28			11.32	19.27
195	5.19	31.61	118.72	162.52		11.41	34.39	44.63			10.54	15.84
210		27.05	104.21	147.87		10.69	30.80	39.03			10.01	13.09
225		22.58	92.53	133.33		9.94	28.55	34.69			9.65	11.90
240		16.07	82.06	120.67		9.75	26.87	32.28			9.27	10.97
255		11.84	72.88	109.63		9.39	25.60	30.76			8.89	10.23
270		10.22	64.57	98.58		8.98	24.67	29.12			8.51	9.57
285		9.38	58.23	89.96		8.32	23.90	27.58			8.15	9.12
300		8.52	51.71	81.52		7.73	22.55	26.23			7.82	8.73
315		7.93	45.66	72.98		7.21	21.97	24.99			7.49	8.34
330		7.81	40.43	64.37			21.15	23.83			7.23	8.15
345		7.76	36.28	58.56			20.80	22.92			6.98	7.98
360		7.71	32.40	51.17			20.42	21.97			6.83	7.84
375		7.68	26.82	45.25			20.07	21.19				7.69
390		7.64	23.78	39.60			19.82	20.42				7.56
405		7.59	21.39	34.19			17.43	19.69				7.45
420		7.55	19.74	29.97			16.11	19.13				7.37
435		7.52	18.41	25.32			14.63	18.61				7.32
450		7.49	17.44	22.67			13.12	18.22				7.26
465		7.45	16.83	20.27			12.24	17.83				7.19
480		7.42	16.15	17.96			11.43	17.46				
495		7.39	15.81	17.28			10.32	17.09				
510		7.36	14.96	16.62			9.51	16.54				
525		7.33	14.62	15.98			8.71	15.67				
540		7.29	14.34	15.37			7.93	15.12				
555		7.25	13.98	14.82			7.16	14.68				
570		7.21	13.7	14.50				14.43				
585		7.17	13.41	14.26				14.15				
600			13.13	13.99				13.68				
615			12.84	13.86				13.17				
630			12.56	13.69				12.73				
645			12.29	13.53				12.36				
660			11.97	13.34				11.99				
675			11.69	13.12				11.53				
690			11.4	12.89				11.07				
705			11.12	12.70				10.64				
720			10.84	12.51				10.26				
735			10.59	12.33				9.93				
750			10.32	12.15				9.51				
765			10.05	11.97				9.14				
780			9.87	11.76				8.76				
795			9.68	11.58				8.42				
810			9.5	11.39				8.09				
825			9.31	11.20				7.83				
840			9.22	11.02				7.61				
855			9.05	10.85				7.40				

Slice thickness- 6mm					Slice thickness- 4mm				Slice thickness- 2mm			
Time, min	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db
870			8.88	10.66				7.25				
885			8.69	10.47				7.15				
900			8.51	10.28								
915			8.33	10.09								
930			8.15	9.91								
945			7.97	9.72								
960			7.79	9.53								
975			7.63	9.34								
990			7.45	9.15								
1005			7.28	8.97								
1020			7.19	8.78								
1035				8.59								
1050				8.40								
1065				8.22								
1080				8.08								
1095				7.97								
1110				7.86								
1125				7.77								
1140				7.64								
1155				7.52								
1170				7.43								
1185				7.36								
1200				7.28								
1215				7.22								

Air velocity- 2.5 m/s

Slice thickness- 6mm					Slice thickness- 4mm				Slice thickness- 2mm			
Time, min	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db
0	779.51	779.51	779.51	779.51	779.52	779.50	779.51	779.51	779.51	779.51	779.51	779.50
15	462.61	534.22	603.53	674.30	445.21	503.53	588.17	654.31	335.15	413.14	461.44	511.24
30	273.20	387.79	507.59	615.22	260.45	347.46	477.13	544.83	142.35	208.00	258.15	348.85
45	154.20	282.70	420.50	561.00	146.67	241.45	387.35	436.84	61.20	108.91	151.98	245.22
60	83.34	211.88	351.19	511.42	78.90	187.38	321.06	348.74	26.57	65.49	98.37	154.19
75	47.02	185.01	311.51	464.13	42.90	138.09	268.85	290.65	17.92	31.50	70.17	113.15
90	28.52	164.69	277.01	420.39	26.41	93.26	215.88	245.26	14.57	22.00	54.10	86.99
105	25.78	149.00	246.09	380.30	23.14	78.80	165.99	181.14	11.77	19.64	43.67	75.78
120	21.45	133.19	223.84	341.15	19.26	49.12	119.16	154.02	7.24	18.01	34.75	60.75
135	17.77	110.51	203.94	303.14	16.91	41.61	82.10	132.59	6.21	17.03	30.52	49.05
150	14.37	91.78	187.72	268.05	13.45	27.27	68.81	113.62	5.19	16.05	27.42	42.90
165	10.99	82.72	164.31	240.96	8.75	24.33	58.64	98.39		15.10	25.69	34.10
180	9.23	73.30	153.19	215.86	7.23	23.01	49.49	86.26		14.15	23.42	28.62
195	7.75	61.61	143.90	197.82	6.14	22.60	42.72	75.70		13.20	22.24	25.55
210	7.32	52.81	134.38	183.90	5.12	21.13	37.59	67.26		12.26	21.27	23.33
225	6.95	43.24	125.76	172.11		19.88	33.25	60.15		11.34	20.29	22.07
240	6.46	34.81	117.73	160.11		17.35	30.86	54.49		10.43	19.31	20.92
255	6.12	25.97	109.44	150.02		15.99	25.81	49.59		9.51	18.43	19.70
270	5.83	17.19	101.87	142.73		14.92	22.90	45.81		8.62	17.51	18.49
285	5.51	15.76	95.04	135.46		13.87	19.26	42.40		7.77	16.59	17.38
300	5.09	15.08	87.61	129.28		12.90	17.37	39.30		6.85	15.67	16.33
315		14.41	81.23	122.69		11.87	15.72	36.38		6.12	14.78	15.37
330		13.73	75.28	116.57		10.91	14.34	34.10		5.88	13.83	14.45
345		13.09	68.67	110.01		9.95	13.41	32.19		5.76	12.89	13.56
360		12.42	61.12	104.11		9.45	12.47	30.55		5.70	11.96	12.77
375		11.84	55.57	98.08		9.02	11.64	28.12		5.62	11.02	12.02
390		11.25	49.98	92.87		8.58	10.96	25.13		5.58	10.22	11.54
405		10.67	42.42	87.03		8.23	10.34	22.32		5.51	9.35	10.93
420		10.11	37.89	82.65		7.99	9.93	21.68		5.48	8.54	10.36
435		9.53	32.37	78.39		7.72	9.35	20.92		5.46	8.19	9.88
450		8.98	27.96	74.65		7.53	9.17	20.35			7.78	9.45
465		8.61	23.67	70.36		7.41	8.99	19.86			7.40	9.02
480		8.33	20.39	66.12		7.33	8.83	19.40			6.99	8.78
495		8.17	18.12	62.19		7.24	8.68	19.09			6.72	8.45

Slice thickness- 6mm					Slice thickness- 4mm				Slice thickness- 2mm			
Time, min	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db
510		7.96	15.93	58.34		7.15	8.54	18.64			6.40	8.21
525		7.82	15.23	54.43		7.06	8.41	18.49			6.21	8.03
540		7.71	14.79	50.85		6.99	8.29	18.05			6.02	7.91
555		7.59	14.61	47.09		6.91	8.18	17.71			5.92	7.82
570		7.51	14.44	43.43		6.87	8.07	17.32				7.74
585		7.43	13.99	39.87		6.84	7.99	17.03				7.68
600		7.34	13.85	36.27		6.81	7.91	16.77				7.61
615		7.28	13.76	32.69			7.83	16.49				7.58
630		7.22	13.66	29.28			7.75	16.27				7.54
645		7.19	13.57	25.98			7.68	15.83				7.51
660		7.16	13.48	23.42			7.59	15.49				7.47
675		7.14	13.40	20.13			7.51	15.23				7.43
690			13.31	17.76			7.44	15.08				7.39
705			13.23	16.01			7.39	14.90				7.35
720			13.17	15.49			7.34	14.75				7.32
735			13.11	14.98			7.28	14.57				7.29
750			13.05	14.69			7.25	14.43				7.26
765			12.99	14.40			7.22	14.13				7.23
780			12.93	14.12			7.19	13.71				7.20
795			12.88	13.88			7.16	13.38				7.16
810			12.84	13.72			7.13	13.15				7.13
825			12.79	13.57			7.11	12.94				
840			12.74	13.45			7.08	12.83				
855			12.70	13.34			7.05	12.65				
870			12.66	13.24			7.04	12.56				
885			12.62	13.15				12.48				
900			12.59	13.07				12.40				
915			12.55	12.99				12.34				
930			12.51	12.92				12.25				
945			12.48	12.85				12.17				
960			12.44	12.74				12.10				
975			12.40	12.66				12.04				
990			12.35	12.58				11.96				
1005			12.31	12.51				11.91				
1020			12.27	12.47				11.85				
1035			12.23	12.44				11.80				
1050			12.19	12.41				11.75				
1065			12.15	12.37				11.70				
1080			12.11	12.34				11.66				
1095			12.08	12.31				11.62				
1110			12.04	12.28				11.59				
1125			12.01	12.25				11.55				
1140			11.97	12.22				11.51				
1155			11.94	12.19				11.47				
1170			11.89	12.16				11.44				
1185			11.86	12.13				11.39				
1200			11.83	12.10				11.36				
1215			11.79	12.06				11.33				
1230			11.77	12.01				11.29				
1245			11.74	11.97				11.25				
1260			11.71	11.95				11.22				
1275			11.68	11.93				11.19				
1290			11.65	11.91				11.17				
1305				11.89								
1320				11.87								
1335				11.86								
1350				11.85								
1365				11.84								
1380				11.83								
1395				11.82								
1410				11.81								
1425				11.79								
1440				11.78								
1455				11.76								
1470				11.75								

	Slice thickness- 6mm				Slice thickness- 4mm				Slice thickness- 2mm			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,	M.C.,
min	% db	% db	% db	% db	% db	% db	% db	% db	% db	% db	% db	% db
0	779.51	779.51	779.50	779.52	779.50	779.51	779.51	779.51	779.51	779.50	779.52	779.50
15	600.14	644.78	668.78	705.53	530.66	588.09	620.86	683.10	400.53	514.35	585.82	635.65
30	460.51	520.12	540.98	635.38	337.09	426.89	529.23	588.15	228.10	359.24	450.78	545.59
45	351.24	438.24	469.83	568.92	205.77	301.86	441.19	526.85	116.63	251.30	338.70	467.45
60	263.38	366.58	408.12	533.44	120.99	214.29	360.19	466.89	64.59	186.62	247.34	388.92
75	191.46	303.44	357.74	494.79	73.06	152.48	293.16	413.70	34.52	98.69	179.47	315.80
90	134.08	253.29	313.09	459.46	45.15	108.28	237.76	362.14	20.27	58.05	131.12	254.20
105	90.79	210.99	275.13	425.25	33.84	88.63	192.83	315.59	16.53	37.16	95.09	202.60
120	59.75	176.08	241.49	393.92	27.51	66.47	157.29	272.46	12.22	26.02	72.64	163.83
135	39.91	145.88	213.04	363.79	23.25	49.32	129.14	236.63	9.63	21.17	56.12	133.62
150	36.48	128.61	198.39	327.17	19.80	39.98	106.81	201.32	8.24	18.18	44.55	110.96
165	29.73	102.95	184.13	300.37	17.94	32.83	88.35	175.73	6.98	16.21	35.90	93.15
180	25.87	88.79	170.50	272.19	14.97	27.46	73.99	155.04	6.27	15.45	31.82	79.74
195	21.74	74.26	162.03	243.18	12.68	24.88	62.77	134.99	5.96	14.62	29.09	68.24
210	20.49	61.62	154.13	216.73	10.29	22.72	53.80	119.84	5.73	13.53	27.55	60.01
225	19.15	51.66	148.05	190.80	9.89	21.15	46.80	113.27	5.62	12.75	25.95	54.90
240	17.59	44.87	140.88	175.65	8.01	19.84	41.12	95.08	5.55	12.33	24.67	50.57
255	16.31	39.49	133.15	166.86	7.24	18.61	36.17	85.71	5.42	11.88	23.24	46.88
270	14.99	31.66	124.99	157.18	6.82	17.48	32.36	77.56		11.48	21.87	43.28
285	13.68	22.59	118.03	150.64	6.41	16.39	29.02	70.83		11.15	20.30	39.14
300	12.41	20.36	112.03	143.38	5.98	15.45	26.47	65.02		10.80	18.89	34.79
315	11.36	19.09	106.50	137.68	5.62	14.61	24.13	60.08		10.57	17.15	32.99
330	10.39	18.57	100.36	132.51	5.43	13.98	20.43	55.72		10.35	15.86	31.22
345	9.43	18.01	94.34	127.49	5.28	13.42	18.80	51.41		10.12	14.37	29.94
360	8.67	17.47	87.95	122.21	5.18	12.83	17.77	47.54		9.81	13.01	28.83
375	7.89	16.99	81.91	117.42		12.29	16.80	43.59		9.62	12.39	27.79
390	7.49	16.52	76.24	111.91		11.81	15.73	39.81		9.43	11.81	27.03
405	7.12	16.06	70.79	104.54		11.43	15.05	37.53		9.24	11.24	26.27
420	6.71	15.56	64.06	99.55		11.03	14.66	35.81		9.06	10.75	25.46
435	6.34	15.19	58.78	95.04		10.79	13.98	34.22		8.87	10.28	24.70
450	5.98	14.78	53.43	92.22		10.54	13.47	32.71		8.68	9.78	23.91
465	5.69	14.39	47.26	88.91		10.30	13.03	31.27		8.49	9.49	23.12
480	5.48	13.98	42.41	84.98		10.08	12.78	30.05		8.28	9.23	22.34
495	5.37	13.63	37.62	82.24		9.86	12.55	29.95		8.09	8.99	21.68
510	5.26	13.32	33.04	78.60		9.71	12.29	28.40		7.87	8.80	21.09
525		12.97	29.72	75.19		9.49	12.03	27.11		7.70	8.63	20.51
540		12.68	27.14	72.05		9.33	11.87	26.17		7.53	8.47	19.97
555		12.40	23.69	68.93		9.16	11.78	25.33		7.36	8.30	19.48
570		12.12	21.53	65.83		8.99	11.69	24.61		7.18	8.12	18.99
585		11.85	20.04	62.78		8.87	11.60	23.80		6.99	7.99	18.54
600		11.69	18.79	59.68		8.75	11.51	23.02		6.83	7.86	18.10
615		11.45	17.28	57.06		8.64	11.43	22.24		6.75	7.72	17.66
630		11.29	15.82	55.32		8.55	11.34	21.51		6.61	7.59	17.23
645		11.14	14.39	52.49		8.48	11.26	20.77		6.54	7.47	16.85
660		10.99	13.98	49.86		8.39	11.18	20.08			7.35	16.51
675		10.88	13.57	47.24		8.28	11.11	19.52			7.26	16.15
690		10.79	13.50	44.34		8.16	11.03	18.97			7.18	15.79
705		10.70	13.44	41.60		8.02	10.96	18.45			7.11	15.46
720		10.61	13.38	39.13		7.95	10.91	17.98			7.08	15.12
735		10.52	13.33	37.71		7.88	10.86	17.58			7.05	14.83
750		10.42	13.27	36.17		7.81	10.80	17.17			7.01	14.65
765		10.33	13.22	34.77			10.75	16.81			6.96	14.46
780		10.24	13.17	32.29			10.69	16.45			6.92	14.28
795		10.15	13.13	30.97			10.63	16.11			6.88	14.09
810		10.06	13.09	29.62			10.58	15.76			6.84	13.81
825		9.95	13.05	28.28			10.54	15.52			6.81	13.64
840		9.89	13.01	26.99			10.51	15.24			6.78	13.48
855		9.84	12.96	25.61			10.47	14.99			6.75	13.33
870		9.79	12.93	24.27			10.43	14.75			6.72	13.15
885		9.75	12.90	23.93			10.39	14.51			6.70	12.98
900		9.71	12.87	22.72			10.33	14.26			6.58	12.84
915		9.68	12.84	21.49			10.29	14.01				12.69
930		9.63	12.81	20.22			10.25	13.80				12.57
945		9.60	12.78	19.01			10.21	13.61				12.35
960			12.75	17.94			10.17	13.42				12.24

Air velocity- 1m/s

	Slice thickness- 6mm				Slice thickness- 4mm				Slice thickness- 2mm			
Time, min	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db
0	779.51	779.51	779.50	779.52	779.50	779.51	779.51	779.51	779.51	779.50	779.52	779.50
15	600.14	644.78	668.78	705.53	530.66	588.09	620.86	683.10	400.53	514.35	585.82	635.65
30	460.51	520.12	540.98	635.38	337.09	426.89	529.23	588.15	228.10	359.24	450.78	545.59
45	351.24	438.24	469.83	568.92	205.77	301.86	441.19	526.85	116.63	251.30	338.70	467.45
60	263.38	366.58	408.12	533.44	120.99	214.29	360.19	466.89	64.59	186.62	247.34	388.92
75	191.46	303.44	357.74	494.79	73.06	152.48	293.16	413.70	34.52	98.69	179.47	315.80
90	134.08	253.29	313.09	459.46	45.15	108.28	237.76	362.14	20.27	58.05	131.12	254.20
105	90.79	210.99	275.13	425.25	33.84	88.63	192.83	315.59	16.53	37.16	95.09	202.60
120	59.75	176.08	241.49	393.92	27.51	66.47	157.29	272.46	12.22	26.02	72.64	163.83
135	39.91	145.88	213.04	363.79	23.25	49.32	129.14	236.63	9.63	21.17	56.12	133.62
150	36.48	128.61	198.39	327.17	19.80	39.98	106.81	201.32	8.24	18.18	44.55	110.96
165	29.73	102.95	184.13	300.37	17.94	32.83	88.35	175.73	6.98	16.21	35.90	93.15
180	25.87	88.79	170.50	272.19	14.97	27.46	73.99	155.04	6.27	15.45	31.82	79.74
195	21.74	74.26	162.03	243.18	12.68	24.88	62.77	134.99	5.96	14.62	29.09	68.24
210	20.49	61.62	154.13	216.73	10.29	22.72	53.80	119.84	5.73	13.53	27.55	60.01
225	19.15	51.66	148.05	190.80	9.89	21.15	46.80	113.27	5.62	12.75	25.95	54.90
240	17.59	44.87	140.88	175.65	8.01	19.84	41.12	95.08	5.55	12.33	24.67	50.57
255	16.31	39.49	133.15	166.86	7.24	18.61	36.17	85.71	5.42	11.88	23.24	46.88
270	14.99	31.66	124.99	157.18	6.82	17.48	32.36	77.56		11.48	21.87	43.28
285	13.68	22.59	118.03	150.64	6.41	16.39	29.02	70.83		11.15	20.30	39.14
300	12.41	20.36	112.03	143.38	5.98	15.45	26.47	65.02		10.80	18.89	34.79
315	11.36	19.09	106.50	137.68	5.62	14.61	24.13	60.08		10.57	17.15	32.99
330	10.39	18.57	100.36	132.51	5.43	13.98	20.43	55.72		10.35	15.86	31.22
345	9.43	18.01	94.34	127.49	5.28	13.42	18.80	51.41		10.12	14.37	29.94
360	8.67	17.47	87.95	122.21	5.18	12.83	17.77	47.54		9.81	13.01	28.83
375	7.89	16.99	81.91	117.42		12.29	16.80	43.59		9.62	12.39	27.79
390	7.49	16.52	76.24	111.91		11.81	15.73	39.81		9.43	11.81	27.03
405	7.12	16.06	70.79	104.54		11.43	15.05	37.53		9.24	11.24	26.27
420	6.71	15.56	64.06	99.55		11.03	14.66	35.81		9.06	10.75	25.46
435	6.34	15.19	58.78	95.04		10.79	13.98	34.22		8.87	10.28	24.70
450	5.98	14.78	53.43	92.22		10.54	13.47	32.71		8.68	9.78	23.91
465	5.69	14.39	47.26	88.91		10.30	13.03	31.27		8.49	9.49	23.12
480	5.48	13.98	42.41	84.98		10.08	12.78	30.05		8.28	9.23	22.34
495	5.37	13.63	37.62	82.24		9.86	12.55	29.95		8.09	8.99	21.68
510	5.26	13.32	33.04	78.60		9.71	12.29	28.40		7.87	8.80	21.09
525		12.97	29.72	75.19		9.49	12.03	27.11		7.70	8.63	20.51
540		12.68	27.14	72.05		9.33	11.87	26.17		7.53	8.47	19.97
555		12.40	23.69	68.93		9.16	11.78	25.33		7.36	8.30	19.48
570		12.12	21.53	65.83		8.99	11.69	24.61		7.18	8.12	18.99
585		11.85	20.04	62.78		8.87	11.60	23.80		6.99	7.99	18.54
600		11.69	18.79	59.68		8.75	11.51	23.02		6.83	7.86	18.10
615		11.45	17.28	57.06		8.64	11.43	22.24		6.75	7.72	17.66
630		11.29	15.82	55.32		8.55	11.34	21.51		6.61	7.59	17.23
645		11.14	14.39	52.49		8.48	11.26	20.77		6.54	7.47	16.85
660		10.99	13.98	49.86		8.39	11.18	20.08			7.35	16.51
675		10.88	13.57	47.24		8.28	11.11	19.52			7.26	16.15
690		10.79	13.50	44.34		8.16	11.03	18.97			7.18	15.79
705		10.70	13.44	41.60		8.02	10.96	18.45			7.11	15.46
720		10.61	13.38	39.13		7.95	10.91	17.98			7.08	15.12
735		10.52	13.33	37.71		7.88	10.86	17.58			7.05	14.83
750		10.42	13.27	36.17		7.81	10.80	17.17			7.01	14.65
765		10.33	13.22	34.77			10.75	16.81			6.96	14.46
780		10.24	13.17	32.29			10.69	16.45			6.92	14.28
795		10.15	13.13	30.97			10.63	16.11			6.88	14.09
810		10.06	13.09	29.62			10.58	15.76			6.84	13.81
825		9.95	13.05	28.28			10.54	15.52			6.81	13.64
840		9.89	13.01	26.99			10.51	15.24			6.78	13.48
855		9.84	12.96	25.61			10.47	14.99			6.75	13.33
870		9.79	12.93	24.27			10.43	14.75			6.72	13.15
885		9.75	12.90	23.93			10.39	14.51			6.70	12.98
900		9.71	12.87	22.72			10.33	14.26			6.58	12.84
915		9.68	12.84	21.49			10.29	14.01				12.69
930		9.63	12.81	20.22			10.25	13.80				12.57
945		9.60	12.78	19.01			10.21	13.61				12.35
960			12.75	17.94			10.17	13.42				12.24

Slice thickness- 6mm					Slice thickness- 4mm				Slice thickness- 2mm			
Time, min	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db	80°C M.C., % db	70°C M.C., % db	60°C M.C., % db	50°C M.C., % db
975			12.72	17.32			10.13	13.33				12.15
990			12.70	16.78			10.09	13.24				12.06
1005			12.68	16.39			10.05	13.16				11.96
1020			12.66	15.97			10.01	13.02				11.79
1035			12.64	15.59			9.98	12.88				11.71
1050			12.62	15.28			9.94	12.77				11.60
1065			12.59	15.02			9.89	12.65				11.54
1080			12.54	14.77			9.85	12.54				11.49
1095			12.50	14.56			9.81	12.45				11.43
1110			12.45	14.41			9.78	12.36				11.37
1125			12.43	14.25			9.76	12.29				11.31
1140			12.41	14.14			9.74	12.22				11.25
1155			12.39	14.06			9.72	12.17				11.19
1170			12.36	13.95			9.70	12.11				11.14
1185			12.33	13.84			9.68	12.05				11.10
1200			12.29	13.75				12.00				11.05
1215			12.26	13.69				11.94				10.99
1230			12.23	13.63				11.89				10.95
1245			12.21	13.58				11.83				10.91
1260			12.19	13.52				11.78				10.87
1275			12.17	13.47				11.74				10.83
1290			12.15	13.41				11.70				10.79
1305			12.11	13.37				11.63				10.75
1320			12.08	13.31				11.59				10.71
1335			12.05	13.28				11.54				10.67
1350			12.02	13.25				11.49				10.64
1365			11.99	13.22				11.45				10.61
1380			11.97	13.18				11.39				10.58
1395			11.95	13.14				11.36				10.55
1410			11.93	13.11				11.33				10.53
1425			11.91	13.07				11.29				10.50
1440			11.88	13.04				11.25				
1455			11.86	12.99				11.23				
1470			11.84	12.96				11.21				
1485			11.82	12.93				11.18				
1500				12.89				11.15				
1515				12.85				11.13				
1530				12.82				11.12				
1545				12.79								
1560				12.76								
1575				12.73								
1590				12.70								
1605				12.66								
1620				12.63								
1635				12.61								
1650				12.59								
1665				12.55								
1680				12.51								
1695				12.49								
1710				12.47								
1725				12.44								
1740				12.41								
1755				12.39								
1770				12.36								
1785				12.33								
1800				12.30								
1815				12.26								
1830				12.22								
1845				12.18								
1860				12.16								

Appendix F

Drying rates during onion dehydration

Drying rate, g moisture removed/ g dry matter-h

	Slice thickness 6mm, 4m/s				Slice thickness 6mm, 2.5m/s				Slice thickness 6mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
15	9.292	7.975	6.545	5.618	12.676	9.812	7.039	4.208	7.175	5.389	5.112	2.960
30	5.620	4.079	3.353	2.306	7.576	5.857	3.838	2.363	5.585	4.986	4.429	2.806
45	4.091	3.066	2.432	1.915	4.760	4.203	3.484	2.169	4.371	3.275	2.846	1.700
60	3.104	2.379	1.856	1.686	2.834	2.833	2.772	1.983	3.514	2.867	2.468	1.546
75	2.031	1.908	1.538	1.692	1.453	1.075	1.587	1.892	2.877	2.525	2.015	1.419
90	1.305	1.574	1.315	1.202	0.740	0.813	1.380	1.750	2.295	2.006	1.786	1.413
105	0.798	1.276	1.152	1.218	0.110	0.628	1.237	1.604	1.732	1.692	1.518	1.300
120	0.397	1.045	0.962	1.168	0.173	0.632	0.890	1.566	1.241	1.396	1.346	1.253
135	0.194	0.836	0.840	0.802	0.147	0.907	0.796	1.520	0.794	1.208	1.138	0.900
150	0.098	0.678	0.733	0.945	0.136	0.749	0.649	1.404	0.137	0.691	0.586	0.450
165	0.051	0.579	0.656	0.696	0.135	0.362	0.936	1.084	0.270	1.026	0.570	0.440
180	0.024	0.427	0.579	0.934	0.070	0.377	0.445	1.004	0.154	0.566	0.545	0.360
195	0.020	0.150	0.523	0.548	0.059	0.468	0.372	0.722	0.165	0.581	0.339	0.200
210		0.183	0.580	0.586	0.017	0.352	0.381	0.557	0.050	0.506	0.316	0.200
225		0.179	0.467	0.582	0.015	0.383	0.345	0.472	0.054	0.398	0.243	0.150
240		0.260	0.419	0.506	0.020	0.337	0.321	0.480	0.062	0.272	0.287	0.150
255		0.169	0.367	0.442	0.014	0.354	0.332	0.404	0.051	0.215	0.309	0.150
270		0.065	0.332	0.442	0.012	0.351	0.303	0.292	0.053	0.313	0.326	0.150
285		0.034	0.254	0.345	0.013	0.057	0.273	0.291	0.052	0.363	0.278	0.140
300		0.035	0.261	0.338		0.027	0.297	0.247	0.051	0.089	0.240	0.130
315		0.023	0.242	0.342		0.027	0.255	0.264	0.042	0.051	0.221	0.120
330		0.005	0.209	0.344		0.027	0.238	0.245	0.039	0.021	0.246	0.120
345		0.002	0.166	0.232		0.026	0.264	0.262	0.038	0.022	0.241	0.120
360		0.002	0.155	0.296		0.027	0.302	0.236	0.030	0.022	0.256	0.110
375		0.001	0.223	0.237		0.023	0.222	0.241	0.031	0.019	0.242	0.100
390		0.002	0.122	0.226		0.024	0.224	0.208	0.016	0.019	0.227	0.100
405		0.002	0.096	0.216		0.023	0.302	0.234	0.015	0.018	0.218	0.100
420		0.002	0.066	0.169		0.022	0.181	0.175	0.016	0.020	0.269	0.100
435		0.001	0.053	0.186		0.023	0.221	0.170	0.015	0.015	0.211	0.100
450		0.001	0.039	0.106		0.022	0.176	0.150	0.014	0.016	0.214	0.113
465		0.002	0.024	0.096		0.015	0.172	0.172	0.012	0.016	0.247	0.132
480		0.001	0.027	0.092		0.011	0.131	0.170	0.008	0.016	0.194	0.140
495		0.001	0.014	0.027		0.006	0.091	0.157	0.004	0.014	0.192	0.110
510		0.001	0.034	0.026		0.008	0.088	0.154	0.004	0.012	0.183	0.146
525		0.001	0.014	0.026		0.006	0.028	0.156		0.014	0.133	0.136
540		0.002	0.011	0.024		0.004	0.018	0.143		0.012	0.103	0.126
555		0.002	0.014	0.022		0.005	0.007	0.150		0.011	0.138	0.125
570		0.002	0.011	0.013		0.003	0.007	0.146		0.011	0.086	0.124
585		0.002	0.012	0.010		0.003	0.018	0.142		0.011	0.060	0.122
600			0.011	0.011		0.004	0.006	0.144		0.006	0.050	0.124
615			0.012	0.005		0.002	0.004	0.143		0.010	0.060	0.105
630			0.011	0.007		0.002	0.004	0.136		0.006	0.058	0.070

	Slice thickness 6mm, 4m/s				Slice thickness 6mm, 2.5m/s				Slice thickness 6mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
645			0.011	0.006		0.001	0.004	0.132		0.006	0.057	0.113
660			0.013	0.008		0.001	0.004	0.102		0.006	0.016	0.105
675			0.011	0.009		0.001	0.003	0.132		0.004	0.016	0.105
690			0.012	0.009			0.004	0.095		0.004	0.003	0.116
705			0.011	0.008			0.003	0.070		0.004	0.002	0.110
720			0.011	0.008			0.002	0.021		0.004	0.002	0.099
735			0.010	0.007			0.002	0.020		0.004	0.002	0.057
750			0.011	0.007			0.002	0.012		0.004	0.002	0.062
765			0.011	0.007			0.002	0.012		0.004	0.002	0.056
780			0.007	0.008			0.002	0.011		0.004	0.002	0.099
795			0.008	0.007			0.002	0.010		0.004	0.002	0.053
810			0.007	0.008			0.002	0.006		0.004	0.002	0.054
825			0.008	0.008			0.002	0.006		0.004	0.002	0.054
840			0.004	0.007			0.002	0.005		0.002	0.002	0.052
855			0.007	0.007			0.002	0.004		0.002	0.002	0.055
870			0.007	0.008			0.002	0.004		0.002	0.001	0.054
885			0.008	0.008			0.002	0.004		0.002	0.001	0.014
900			0.007	0.008			0.001	0.003		0.002	0.001	0.048
915			0.007	0.008			0.002	0.003		0.001	0.001	0.049
930			0.007	0.007			0.002	0.003		0.002	0.001	0.051
945			0.007	0.008			0.001	0.003		0.001	0.001	0.048
960			0.007	0.008			0.002	0.004			0.001	0.043
975			0.006	0.008			0.002	0.003			0.001	0.025
990			0.007	0.008			0.002	0.003			0.001	0.022
1005			0.007	0.007			0.002	0.003			0.001	0.016
1020			0.004	0.008			0.002	0.002			0.001	0.017
1035				0.008			0.002	0.001			0.001	0.015
1050				0.008			0.002	0.001			0.001	0.012
1065				0.007			0.002	0.002			0.001	0.010
1080				0.006			0.002	0.001			0.002	0.010
1095				0.004			0.001	0.001			0.002	0.008
1110				0.004			0.002	0.001			0.002	0.006
1125				0.004			0.001	0.001			0.001	0.006
1140				0.005			0.002	0.001			0.001	0.004
1155				0.005			0.001	0.001			0.001	0.003
1170				0.004			0.002	0.001			0.001	0.004
1185				0.003			0.001	0.001			0.001	0.004
1200				0.003			0.001	0.001			0.002	0.004
1215				0.002			0.002	0.002			0.001	0.002
1230							0.001	0.002			0.001	0.002
1245							0.001	0.002			0.001	0.002
1260							0.001	0.001			0.001	0.002
1275							0.001	0.001			0.001	0.002
1290								0.001			0.002	0.002
1305								0.001			0.001	0.002
1320								0.000			0.001	0.001
1335												

	Slice thickness 6mm, 4m/s				Slice thickness 6mm, 2.5m/s				Slice thickness 6mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
1350								0.000			0.001	0.001
1365								0.000			0.001	0.001
1380								0.000			0.001	0.002
1395								0.000			0.001	0.002
1410								0.000			0.001	0.001
1425								0.001			0.001	0.002
1440								0.000			0.001	0.001
1455								0.001			0.001	0.002
1470								0.000			0.001	0.001

	Slice thickness 4mm, 4m/s				Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
15	11.844	9.354	7.171	6.204	13.372	11.039	7.654	5.008	9.953	7.657	6.346	3.856
30	6.911	5.205	6.006	5.760	7.390	6.243	4.442	4.379	7.743	6.448	3.665	3.798
45	4.244	3.545	3.890	4.229	4.551	4.240	3.591	3.320	5.253	5.001	3.522	2.452
60	2.455	2.561	2.613	2.560	2.711	2.163	2.652	2.524	3.391	3.503	3.240	2.398
75	1.076	1.941	1.727	1.734	1.440	1.972	2.088	1.986	1.917	2.472	2.681	2.128
90	0.212	1.472	1.205	1.353	0.659	1.793	2.119	1.816	1.117	1.768	2.216	2.062
105	0.162	1.006	0.879	1.025	0.131	0.578	1.996	1.565	0.452	0.886	1.797	1.862
120	0.063	0.672	0.660	0.654	0.155	1.187	1.873	1.085	0.253	0.786	1.422	1.725
135	0.065	0.426	0.500	0.644	0.094	0.300	1.482	0.857	0.170	0.686	1.126	1.433
150		0.258	0.398	0.497	0.138	0.574	0.532	0.759	0.138	0.374	0.893	1.412
165		0.190	0.300	0.362	0.188	0.118	0.407	0.609	0.074	0.286	0.739	1.024
180		0.101	0.259	0.279	0.061	0.053	0.366	0.485	0.119	0.215	0.574	0.828
195		0.046	0.250	0.146	0.044	0.016	0.271	0.422	0.092	0.103	0.449	0.802
210		0.029	0.144	0.224	0.041	0.059	0.205	0.337	0.096	0.086	0.359	0.606
225		0.030	0.090	0.174		0.050	0.174	0.284	0.016	0.063	0.280	0.263
240		0.007	0.067	0.096		0.101	0.096	0.227	0.075	0.052	0.227	0.728
255		0.015	0.051	0.061		0.054	0.202	0.196	0.031	0.049	0.198	0.375
270		0.016	0.037	0.066		0.043	0.116	0.151	0.017	0.045	0.153	0.326
285		0.026	0.031	0.062		0.042	0.146	0.136	0.016	0.044	0.134	0.269
300		0.024	0.054	0.054		0.039	0.076	0.124	0.017	0.038	0.102	0.232
315		0.021	0.023	0.050		0.041	0.066	0.117	0.014	0.034	0.094	0.198
330			0.033	0.046		0.038	0.055	0.091	0.008	0.025	0.148	0.174
345			0.014	0.036		0.038	0.037	0.076	0.006	0.022	0.065	0.173
360			0.015	0.038		0.020	0.037	0.066	0.004	0.024	0.041	0.155
375			0.014	0.031		0.017	0.033	0.097		0.022	0.039	0.158
390			0.010	0.031		0.018	0.027	0.120		0.019	0.043	0.151
405			0.096	0.029		0.014	0.025	0.112		0.015	0.027	0.091
420			0.053	0.022		0.010	0.017	0.026		0.016	0.016	0.069
435			0.059	0.021		0.011	0.023	0.030		0.010	0.027	0.063
450			0.060	0.016		0.008	0.007	0.023		0.010	0.020	0.061
465			0.035	0.016		0.005	0.007	0.019		0.010	0.018	0.058
480			0.032	0.015		0.003	0.006	0.019		0.009	0.010	0.049
495			0.044	0.015		0.004	0.006	0.012		0.009	0.009	0.004

	Slice thickness 4mm, 4m/s				Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
510			0.032	0.022		0.004	0.006	0.018		0.006	0.010	0.062
525			0.032	0.035		0.004	0.005	0.006		0.009	0.010	0.052
540			0.031	0.022		0.003	0.005	0.018		0.006	0.006	0.038
555			0.031	0.018		0.003	0.004	0.013		0.007	0.004	0.034
570				0.010		0.002	0.004	0.016		0.007	0.004	0.029
585				0.011		0.001	0.003	0.012		0.005	0.004	0.032
600				0.019		0.001	0.003	0.010		0.005	0.004	0.031
615				0.020			0.003	0.011		0.004	0.003	0.031
630				0.018			0.003	0.009		0.004	0.004	0.029
645				0.015			0.003	0.018		0.003	0.003	0.030
660				0.015			0.004	0.014		0.004	0.003	0.028
675				0.018			0.003	0.010		0.004	0.003	0.022
690				0.018			0.003	0.006		0.005	0.003	0.022
705				0.017			0.002	0.007		0.006	0.003	0.021
720				0.015			0.002	0.006		0.003	0.002	0.019
735				0.013			0.002	0.007		0.003	0.002	0.016
750				0.017			0.001	0.006		0.003	0.002	0.016
765				0.015			0.001	0.012			0.002	0.014
780				0.015			0.001	0.017			0.002	0.014
795				0.014			0.001	0.013			0.002	0.014
810				0.013			0.001	0.009			0.002	0.014
825				0.010			0.001	0.008			0.002	0.010
840				0.009			0.001	0.004			0.001	0.011
855				0.008			0.001	0.007			0.002	0.010
870				0.006			0.000	0.004			0.002	0.010
885				0.004				0.003			0.002	0.010
900								0.003			0.002	0.010
915								0.002			0.002	0.008
930								0.004			0.002	0.008
945								0.003			0.002	0.008
960								0.003			0.002	0.004
975								0.002			0.002	0.004
990								0.003			0.002	0.003
1005								0.002			0.002	0.006
1020								0.002			0.001	0.006
1035								0.002			0.002	0.004
1050								0.002			0.002	0.005
1065								0.002			0.002	0.004
1080								0.002			0.002	0.004
1095								0.001			0.001	0.004
1110								0.002			0.001	0.003
1125								0.002			0.001	0.003
1140								0.002			0.001	0.002
1155								0.001			0.001	0.002
1170								0.002			0.001	0.002
1185								0.001				0.002
1200												

	Slice thickness 4mm, 4m/s				Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
1215								0.001				0.002
1230								0.002				0.002
1245								0.002				0.002
1260								0.001				0.002
1275								0.001				0.002
1290								0.001				0.002
1305												0.003
1320												0.002
1335												0.002
1350												0.002
1365												0.002
1380												0.002
1395												0.001
1410												0.001
1425												0.002
1440												0.002
1455												0.001
1470												0.001
1485												0.001
1500												0.001
1515												0.000
1530												

	Slice thickness 4mm, 4m/s				Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
15	16.044	13.958	11.514	9.580	17.774	14.655	12.723	10.730	15.159	10.606	7.748	5.754
30	6.422	6.811	6.317	6.176	7.712	8.205	8.132	6.496	6.897	6.204	5.401	3.602
45	3.026	3.477	3.852	3.735	3.246	3.964	4.247	4.145	4.459	4.318	4.483	3.125
60	1.059	1.064	2.095	2.454	1.385	1.737	2.144	3.641	2.081	3.517	3.654	3.141
75	0.128	0.831	1.091	1.320	0.346	1.359	1.128	1.642	1.203	2.587	2.715	2.925
90	0.206	0.488	0.599	0.853	0.134	0.380	0.643	1.046	0.570	1.626	1.934	2.464
105	0.052	0.188	0.383	0.549	0.112	0.094	0.417	0.448	0.150	0.836	1.441	2.064
120	0.088	0.069	0.263	0.410	0.181	0.065	0.357	0.601	0.172	0.446	0.898	1.551
135		0.058	0.305	0.401	0.041	0.039	0.169	0.468	0.104	0.194	0.661	1.208
150		0.041	0.128	0.371	0.041	0.039	0.124	0.246	0.056	0.120	0.463	0.906
165		0.033	0.180	0.318		0.038	0.069	0.352	0.050	0.079	0.346	0.713
180			0.052	0.295		0.038	0.091	0.219	0.028	0.030	0.163	0.537
195			0.031	0.137		0.038	0.047	0.123	0.012	0.033	0.109	0.460
210			0.021	0.110		0.038	0.039	0.089	0.009	0.044	0.062	0.329
225			0.014	0.048		0.037	0.039	0.050	0.004	0.031	0.064	0.204
240			0.015	0.037		0.036	0.039	0.046	0.003	0.017	0.051	0.173
255			0.015	0.030		0.037	0.035	0.049	0.005	0.018	0.057	0.148
270			0.015	0.026		0.036	0.037	0.048		0.016	0.055	0.144

	Slice thickness 4mm, 4m/s				Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
285			0.014	0.018		0.034	0.037	0.044		0.013	0.063	0.166
300			0.013	0.016		0.037	0.037	0.042		0.014	0.056	0.174
315			0.013	0.016		0.029	0.036	0.038		0.009	0.070	0.072
330			0.010	0.008		0.010	0.038	0.037		0.009	0.052	0.071
345			0.010	0.007		0.005	0.038	0.036		0.009	0.060	0.051
360			0.006	0.006		0.002	0.037	0.032		0.012	0.054	0.044
375				0.006		0.003	0.038	0.030		0.008	0.025	0.042
390				0.005		0.002	0.032	0.019		0.008	0.023	0.030
405				0.004		0.003	0.035	0.024		0.008	0.023	0.030
420				0.003		0.001	0.032	0.023		0.007	0.020	0.032
435				0.002		0.001	0.014	0.019		0.008	0.019	0.030
450				0.002			0.016	0.017		0.008	0.020	0.032
465				0.003			0.015	0.017		0.008	0.012	0.032
480							0.016	0.010		0.008	0.010	0.031
495							0.011	0.013		0.008	0.010	0.026
510							0.013	0.010		0.009	0.008	0.024
525							0.008	0.007		0.007	0.007	0.023
540							0.008	0.005		0.007	0.006	0.022
555							0.004	0.004		0.007	0.007	0.020
570								0.003		0.007	0.007	0.020
585								0.002		0.008	0.005	0.018
600								0.003		0.006	0.005	0.018
615								0.001		0.003	0.006	0.018
630								0.002		0.006	0.005	0.017
645								0.001		0.003	0.005	0.015
660								0.002			0.005	0.014
675								0.002			0.004	0.014
690								0.002			0.003	0.014
705								0.002			0.003	0.013
720								0.001			0.001	0.014
735								0.001			0.001	0.012
750								0.001			0.002	0.007
765								0.001			0.002	0.008
780								0.002			0.002	0.007
795								0.001			0.002	0.008
810											0.001	0.011
825											0.001	0.007
840											0.001	0.006
855											0.001	0.006
870											0.001	0.007
885											0.005	0.007
900												0.006
915												0.006
930												0.005
945												0.009
960												0.004
975												0.004

	Slice thickness 4mm, 4m/s				Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate	Drying rate
990												0.004
1005												0.004
1020												0.007
1035												0.003
1050												0.004
1065												0.002
1080												0.002
1095												0.002
1110												0.002
1125												0.002
1140												0.002
1155												0.002
1170												0.002
1185												0.002
1200												0.002
1215												0.002
1230												0.002
1245												0.002
1260												0.002
1275												0.002
1290												0.002
1305												0.002
1320												0.002
1335												0.001
1350												0.001
1365												0.001
1380												0.001
1395												0.001
1410												0.001
1425												

Appendix G

Moisture ratio values during onion dehydration

	Slice thickness 6mm, 4m/s				Slice thickness 6mm, 2.5m/s				Slice thickness 6mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
0	1	1	1	1	1	1	1	1	1	1	1	1
15	0.656	0.704	0.757	0.791	0.591	0.682	0.771	0.863	0.768	0.825	0.856	0.904
30	0.448	0.553	0.633	0.706	0.346	0.493	0.646	0.786	0.588	0.663	0.689	0.812
45	0.297	0.439	0.542	0.635	0.192	0.357	0.532	0.715	0.447	0.557	0.597	0.726
60	0.182	0.351	0.474	0.572	0.101	0.265	0.442	0.651	0.333	0.464	0.516	0.679
75	0.107	0.280	0.416	0.509	0.054	0.230	0.391	0.589	0.240	0.382	0.451	0.629
90	0.059	0.221	0.368	0.465	0.030	0.204	0.346	0.532	0.166	0.317	0.392	0.583
105	0.029	0.174	0.325	0.420	0.026	0.184	0.305	0.480	0.110	0.262	0.343	0.538
120	0.014	0.135	0.289	0.376	0.021	0.163	0.276	0.429	0.070	0.216	0.299	0.497
135	0.007	0.104	0.258	0.346	0.016	0.134	0.250	0.380	0.045	0.177	0.262	0.458
150	0.004	0.079	0.231	0.311	0.011	0.110	0.229	0.334	0.040	0.155	0.243	0.411
165	0.002	0.058	0.206	0.286	0.007	0.098	0.199	0.299	0.032	0.121	0.224	0.376
180	0.001	0.042	0.185	0.251	0.005	0.086	0.184	0.266	0.027	0.103	0.207	0.339
195		0.036	0.166	0.231	0.003	0.071	0.172	0.242	0.021	0.084	0.196	0.301
210		0.030	0.144	0.209	0.002	0.059	0.160	0.224	0.020	0.068	0.185	0.267
225		0.023	0.127	0.187	0.002	0.047	0.149	0.209	0.018	0.055	0.177	0.233
240		0.013	0.111	0.168	0.001	0.036	0.138	0.193	0.016	0.046	0.168	0.213
255		0.007	0.098	0.152	0.001	0.024	0.127	0.180	0.014	0.039	0.158	0.202
270		0.005	0.085	0.136	0.000	0.013	0.117	0.171	0.013	0.029	0.147	0.189
285		0.003	0.076	0.123	0.000	0.011	0.109	0.161	0.011	0.017	0.138	0.180
300		0.002	0.066	0.110		0.010	0.099	0.153	0.009	0.014	0.131	0.171
315		0.001	0.057	0.098		0.009	0.091	0.144	0.008	0.012	0.123	0.164
330		0.001	0.049	0.085		0.009	0.083	0.137	0.007	0.012	0.115	0.157
345		0.001	0.043	0.076		0.008	0.074	0.128	0.005	0.011	0.107	0.150
360		0.001	0.037	0.065		0.007	0.064	0.120	0.004	0.010	0.099	0.143
375		0.001	0.029	0.056		0.006	0.057	0.112	0.003	0.010	0.091	0.137
390		0.001	0.025	0.048		0.005	0.050	0.106	0.003	0.009	0.084	0.130
405		0.001	0.021	0.040		0.005	0.040	0.098	0.002	0.008	0.077	0.120
420		0.001	0.019	0.034		0.004	0.034	0.092	0.002	0.008	0.068	0.114
435		0.001	0.017	0.027		0.003	0.027	0.087	0.001	0.007	0.061	0.108
450		0.000	0.015	0.023		0.002	0.021	0.082	0.001	0.007	0.054	0.104
465		0.000	0.014	0.019		0.002	0.016	0.076	0.001	0.006	0.046	0.100
480		0.000	0.013	0.016		0.002	0.011	0.071	0.000	0.006	0.040	0.095
495		0.000	0.013	0.015		0.001	0.008	0.066	0.000	0.005	0.034	0.091
510		0.000	0.012	0.014		0.001	0.006	0.061	0.000	0.005	0.028	0.087
525		0.000	0.011	0.013		0.001	0.005	0.056		0.004	0.023	0.082
540		0.000	0.011	0.012		0.001	0.004	0.051		0.004	0.020	0.078
555		0.000	0.010	0.011		0.001	0.004	0.046		0.004	0.015	0.074
570		0.000	0.010	0.011		0.000	0.004	0.041		0.003	0.013	0.070
585		0.000	0.009	0.010		0.000	0.003	0.037		0.003	0.011	0.066
600			0.009	0.010		0.000	0.003	0.032		0.003	0.009	0.062
615			0.008	0.010		0.000	0.003	0.027		0.002	0.007	0.059
630			0.008	0.010		0.000	0.003	0.023		0.002	0.005	0.056
645			0.008	0.009		0.000	0.003	0.019		0.002	0.003	0.053
660			0.007	0.009		0.000	0.002	0.015		0.002	0.003	0.049

Slice thickness 6mm, 4m/s					Slice thickness 6mm, 2.5m/s				Slice thickness 6mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
675			0.007	0.009		0.000	0.002	0.011		0.002	0.002	0.046
690			0.006	0.008			0.002	0.008		0.002	0.002	0.042
705			0.006	0.008			0.002	0.006		0.001	0.002	0.038
720			0.005	0.008			0.002	0.005		0.001	0.002	0.035
735			0.005	0.008			0.002	0.004		0.001	0.002	0.033
750			0.005	0.007			0.002	0.004		0.001	0.002	0.031
765			0.004	0.007			0.002	0.003		0.001	0.002	0.029
780			0.004	0.007			0.002	0.003		0.001	0.002	0.026
795			0.004	0.006			0.002	0.003		0.001	0.002	0.025
810			0.003	0.006			0.002	0.003		0.001	0.002	0.023
825			0.003	0.006			0.001	0.002		0.000	0.002	0.021
840			0.003	0.006			0.001	0.002		0.000	0.002	0.019
855			0.003	0.005			0.001	0.002		0.000	0.001	0.018
870			0.003	0.005			0.001	0.002		0.000	0.001	0.016
885			0.002	0.005			0.001	0.002		0.000	0.001	0.015
900			0.002	0.005			0.001	0.002		0.000	0.001	0.014
915			0.002	0.004			0.001	0.002		0.000	0.001	0.012
930			0.001	0.004			0.001	0.002		0.000	0.001	0.011
945			0.001	0.004			0.001	0.001		0.000	0.001	0.009
960			0.001	0.003			0.001	0.001			0.001	0.008
975			0.001	0.003			0.001	0.001			0.001	0.007
990			0.000	0.003			0.001	0.001			0.001	0.006
1005			0.000	0.003			0.001	0.001			0.001	0.006
1020			0.000	0.002			0.001	0.001			0.001	0.005
1035				0.002			0.001	0.001			0.001	0.004
1050				0.002			0.001	0.001			0.001	0.004
1065				0.001			0.001	0.001			0.001	0.004
1080				0.001			0.001	0.001			0.001	0.003
1095				0.001			0.001	0.001			0.001	0.003
1110				0.001			0.001	0.001			0.001	0.003
1125				0.001			0.000	0.001			0.001	0.003
1140				0.001			0.000	0.001			0.001	0.003
1155				0.000			0.000	0.001			0.001	0.002
1170				0.000			0.000	0.001			0.001	0.002
1185				0.000			0.000	0.000			0.001	0.002
1200				0.000			0.000	0.000			0.001	0.002
1215				0.000			0.000	0.000			0.001	0.002
1230							0.000	0.000			0.001	0.002
1245							0.000	0.000			0.000	0.002
1260							0.000	0.000			0.000	0.002
1275							0.000	0.000			0.000	0.002
1290								0.000			0.000	0.002
1305								0.000			0.000	0.001
1320								0.000			0.000	0.001
1335								0.000			0.000	0.001
1350								0.000			0.000	0.001
1365								0.000			0.000	0.001
1380												

Slice thickness 6mm, 4m/s					Slice thickness 6mm, 2.5m/s				Slice thickness 6mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
1395								0.000			0.000	0.001
1410								0.000			0.000	0.001
1425								0.000			0.000	0.001
1440								0.000			0.000	0.001
1455								0.000			0.000	0.001
1470								0.000			0.000	0.001
1485												0.001
1500												0.001
1515												0.001
1530												0.001
1545												0.001
1560												0.001
1575												0.001
1590												0.001
1605												0.001
1620												0.001
1635												0.001
1650												0.001
1665												0.000
1680												0.000
1695												0.000
1710												0.000
1725												0.000
1740												0.000
1755												0.000
1770												0.000
1785												0.000
1800												0.000
1815												0.000
1830												0.000
1845												0.000
1860												

Slice thickness 4mm, 4m/s					Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
0	1	1	1	1	1	1	1	1	1	1	1	1
15	0.562	0.653	0.734	0.786	0.568	0.643	0.752	0.837	0.679	0.752	0.794	0.875
30	0.306	0.460	0.511	0.556	0.330	0.441	0.609	0.695	0.429	0.543	0.675	0.751
45	0.149	0.328	0.367	0.399	0.183	0.304	0.492	0.554	0.259	0.381	0.561	0.671
60	0.058	0.233	0.270	0.304	0.095	0.234	0.407	0.439	0.150	0.268	0.455	0.593
75	0.019	0.161	0.206	0.240	0.049	0.170	0.339	0.364	0.088	0.187	0.368	0.524
90	0.011	0.106	0.161	0.189	0.027	0.112	0.270	0.305	0.052	0.130	0.296	0.457
105	0.005	0.069	0.128	0.151	0.023	0.093	0.206	0.221	0.037	0.105	0.238	0.396
120	0.002	0.044	0.104	0.127	0.018	0.055	0.145	0.186	0.029	0.076	0.192	0.340
135	0.000	0.028	0.085	0.103	0.015	0.045	0.097	0.158	0.023	0.054	0.155	0.293

Slice thickness 4mm, 4m/s					Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
150		0.019	0.070	0.090	0.011	0.026	0.080	0.133	0.019	0.042	0.126	0.248
165		0.012	0.059	0.071	0.005	0.023	0.067	0.114	0.016	0.032	0.102	0.214
180		0.008	0.050	0.061	0.003	0.021	0.055	0.098	0.013	0.025	0.084	0.187
195		0.006	0.040	0.056	0.001	0.020	0.046	0.084	0.010	0.022	0.069	0.161
210		0.005	0.035	0.047	0.000	0.019	0.040	0.073	0.007	0.019	0.057	0.141
225		0.004	0.032	0.041		0.017	0.034	0.064	0.006	0.017	0.048	0.133
240		0.004	0.029	0.037		0.014	0.031	0.056	0.004	0.016	0.041	0.109
255		0.003	0.027	0.035		0.012	0.024	0.050	0.003	0.014	0.034	0.097
270		0.003	0.026	0.033		0.010	0.021	0.045	0.002	0.013	0.029	0.086
285		0.002	0.025	0.030		0.009	0.016	0.041	0.002	0.011	0.025	0.078
300		0.001	0.023	0.028		0.008	0.013	0.037	0.001	0.010	0.022	0.070
315		0.000	0.022	0.026		0.007	0.011	0.033	0.001	0.009	0.019	0.064
330			0.021	0.025		0.005	0.009	0.030	0.000	0.008	0.014	0.058
345			0.020	0.023		0.004	0.008	0.027	0.000	0.007	0.012	0.052
360			0.020	0.022		0.003	0.007	0.025	0.000	0.007	0.011	0.047
375			0.019	0.021		0.003	0.006	0.022		0.006	0.009	0.042
390			0.019	0.020		0.002	0.005	0.018		0.005	0.008	0.037
405			0.015	0.019		0.002	0.004	0.015		0.005	0.007	0.034
420			0.013	0.018		0.002	0.004	0.014		0.004	0.006	0.032
435			0.011	0.017		0.001	0.003	0.013		0.004	0.006	0.030
450			0.009	0.016		0.001	0.003	0.012		0.004	0.005	0.028
465			0.008	0.016		0.001	0.003	0.011		0.003	0.004	0.026
480			0.006	0.015		0.001	0.002	0.011		0.003	0.004	0.025
495			0.005	0.015		0.001	0.002	0.010		0.003	0.004	0.025
510			0.003	0.014		0.000	0.002	0.010		0.002	0.003	0.022
525			0.002	0.013		0.000	0.002	0.010		0.002	0.003	0.021
540			0.001	0.012		0.000	0.002	0.009		0.002	0.003	0.020
555			0.000	0.011		0.000	0.001	0.009		0.002	0.003	0.018
570				0.011		0.000	0.001	0.008		0.002	0.003	0.018
585				0.010		0.000	0.001	0.008		0.001	0.002	0.017
600				0.010		0.000	0.001	0.007		0.001	0.002	0.015
615				0.009			0.001	0.007		0.001	0.002	0.014
630				0.008			0.001	0.007		0.001	0.002	0.014
645				0.008			0.001	0.006		0.001	0.002	0.013
660				0.007			0.001	0.006		0.001	0.002	0.012
675				0.007			0.001	0.005		0.001	0.002	0.011
690				0.006			0.001	0.005		0.000	0.002	0.010
705				0.005			0.000	0.005		0.000	0.002	0.010
720				0.005			0.000	0.005		0.000	0.002	0.009
735				0.004			0.000	0.004		0.000	0.002	0.008
750				0.004			0.000	0.004		0.000	0.001	0.008
765				0.003			0.000	0.004			0.001	0.007
780				0.002			0.000	0.003			0.001	0.007
795				0.002			0.000	0.003			0.001	0.006
810				0.001			0.000	0.003			0.001	0.006
825				0.001			0.000	0.002			0.001	0.006
840				0.001			0.000	0.002			0.001	0.005
855				0.000			0.000	0.002			0.001	0.005

Slice thickness 4mm, 4m/s					Slice thickness 4mm, 2.5m/s				Slice thickness 4mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
870				0.000			0.000	0.002			0.001	0.005
885				0.000				0.002			0.001	0.004
900								0.002			0.001	0.004
915								0.002			0.001	0.004
930								0.001			0.001	0.003
945								0.001			0.001	0.003
960								0.001			0.001	0.003
975								0.001			0.001	0.003
990								0.001			0.001	0.003
1005								0.001			0.000	0.003
1020								0.001			0.000	0.002
1035								0.001			0.000	0.002
1050								0.001			0.000	0.002
1065								0.001			0.000	0.002
1080								0.001			0.000	0.002
1095								0.001			0.000	0.002
1110								0.000			0.000	0.002
1125								0.000			0.000	0.001
1140								0.000			0.000	0.001
1155								0.000			0.000	0.001
1170								0.000			0.000	0.001
1185								0.000				0.001
1200								0.000				0.001
1215								0.000				0.001
1230								0.000				0.001
1245								0.000				0.001
1260								0.000				0.001
1275								0.000				0.001
1290												0.001
1305												0.001
1320												0.001
1335												0.000
1350												0.000
1365												0.000
1380												0.000
1395												0.000
1410												0.000
1425												0.000
1440												0.000
1455												0.000
1470												0.000
1485												0.000
1500												0.000
1515												0.000
1530												

Slice thickness 2mm, 4m/s					Slice thickness 2mm, 2.5m/s				Slice thickness 2mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
0	1	1	1	1	1	1	1	1	1	1	1	1
15	0.406	0.483	0.573	0.644	0.426	0.527	0.589	0.653	0.510	0.657	0.749	0.813
30	0.169	0.231	0.339	0.415	0.177	0.262	0.326	0.442	0.288	0.456	0.575	0.696
45	0.057	0.103	0.196	0.277	0.072	0.134	0.189	0.308	0.144	0.317	0.430	0.594
60	0.018	0.063	0.118	0.186	0.028	0.078	0.120	0.190	0.076	0.233	0.311	0.492
75	0.013	0.032	0.078	0.137	0.016	0.034	0.083	0.137	0.038	0.119	0.224	0.397
90	0.005	0.014	0.055	0.105	0.012	0.021	0.062	0.103	0.019	0.067	0.161	0.317
105	0.003	0.007	0.041	0.085	0.008	0.018	0.049	0.089	0.014	0.040	0.115	0.250
120	0.000	0.005	0.031	0.069	0.003	0.016	0.037	0.069	0.009	0.025	0.085	0.199
135		0.003	0.020	0.054	0.001	0.015	0.032	0.054	0.005	0.019	0.064	0.160
150		0.001	0.015	0.041	0.000	0.014	0.028	0.046	0.004	0.015	0.049	0.131
165		0.000	0.009	0.029		0.012	0.026	0.035	0.002	0.013	0.038	0.107
180			0.007	0.018		0.011	0.023	0.028	0.001	0.012	0.033	0.090
195			0.006	0.013		0.010	0.021	0.024	0.001	0.010	0.029	0.075
210			0.005	0.009		0.009	0.020	0.021	0.000	0.009	0.027	0.064
225			0.004	0.007		0.008	0.019	0.019	0.000	0.008	0.025	0.058
240			0.004	0.006		0.006	0.017	0.018	0.000	0.007	0.023	0.052
255			0.003	0.005		0.005	0.016	0.016	0.000	0.007	0.022	0.047
270			0.002	0.004		0.004	0.015	0.015		0.006	0.020	0.043
285			0.002	0.003		0.003	0.014	0.013		0.006	0.018	0.037
300			0.001	0.002		0.002	0.013	0.012		0.006	0.016	0.032
315			0.001	0.002		0.001	0.011	0.011		0.005	0.014	0.029
330			0.001	0.001		0.001	0.010	0.009		0.005	0.012	0.027
345			0.000	0.001		0.000	0.009	0.008		0.005	0.010	0.025
360			0.000	0.001		0.000	0.008	0.007		0.004	0.008	0.024
375				0.001		0.000	0.007	0.006		0.004	0.008	0.022
390				0.001		0.000	0.006	0.006		0.004	0.007	0.021
405				0.000		0.000	0.004	0.005		0.003	0.006	0.021
420				0.000		0.000	0.003	0.004		0.003	0.005	0.019
435				0.000		0.000	0.003	0.004		0.003	0.005	0.018
450				0.000			0.002	0.003		0.003	0.004	0.017
465				0.000			0.002	0.002		0.003	0.004	0.016
480							0.001	0.002		0.002	0.003	0.015
495							0.001	0.002		0.002	0.003	0.015
510							0.001	0.001		0.002	0.003	0.014
525							0.000	0.001		0.002	0.003	0.013
540							0.000	0.001		0.001	0.002	0.012
555							0.000	0.001		0.001	0.002	0.012
570								0.001		0.001	0.002	0.011
585								0.001		0.001	0.002	0.010
600								0.001		0.000	0.002	0.010
615								0.001		0.000	0.001	0.009
630								0.001		0.000	0.001	0.009
645								0.000		0.000	0.001	0.008
660								0.000			0.001	0.008
675								0.000			0.001	0.007
690								0.000			0.001	0.007
705											0.001	0.006

	Slice thickness 2mm, 4m/s				Slice thickness 2mm, 2.5m/s				Slice thickness 2mm, 1m/s			
	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C	80°C	70°C	60°C	50°C
Time, min	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR	MR
720								0.000			0.001	0.006
735								0.000			0.001	0.006
750								0.000			0.001	0.005
765								0.000			0.000	0.005
780								0.000			0.000	0.005
795								0.000			0.000	0.005
810								0.000			0.000	0.004
825											0.000	0.004
840											0.000	0.004
855											0.000	0.004
870											0.000	0.003
885											0.000	0.003
900											0.000	0.003
915												0.003
930												0.003
945												0.002
960												0.002
975												0.002
990												0.002
1005												0.002
1020												0.002
1035												0.002
1050												0.001
1065												0.001
1080												0.001
1095												0.001
1110												0.001
1125												0.001
1140												0.001
1155												0.001
1170												0.001
1185												0.001
1200												0.001
1215												0.001
1230												0.001
1245												0.000
1260												0.000
1275												0.000
1290												0.000
1305												0.000
1320												0.000
1335												0.000
1350												0.000
1365												0.000
1380												0.000
1395												0.000
1410												0.000
1425												