The University of Manitoba

FOAM-MAT DEHYDRATION OF ONIONS

by

DESMOND YIU-KWONG FUNG

A Thesis
Submitted to
The Faculty of Graduate Studies
In Partial Fulfillment
of the Requirement for the Degree of
Master of Science

Department of Food Science

Winnipeg, Manitoba
October, 1976

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To My Mother

ABSTRACT

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The production of onion powder by the foam-mat process utilizing hot air and microwave energy was studied. Spanish yellow onions (11% total solids) were pureed and foamed in two separate stabilizer systems. In some trials, fixed amounts of white corn dextrin were added to enhance the whipping properties of the purees by increasing the total solids contents to 19% and 24% respectively. Two stabilizer systems (a monoglyceride and a polyglycerol ester) were evaluated on their foam-inducing and stabilizing properties. The foams were prepared by whipping the purees with four different levels of stabilizer (1%, 1.3%, 1.5%, 2%). The foams were characterized by density, oven stability, and quality.

The foams prepared under controlled conditions were successfully dried in two different drying systems: hot-air convection, and microwave radiation. In the hot air system, foams of three total solids contents (11%, 19%, 24%), different densities (0.25 - 0.49 g/ml) and two thicknesses (3.2 mm, 6.4 mm) were dried at two temperatures (60°C, 70°C). The drying times were recorded in the range of 15-60 minutes. In the microwave system, foams of 11% total solids, and two thicknesses (6.4 mm, 12.7 mm) were dried at two forward power levels (1.0 kW, 1.5 kW). The range of drying times was from 14-26 minutes.

The foam-mat dried onion products were evaluated by their moisture contents, reconstitution rates, color, and aroma.

This study demonstrated some of the advantages offered by the foam-mat drying process, such as short drying times with low temperatures, and products with desirable color and reconstitution rates. Microwave heating also proved to have the potential in improving the product throughput by virtue of its ability to improve the drying rates.

ACKNOWLEDGEMENTS

The author would like to extend his sincerest appreciation to Dr. M.B. McConnell, Department of Food Science, University of Manitoba, for his supervision, advice, and unending support throughout the project. Special thanks are also extended to Dr. M. Rzepecka, and Dr. R.A. Gallop, Head, Department of Food Science, for their advice and encouragement.

The author wishes to thank all the staff and graduate students of the Department of Food Science, for their co-operation and friendship. In addition, special thanks are extended to Mrs. E. Wong for her assistance in the typing of this thesis.

The author also wishes to thank the University of Manitoba for granting the University Fellowship.

A deepest appreciation is accorded to Dr. H.Y.M. Fung for his inspiration and invaluable support, without which this work would not have been possible.

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CHAPTER 1

INTRODUCTION

Dehydration is one of the oldest means of food preservation. To-day, dehydrated foods span a wide spectrum of food products, the major commodities are dairy (milk and whey) products, eggs, fruits, vegetables, coffee, tea, and meat (Table 1). Some of these products are dried not for the sake of preservation but for convenience. Dehydrated foods are especially favored by the food service industry and the food manufacturers mainly because of their lower transportation and storage costs, prolonged shelf-life, and their compatibility with other ingredients in dry food mixes. The retail market for dehydrated foods is also growing at a rapid rate.

In the United States, more than 3,776 million pounds of dehydrated foods worth over 1.4 billion dollars (wholesale) were produced in 1970. Among the dehydrated vegetables, the major growth has been in potatoes, followed by onions, garlic, and peppers. In fact, the production of dry onions and garlic doubled between 1965 and 1970 (Table 2). In 1970, 20 to 25% of the onion crop and

TABLE 1: PRODUCTION OF DEHYDRATED FOODS IN THE UNITED STATES, 1966 & 1970*

(millions of pounds, dry weight basis)

FOOD CATEGORY	1966	1970
Dairy products	2,273	2,321
Fruits	892	817
Vegetables	330	373
Eggs	52	75
Meat & Poultry	NA	24
Fish	1	1
Coffee & Tea	166	165
TOTAL	3,714	3,716

Source: Annual reports of the USDA Statistical Reporting Service.

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* Adapted from Van Arsdale (1973).

TABLE 2: PRODUCTION OF DEHYDRATED ONIONS & GARLIC UNITED STATES, 1965/1970*

(millions of pounds, dry weight basis)

YEAR	ONIONS	GARLIC
1965	36.0	11.6
1970	86.5	21.9

Source: American Dehydrated Onion & Garlic Assoc. (1971).

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[*] Adapted from Van Arsdale (1973).

more than 90% of the garlic crop were dehydrated. In Canada, over 200 million pounds of onions are produced annually (Statistics Canada). Very little of these are dehydrated.

Dehydrated foods are not without short-comings. Apart from the high unit processing costs, and poor quality of texture and flavor in some foods, the diversity of the food products also demands some unique processing methods. Some of these methods in use to-day are air drying, drum drying, spray drying, foam-mat drying, vacuum-puff drying, and freeze drying. The selection of drying method is determined by economic factors, quality requirements, and raw material characteristics.

When heat sensitive products such as milk, eggs, tomato, citrus and tropical fruits are dehydrated, the finished quality is largely dependent on the time - temperature conditions to which they are exposed. One way of dehydrating these products is by means of foam-mat drying. This method offers short drying times with low temperatures and the final products have excellent reconstitutability. Although the foam structure hinders heat transfer, it favors the escape of water vapor. The latter phenomenon is the dominating factor in producing increased drying rates characteristic of the foam-mat process. Basically, the product to be foam-mat dried is concentrated or comminuted into a puree which is then whipped into a low density stiff foam with the aid of a foam inducing agent or stabilizer. The foam is spread in thin layers upon trays or a continuous belt and dried by heated air.

One way of overcoming the heat transfer problem inherent in the foam system is by means of microwave heating. In contrast to conventional heating, microwave energy penetrates beyond the surfaces of food materials and dissipates evenly internally. Another unique characteristic of microwaves is the selective energy absorption exhibited by some materials, especially water. Thus, if the amount of microwave energy is properly regulated, food products can be dried without getting grossly overheated.

The foam-mat drying process is slowly gaining popularity in Japan and the United States. At present, orange, grapefruit, pineapple, berry, and tomato powders are being made.

The purpose of this thesis was to study the application of the foam-mat drying process on a heat sensitive product - onion. The main areas of concern were: 1) foam production and evaluation; 2) drying characteristics of foam in hot air and microwaves; and 3) product evaluation.

CHAPTER 2

REVIEW OF LITERATURE

Food dehydration is the virtually complete removal of water from foods under controlled conditions which cause minimum or ideally no other changes in the food properties (Potter 1973). Food is dehydrated for three major reasons: (1) preservation (microbiological and chemical stability); (2) cost reduction in storage and transportation (reduction in bulk and weight); and (3) convenience.

In principle, the drying process involves two separate physical phenomena which occur simultaneously: (1) the transfer of heat into the product, and (2) the transfer of mass (water) out of the product. Holsworth (1971) attributed the following to be the main factors which affect the rate of drying, (a) physical properties of the product; (b) geometrical arrangement of product in relation to heat transfer surface or medium; (c) physical properties of drying environment, and (d) characteristics of the drying experiment.

2.1 The Mechanism of Drying

When foods are dried, the rate of water removal is not constant throughout the entire drying cycle. Generally, two distinct stages representing different mechanisms of drying are observed; these are the constant rate period, and the falling rate period (Borgstrom 1968; Potter 1973; Van Arsdale 1973). The constant rate period occurs at the beginning of drying, and for some time thereafter, when water evaporates from the food piece at a constant and rapid rate as if it were drying from a free surface. As drying progresses, the surface of the material dries out gradually. This leaves behind an insulation barrier against heat transfer to the center of the food piece. Furthermore, the moisture from the center now has a longer way to travel to the surface. Consequently, the drying rate slows down. This stage of the drying cycle is called the falling rate period which continues until equilibrium moisture content has been reached.

In any drying operation, heat is transferred as a result of conduction, convection or radiation, and in some cases a combination of these effects. The rate of heat transfer is influenced by temperature, humidity, air velocity and the orientation of the material. Mass transfer, i.e. the migration of water within the sample and through the residual dried mass, is controlled largely by the physical properties of the product. Drying is initiated when heat is transferred to a wet surface. As a temperature gradient develops from the heated surface inwards, there occurs a migration of moisture from within the food particle to the surface. Gorling (1958); Marshall and Friedman (1950) theorized several physical mechanisms pertaining to the movement of water: (1) liquid movement under capillary forces; (2) diffusion of liquid caused by a difference in concentration; (3) flow caused by shrinkage and pressure gradients; (4) flow caused by gravity; and (5) flow caused by vaporization - condensation sequence. Harmathy (1968) proposed that all movement of moisture in a porous material takes place in the gaseous phase. This theory applies well to drying low moisture materials. At higher moisture contents, however, capillary and/or surface diffusion will take place in addition to the transport of water in the gaseous phase (King 1968). Detailed descriptions of the mechanism of drying and the quantitative aspects of heat and mass transfers are well reviewed by Williams-Gardner 1971; Chen 1973; Van Arsdale 1973 and Bomben et al 1973 .

One of the advantages of the foam-mat process is short drying times. One reason is that liquid moves more easily through a dry foam structure than through a dense layer of the same material. Van Arsdale (1973) attributed three mechanisms to be involved in foam drying: (1) capillary action along the dry interstices, (2) evaporation inside bubble spaces, and (3) gaseous diffusion through the thin outer dry walls.

2.2 Foam Drying Processes

The practice of foam drying dates back to 1918 when a patent was issued to Washington for a vacuum drying process of food extracts and beverages (Hertzendorf and Moshy 1970). Since then several foam drying processes have been developed. These include vacuum-puff drying, foam-spray drying, and foam-mat drying.

2.2.1 Vacuum-Puff Drying

When a thin film of liquid is put under vacuum conditions, puffing or foaming of the film will occur. The result of foaming is to impart a more rigid structure to the product and to increase the surface area for moisture diffusion. This process has been successfully applied to juice concentrates of orange, with and without corn syrup solids, apple, grape, depulped tomato and depulped pineapple (Strashun and Talburt 1953), and milk (Sinnamon et al 1957). The vacuum-puff method is reported to work well with depulped materials. It is believed that the pulp affects the surface tension of the mass or decreases its elasticity, and interferes with the expansion effect (Noyes 1969).

The foamed products offer rapid reconstitution, even in cold water (Strashun and Talburt 1953); (Reeve et al 1959). However, like products with high surface areas, they are hygroscopic and undergo oxidative degradation easily. Aroma retention in some products is quite unsatisfactory, and flavor add-back is required, e.g. orange oil on sorbitol is added back to orange powder (Strashun and Talburt 1958).

2.2.2 Foam-Spray Drying

Although spray-drying is limited to foods that can be atomized, such as liquids and low viscosity pastes or purees, it is by far the most extensively used method of dehydration. Products like instant coffee, soluble tea, non-fat milk solids and powdered egg are produced by this technique.

The efficiency of spray-drying is determined by the particle size during drying. Some limited control of particle size is possible through techniques of atomization, variation of the nature and concentration of the feed liquor, and the air temperature and air flow pattern. For greater control over particle size during drying, the feed material can be foamed before atomization. Incorporation of gas (e.g. air, carbon dioxide, nitrogen) results in a greater expansion of the spray droplets and particles, increases their surface area, lowers their density and facilitates their heat transfer, and thus increases the effectiveness of the heating medium (Noyes 1969). Reich and Johnston (1957) have found that the spray-drying time is proportional to the square of the particle diameter, to the water/solids ratio in the feed, and to the bulk density of the dry product. Since the amount of gas incorporated into the feed determines the foam density, which in turn governs product bulk density, the foaming or gas inflation level can be used to control the drying time and the product moisture content. The foam-sprayed products are characterized by particles having many internal spaces, separated by thin walls. During reconstitution, such products disperse quickly and completely with no sedimentation.

2.3 Foam-Mat Drying

The foam-mat process was developed by Morgan et al (1959, 1960, 1961); later developments have also been described by Bissett et al (1963, 1973), Ginnett et al (1963), and Berry et al (1967, 1972). Unlike vacuum-puff drying, foam-mat drying is operated at atmospheric pressure. Hertzendorf and Moshy (1970), Van Arsdale (1973) have given excellent reviews on the foam-mat process, while Noyes (1969) has compiled the foam-mat processes patented from 1960 to 1968. In general, the process involves these essential steps: (1) a liquid concentrate or puree of the food is converted into a stable foam by incorporating a small amount of surface active agent and a substantial amount of air or other non-toxic gas. (2) The foam is dried at atmospheric pressure by hot air to form a thin porous sheet or mat. (3) The mat is compressed and disintegrated to yield a free-flowing powder (Noyes 1969).

2.3.1 Foam Preparation

Foams are dispersions of gas bubbles in a continuous liquid or solid phase (Bikerman 1960). Foaming may be achieved by either bubbling or whipping. Ward (1976) has reviewed the foam theories put forth by DeVries (1958), Alikonis (1960), Wolnak (1960), Glicksman (1968), and several others. A general treatise on foams was provided by Bikerman (1953).

With the exception of a few food products (e.g. egg white, whole milk concentrate), most foods require the addition of foaming agents to effect foam formation. Foam stabilizers commonly used are glycerol monostearate, sucrose palmitate, and a multitude of hydrophilic colloids such as methyl cellulose, gums and starches (Morgan et al 1960; Eolkin 1962). Gunther (1964a,b) was awarded patents on the use of a mixture of enzyme modified by protein and ether of cellulose. The proportion of stabilizer used will vary depending on the properties of the product and the stabilizer in question. In general, o.1% to 2.0% by weight of stabilizer (based on the total solids in the food product) may be employed (Chandak and Chivate 1972).

Several factors other than the type and level of stabilizers have been found to affect foam production and stability. Hart et al (1963) studied a wide range of food products and investigated variables such as solids content, fluid consistencies, type and rate of agitation, temperature of foaming, and whipping time. Bates (1964) did similar studies on tropical fruit products.

2.3.2 Foam Evaluation

The first and most important step in foam-mat drying is the formation of a suitable and stable foam. According to Hart et al (1963), foams to be used in foam-mat drying must have the ability to withstand a variety of processing conditions including pumping, spreading, cratering and extrusion, as well as drying. Apart from the many variables mentioned by Hart et al and Bates, foam stability is also dependent upon bubble size, and the rate of heating of the foam (Noyes 1969). The rate of foam collapse during drying can only be determined empirically.

In order to determine the suitability of the foam for foam-mat drying, several authors have devised methods of foam characterization. LaBelle (1966) characterized foams by measuring the rates of change of foam density, viscosity, drainage, bubble size and light transmission. Berry et al (1965) described the technique of photomicroscopy for the determination of bubble size index.

2.3.3 Foam-Mat Drying Techniques

One of the major advantages offered by the foam-mat process is rapid drying rates with low temperatures. Although foams are typified by very low thermal conductivity (i.e. poor heat transfer), the expanded structure enhances the movement of moisture. The latter phenomenon is responsible for the relatively high rates of drying. Various time-temperature drying studies have been done by Ginnette et al (1963); Bissett et al (1963); and Berry et al (1965, 1967).

The original foam-mat model as developed by Morgan et al (1959) called for spreading the foam on a tray or belt in a layer 1/8 inch thick, and drying with crossflow air at temperatures between 130-190°F. Drying times were 60 minutes in most cases. The original model was later modified. An improved technique called the spaghetti process involved extruding the foam in the form of 1/16 - 1/8 inch diameter spaghetti-like strips. Komanowsky et al (1964) studied the mass transfer rate of such strips of foams and found that drying times were inversely related to the square of the thickness, indicating a diffusion-controlling mechanism.

Another technique called the perforated mat (Cratering) process was developed by Ginnette, Graham, and Morgan (1961). A layer of foam about 1/8 inch thick is deposited on a perforated tray. The foam is then perforated or cratered by impinging against the mat spaced jets of gas directed at the bottom of the tray. The cratered foam has a larger surface area and dries faster (Noyes 1969). Foam cratering also improves throughput because the cratered trays can be dried by through circulation in a vertical stack. A continuous cratering and drying system was developed by the Western Regional Research Laboratories, USDA (Rockwell et al 1962). A scaled-up commercial version of this system was later developed by Chemet Engineers, Inc., (Sjorgren 1962).

Still another refinement of the basic foam-mat process is called the Microflake^T process. This technique involves the drying of a continuous sheet of foam 20 mils[1] thick on a rapidly moving stainless steel belt (Anon., 1964). Heat transfer is improved by heating the belt from below with steam, and above by a high velocity air stream. Drying times one tenth of the standard processes have been reported. Microflake dehydration has been applied to at least 28 food products ranging from high-pectin fruits and vegetables to colloidal substances such as gelatin, including tacky substances such as molasses and maple syrup; high-fat whipped toppings and cheese; and beverages such as coffee and tea (Beck 1968). A commercial three million lb/yr Microflake^T drying unit, primarily for orange juice, was developed in Florida (Anon., 1968).

2.4 Microwave Heating

The existence of electromagnatic waves, including microwaves, was predicted by James Clerk Maxwell one hundred years ago. Twenty years later Hertz was able to generate microwaves experimentally. However, it was not until World War II, and the subsequent development of radar that the industrial potential of microwave

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[1] 1 mil = 1/1000 inch

energy was recognised. To-day, the sales of microwave ovens in the consumer and institutional markets have been phenomenal. It is estimated that two million microwave ovens will be sold yearly by 1980 (Martin 1975). The applications of microwave heating in the food industry are many and of growing importance. They include baking, cooking, drying, pasteurization, tempering and thawing.

2.4.1 Properties of Microwaves

Microwaves are a form of electromagnetic radiation, differing from other electromagnetic radiations such as light waves and radio waves primarily in wavelength and frequency (Figure 1). Four frequencies have been allocated by the Federal Communications Commission (FCC) for Industrial, Scientific, and Medical (ISM) purposes. Only two of these frequencies are of concern to the food industry; 915 MHz and 2450 MHz (Decareau 1970).

Microwaves radiate through space at the speed of light (3×10^8 meter per second). They are reflected by metals; pass through air, and many types of glass, paper and plastic materials; and are absorbed by several food constituents including water (Potter 1973).

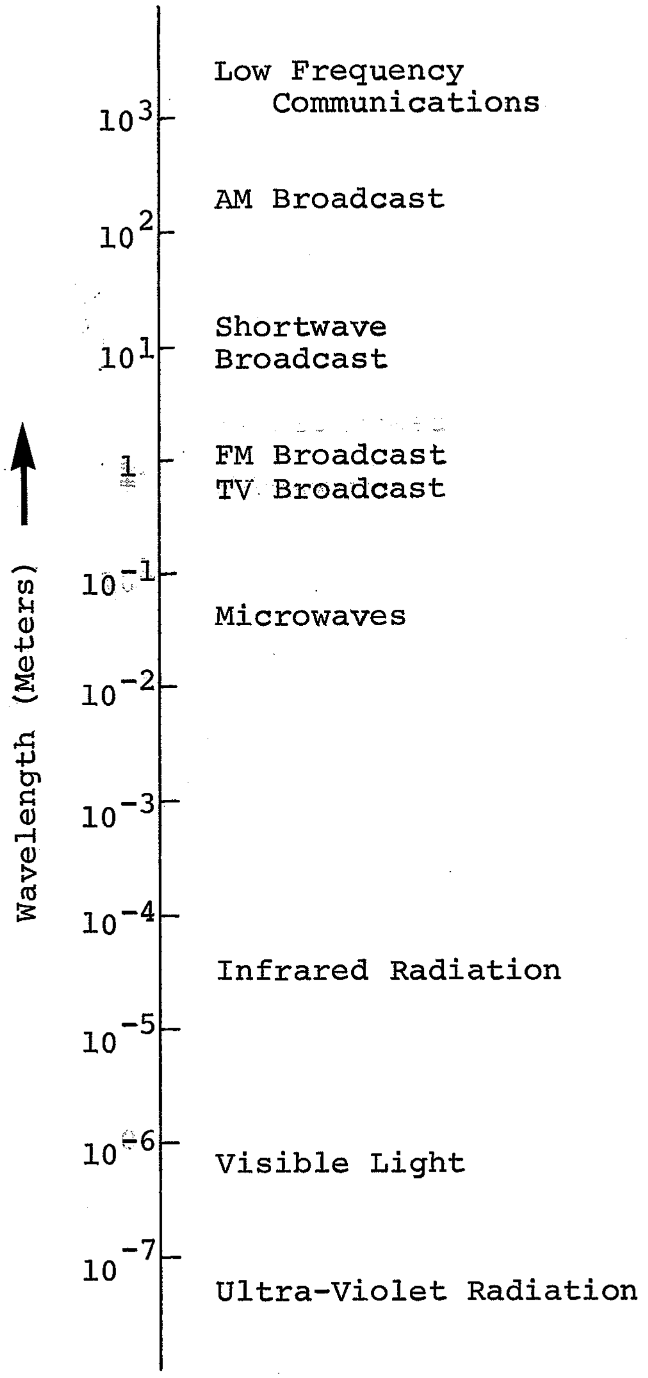

Figure 1

The Electromagnetic Spectrum

2.4.2 Mechanism of Heating

The mechanism of microwave heating has been extensively reviewed (Copson 1962; Van Koughnett 1973; White 1971). An oversimplified model is described below. Molecules are electrically neutral but consist of positively and negatively charged ions. The water molecule, for example, has two positively charged hydrogen ions and one double negatively charged oxygen ion. Although the molecule is neutral, the ions are unsymmetrically distributed in such a way that the molecule possesses a dipole moment. When such a molecule is exposed to an electric field, it rotates to tend to align itself with the field. When the field is changing millions of times each second, the molecular vibration is so great that heat is generated (Van Koughnett 1973). This model may be described by the relationship $P \alpha E^2 f K$, or that power absorbed by the material to be heated by electric field is proportional to the square of the field, to the frequency of relaxation of the field, and to the loss factor of the material to be processed (Badger 1970).

The terms dielectric constant[1], dielectric loss factor[2], and loss tangent[3] (Day and Leidigh 1971) are generally used to describe the microwave properties of materials. The dielectric constant is influenced by several parameters: moisture content, density, temperature, frequency, physical geometry, conductivity, thermal conductivity, and specific heat (Tinga 1970). One of the main assets of microwaves is their ability to penetrate and heat beyond the surfaces of materials. The penetration depth is determined by the dielectric constant and the dielectric loss of the material. A collection of dielectric and other physical data for foods has been tabulated by Tinga and Nelson (1973).

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[1] When an electric field is applied to a dielectric, polarization takes place and as a consequence, the electric displacement field inside the dielectric is greater than if the dielectric were not there. The ratio of these fields is the dielectric constant.

[2] When an alternating electric field is applied to a dielectric, there is usually a loss of energy because of the interaction of the alternating polarization of the molecules with each other. The dielectric loss factor is a measure of the amount of dissipation in the dielectric medium.

[3] The ratio of the dielectric loss factor to the dielectric constant is called the loss tangent.

(Day and Leidigh 1971)

2.4.3 Microwave Applications

The advantages of microwave processing are well documented (Dench 1971, Wade 1972, Edgar 1972, Anonymous 1974). These include better working environment, improved process controllability, superior product quality, and economic savings. The industrial applications of microwave energy are also well reviewed by Decareau 1970; Bengtsson 1974; Schiffman 1970; and Edgar 1972 . Some specific applications are the drying of pasta (Maurer et al 1972; Anonymous 1972; Anonymous 1974); proofing of yeast-leavened doughnuts (Schiffman et al 1971; Moyer 1973), dehydration of potatoes and apples (Huxsoll and Morgan 1968); defrosting of shrimp (Bezanson et al 1973); meat tempering (Bezanson et al 1973); chicken cooking (Smith 1969); and finish-drying of onions (Anonymous 1975). Recent research on microwave dehydration includes vacuum drying of fruit juices (Archieri et al 1971); water removal from fats (Guerga 1972); freeze-drying of beef (Grimm 1969); and foam-mat drying of tomato paste (Rzepecka et al 1975).

2.4.4 Microwave Systems

All microwave processing systems are comprised of the following components (Jeppson 1968):

(a) An applicator through which product may be passed to receive a desired amount of heat for a specified amount of time.

(b) A microwave generator of the proper frequency, incorporating one or a few tubes of high efficiency, long life, low cost, proven stability and reliability.

(c) A material handling system, compatible with the microwaves, which will transport product to, through and out of the applicator.

Several categories of patented applicators have been described by Gerling 1970. Their design is geared to the material being processed. The basic categories are: (a) Cavity systems (batch); (b) Conveyor systems (continuous); (c) Articulator conveyor systems; (d) film systems; and (e) filamentary systems.

The microwave generator is the single most important component of any microwave heating device. Two types of generator currently in use are the klystron and the magnetron (Kumpfer 1970).

Since microwaves are reflected, absorbed or transmitted by certain materials, many conventional material handling systems are not applicable in microwave processing. The conveyor system used for microwave processing is comprised of dielectric material (e.g. fiberglass) which does not affect the microwave field; it may be perforated or open mesh to allow free circulation of hot air through the product from beneath (Microdry Corp.; Raytheon Co.; Varian Corp.; LMI Industries).

2.4.5 Effects of Microwaves on Foods

Unlike ionizing radiations (UV, X-rays, gamma rays), microwaves do not possess germicidal effects. Rosen (1972) claims the bacteriocidal property of microwaves is caused by thermal rather than nonthermal effects. Microwave heating has considerable potential for high temperature - short time (HTST) sterilization of foods with improved quality (Bengtsson and Ohlsson 1974). Microwave dehydration has been known to yield products with lower bacterial counts (Anonymous 1975; Maurer et al 1972).

Goldblith et al (1968) studied the effects of microwaves on nutrients (thiamine) and concluded that thiamine destruction was caused by thermal rather than non-thermal effects. Since microwaves generally offer faster processing rates than conventional heating, foods may retain more nutrients if so processed.

2.5 Onion Dehydration

Dehydrated onions are considered as a spice as well as an ingredient. They are used in a variety of food products like catsup, sauces, soup mixes, salad dressings and prepared meals. Onions to be dehydrated must meet some stringent requirements. Only white globes of the pungent varieties are normally considered to be desirable (Stephenson 1949). The characteristics of principal varieties of onions and the factors pertaining to their commercial production were tabulated by Van Arsdale (1973). Yellow onions are seldom used in dehydration because of their milder flavor, inferior color and bitter taste. Chan (1974) studied the fluidized-bed drying process of yellow and white onions. His results showed that the yellow varieties were inferior in color but they did possess a flavor comparable to the white varieties. No bitterness was detected in the dehydrated flakes.

2.5.1 Methods of Onion Dehydration

In the United States, onions are no longer dried on trays in tunnels. To-day, most companies use the multistage, continuous-belt dryers operated by automatic controls which maintain the desired temperature, humidity, rate of exhaust, and in-transit speed (Van Arsdale 1973).

One of the shortcomings of tunnel drying is that the onions tend to stick to the conveyor belts. Van Gelder (1962) has patented a fluidized bed process which virtually eliminates the sticking problem, mechanical damage, and scorching of onions. A four-stage fluidized-bed drying system for onion dehydration has also been proposed by Fleming and Doole (1969).

Onion is a heat sensitive product and cannot be dried at high temperatures. Consequently, onion dehydration is notorious for its long drying cycle (over 20 hours). Gentry International and Microdry Corp. have jointly developed a microwave finish-drying system which they claim can reduce gas consumption during the final stage of drying by 80%, and total bacterial count by 90% (Anonymous 1975).

The production of free flowing onion requires the milling of dried onion flakes, or milling of the semi-dried flakes and then finish drying the milled powder. In a process developed by Noznick, Bundar, and Luksas (1963), raw onions of the desired pungency are comminuted into a puree. The puree is mixed with 30 to 40% by weight of dextrin and then spray dried at 155°F (73°C). The powder produced by this method is claimed to be at least 20% stronger in flavor than powder produced by conventional dehydration of the same onions. The powder also has lower bacterial counts and reconstitutes better.

Ammon (1968) reported another spray drying process. Onion oil is separated and then recovered from onion juice. The oil of onion is stirred into a gelatin-gum emulsion and then spray dried. Much flavor is retained as the colloidal material serves to encapsulate the onion oil. The onion juice is concentrated to 80% solids and then spray dried. Dextrin-gum is used as a vehicle to alleviate the thermoplastic problem. The two components of onion flavor - the oil and the solids - are then combined to yield the full-range fresh onion flavor.

2.6 Problems Associated With Onion Dehydration

The quality of dehydrated onions is judged mainly by their color, pungency, and cleanliness. These three factors are affected by the processing techniques and the subsequent storage conditions. Some of the common problems associated with onion dehydration have been reviewed by Chan (1974).

2.6.1 Pinking of Onions

The pinking of onions have been studied and reported by Lukes (1959); Yamaguchi et al (1965) and Joslyn and Peterson (1958, 1960). Later study by Shannon et al (1967) demonstrated that the pink pigment formation involves an enzymatic reaction. The factors that affect the rate and intensity of pinking most are high temperatures and low pH. Pureed onion is especially susceptible to pinking.

2.6.2 Browning of Dehydrated Onions

During storage, dehydrated onions are subjected to another color deterioration called browning. Nonenzymatic browning in dehydrated products has been attributed to the reducing sugar-amino nitrogen reaction known as the Maillard Reaction (Hodge 1953). Yamaguchi et al (1957) reported that the darkening effect was associated with the storage temperature prior to dehydration. The study indicated that with increasing storage temperatures, the content of reducing sugars was lower and that of non-reducing sugars was higher. Free-amino nitrogen content of the bulbs was only slightly higher at the higher temperatures.

2.6.3 Aroma of Onions

The mechanism of onion aroma formation has been studied extensively by Niegish and Stahl (1956); Carson and Wong (1961); Schwimmer et al (1960, 1961); and Schwimmer and Mazelis (1963), etc. The onion aroma and lachrymatory craponents arise as a result of the interaction between the S-substituted L-cysteine sulfoxide derivatives and enzymes of the alliinase type when onion tissues are macerated. Onion aroma is a combination of several volatile odoriferous disulfide oxides. Much of the volatiles are lost during the slicing or chopping operations prior to drying (Stephenson 1949), and some more are released in the early stages of drying (Bernhard 1968).

Aroma retention in the drying of foods has been reviewed by Bomben et al (1971). Bolin and Salunkhe (1971) also reported aroma retention in the foam mat drying process. It is speculated that foam drying can have aroma retention comparable to (perhaps better than) spray drying, if care is taken to avoid heat transfer limitation in the early stages of the drying process.

2.6.4 Bitterness in Onions

The pigment in yellow onions has long been associated with the cause of bitterness, although neither quercetin nor quercetin glycoside is bitter in nature. Schwimmer (1967) claimed that bitterness is detected within forty seconds of cell rupture. The bitter substance is non-volatile, non-ionic, and its formation can be prevented without affecting odor intensity by acidification below pH 3.9 of the freshly comminuted onion extract. Schwimmer (1968) further reported that trans - (+) - S - 1 - propenyl-L-cysteine S-oxide, a compound that is transformed enzymatically into the lachrymatory substance of freshly cut onion tissue, is also the sole precursor of the substance responsible for the bitter taste in onion macerates.

2.6.5 Microbiology of Dehydrated Onions

Onions must be dehydrated at low temperatures and without blanching in order to retain most of their characteristic organoleptic properties. Subsequently, the bacterial population is expected to be quite high in dehydrated onions. Vaughn (1951, 1962) studied the technological problems associated with the dehydration of unblanched vegetables. Since dehydrated onions are used as ingredients in many foods preserved by different methods, Vaughn (1970) suggested the microbial index chosen for quality control should reflect the use and method of preparation of the final product.

2.7 Product Evaluation

The quality of dehydrated products is generally determined by their moisture content, color, flavor, rehydration rate, microbial and defect count.

2.7.1 Moisture Content Determination

The term moisture content is seriously ambiguous unless the method used to determine its value is clearly understood (Van Arsdale 1973). The American Dehydrated Onion and Garlic Association (ADOGA) specifies that dehydrated onions must not contain more than 4.25% moisture (Vacuum oven method, 70°C/100 mmHg/6 hours). Moisture contents invariably determine the stability of dried products in storage (Ponting et al 1964). Peleg and Mannheim (1969) reported when the moisture content of dehydrated onions is beyond 7%, further addition of anti-caking agent is futile. The porous structure of foam-dried products is conducive to the adsorption of oxygen and moisture, which may lower the product quality. Several methods of in-package dessication have been reviewed by Hertzendorf and Moshy (1970).

2.7.2 Color Evaluation

The color of dehydrated food products is a good indicator of quality. Two of the most widely used instrument for color measurement are the spectrophotometer and the colormeter.

A spectrophotometer measures reflectance or absorbance as a function of wavelength. It does not measure color on any visual scale. The most commonly used colorimeter is the Hunterlab Color and Color Difference Meter. This instrument measures the average diffuse daylight color of a flat opaque surface in terms of the tristimulus parameters (L, aL, and bL values).

The L value measures the lightness or intensity of a color. It varies from 99.9 for total whiteness to 0.00 for total blackness. The aL value measures the degree of greeness versus redness. A positive aL value indicates red predominance and a negative aL value indicates green predominance. Likewise, a positive bL value means more yellowness and negative bL value means more blueness in the sample.

Two additional attributes of color, hue and saturation, can be determined from the aL and bL readings. Hue is defined as that attribute of color perception denoted by green, yellow, red, and brown, etc. It is mathematically equal to the ratio aL/bL. Saturation (Chroma, purity) is defined as the strength of the color.

It is numerically equal to $\sqrt{aL^2 + bL^2}$ (Kramer and Twigg 1970).

Peleg et al (1970) reported that the tristimulus determinations offer more information than absorbance readings on the color changes in dehydrated kibbled onions during storage. The Official Methods of ADOGA (1969), however, specify the use of a spectrophotometer and that dehydrated white onions shall not have an optical index above 105 at 420 nm.

2.7.3 Flavor Evaluation

During the last several decades, the development of instrumental or chemical methods for measuring food attributes has progressed substantially. To this day, however, flavor factors are particularly difficult, if not impossible, to measure by any but the subjective human instrument (Kramer 1966). The application of taste panels and the various methods used for sensory evaluation are described thoroughly by Amerine, Pangborn and Roessler (1965).

Bernhard (1966) published a critical review on the various objective methods for evaluation of aroma and flavor of onions. Saguy, Mannheim and Peleg (1970) classified these methods into three categories - namely, overall indices, gas chromatographic evaluations, and determination of enzymatic products.

Among the earliest to adapt the overall indices methods were Platenius and Knott (1941) who found a correlation between total solids of onions and pungency; and Farber (1957) who suggested using total volatile reducing substances as an index of onion pungency. Most of these methods, however, are laborious and expensive.

In the gas chromatographic methods, the volatile products of the enzymatic reactions are evaluated. Saghir et al (1964) estimated and identified mono- and disulfides taken from the headspace; while Bernhard (1968) estimated disulfides in fresh onions and dried onion products.

Schwimmer and Weston (1961) devised a method estimating the enzymatic development of pyruvic acid in onions as a measure of pungency. Schwimmer and Guadagni

(1962) later found a good correlation (r = -0.97) between olfactory threshold concentration and pyruvic content of onion juice. Schwimmer et al (1964) claimed that the pyruvic acid test could also be used for evaluation of pungency in dried onion powders as well as in raw onions. However, Peleg et al (1970) found that the pyruvic acid test - method A, used by Schwimmer et al (1961, 1962, 1964), did not correlate with the odor-threshold values of dehydrated kibbled onions. It was speculated that the formation of carbonyls, other than pyruvic acid, during storage, affected the results of the test.

Saguy, Mannheim and Peleg (1970) used the Chemical Oxygen Demand (COD) method for evaluating onion aroma. The COD method was suggested by McNary et al (1957) and modified by Dougherty (1968) for evaluating water-soluble volatile constituents of citrus juices. The procedure involved oxidizing a distillate of the product with potassium dichromate and determining the volatile aroma compounds colorimetrically. A good correlation (r = -0.98) was found between odor threshold and COD of fresh onions. However, no correlation was found between odor threshold and COD of dehydrated onions. Saguy et al did find that COD values decreased with storage time as well as with storage temperature.

2.7.4 Rehydration Rate

Foam-mat dried products are well known for their instant reconstitution properties. Wagner et al (1964) suggested densification of the foam-mat powder to eliminate the inclusion of air bubbles on rehydration. Graham et al (1965) achieved densification of orange and lemon juice powder by a heat compaction procedure. Berry et al (1967) reported the use of cold compaction on grapefruit powder. Solubility of the grapefruit crystals depended on particle size and ranged from 37 seconds to 2 minutes.

Ward (1976) has carried out studies on reconstitution rates of foam-mat dried tropical root crops.

2.7.5 Microbial and Defect Evaluation

Most processors use total plate count as the sole indicator of cleanliness. Vaughn (1970) suggested the microbial index used should reflect the end use of the product. The Official Methods of ADOGA specify standard procedures of speck count and defect count for dehydrated onions.

CHAPTER 3

METHODS AND MATERIALS

The onions (Spanish yellow variety) used in the study were purchased entirely from the Manitoba Vegetable Marketing Board, Winnipeg. Approximately 300 pounds of onions were used between September 1975 and May 1976. Spanish yellow onions were seldom used for dehydration purposes because of their mild flavor and yellowish color (Van Arsdale 1973). The choice of these onions, however, was due mainly to their uniformity in terms of solids content and flavor, and their availability during the time and season when the project was conducted.

3.1 Experimental Design

Experiments were designed with the following objectives:

(a) to investigate and evaluate the foam production system for onions.

(b) to study the applicability of the hot-air foam mat drying process and the microwave foam-mat drying process on foams produced from (a).

(c) to evaluate the foam-dried product by objective analyses.

Fresh purees of Spanish Yellow Onions (av. total solids = 11%; storage temperature = $4.4^{\circ}C$ ($40^{\circ}F$)) were whipped with the aid of known concentrations of stabilizers in a Hobart Kitchen Aid mixer under known conditions. In some instances, pre-determined amounts of white corn dextrin were added to the purees to increase their solids contents up to 19% or 24%. The foams produced were characterized primarily by their densities and oven stability. They were then dried to constant weights in an Aeromatic batch type fluidized bed drier at known temperatures, or in a microwave cavity at known microwave power settings. Drying rates were monitored by weighing the samples at fixed time intervals. The dried products were stored in opaque snap top plastic containers for further study.

3.2 Preparation of Puree

A total solids content determination was performed for each 50 pound bag of onions used. Approximately ten onion bulbs were randomly selected and their solids content determined as described in 3.2.1. The average reading of these ten onions was used as the mean reading of the 50 pound lot.

In each trial, 3 or 4 onion bulbs (depending on size) were removed from cool storage (4.4°C), hand peeled, cored, and diced. They were then blended at high speed in an Osterizer blender for approximately one minute or till a smooth, uniform puree was obtained. Four hundred grams of puree were measured into a glass mixing bowl in preparation for foaming (section 3.4). In some trials, white corn dextrin (Fisher Scientific Co.) was added to the puree according to the following scheme (Table 3).

TABLE 3: AMOUNT OF DEXTRIN USED IN PUREE PREPARATION

Wt. of Onions	Wt. of Dextrin	Total Solids
400 g	0 g	11 ± 0.5 %
400 g	42.5 g	19 ± 0.5 %
400 g	72.0 g	24 ± 0.5 %

3.2.1 Determination of Total Solids

1. In each trial, triplicate samples of onion puree (approx. 10 g) were weighed into 3 separate pre-dried, disposable aluminum dishes. A Sartorius 2462 analytical balance was used for all the weighing.
2. The samples were dried in a Blue M power-0-matic 70 mechanical convection oven at 70°C to constant weights.
3. Total solids content was determined by calculations given in Appendix 1.

3.2.2 Determination of puree density

A tared 40 ml glass graduated cylinder was filled from a syringeful of puree, taking care to exclude accidental voids. The filled cylinder was weighed to the nearest 0.1 gram. Density was calculated as follows:

$$\frac{\text{Wt of foam (g)}}{\text{40 ml}} = \text{ and reported as gram/ml.}$$

3.2.3 Measurement of Color

The color of onion puree was measured by the colorimetry method, using the Hunterlab Color and Color Difference Meter model D25. The samples were measured for intensity or lightness (L values); redness or greenness (aL values); and yellowness or blueness (bL values). The average result of three individual readings was taken. Standardization of the Hunter meter was done against a white plate having values of L = 93.8, aL = -1.1, bL = 2.3.

The operating procedures are given in the Hunter D25 Color Difference meter instruction manual. The numerical values of hue, saturation and total color difference were calculated from the expressions presented in appendix 2.

3.3 Preparation of Stabilizers

Two types of foam stabilizer systems were used in the study. They were evaluated primarily upon their contribution to foam production and stabilization.

(1) MYVEROL 18-00 —— a saturated (high-melting) distilled monoglyceride (minimum 90% monoesters), foam inducer and stabilizer, manufactured by Eastman Kodak.

Myverol 18-00 was prepared as a 10% wt/wt dispersion. Twenty grams of Myverol 18-00 granules were added with stirring to 180 g of heated tap water (69°C). The mixture was agitated vigorously for 5 minutes, or until there were no discrete particles present. The dispersion was cooled to the desired processing temperature. Continuous stirring was necessary to maintain a homogenous dispersion.

(2) ADMUL 1405 (formerly Admul Polyester 57) —— a polyglycerol ester prepared by the interesterification of polyglycerol with triglycerides or fatty acids. It has more hydrophilic properties than the conventional monoesters. Supplier - Food Industries Ltd. Bromborough Port, Wirral Merseyside L62 4SU, U.K.

Admul 1405 was prepared as a 10% wt/wt dispersion. Twenty grams of Admul 1405 (microbead form) were placed in a 6 oz blending jar and 180 g of boiling water were added. The mixture was blended for 1-1/2 minutes and stored at 69°C with constant agitation.

3.4 Preparation of Foam

Foaming was carried out at room temperature (21 ± 1°C). Four hundred grams of onion puree, plus predetermined levels of dextrin, and plus predetermined levels of stabilizer (Table 4) were mixed at a slow speed for 1 minute in a glass mixing bowl. Foaming was done with a Hobart Kitchen Aid mixer (Model 4C) equipped with wire whisk beater. Several whipping speeds were tried. Preliminary tests showed that when the puree/stabilizer mixture was whipped at 145 rpm (no. 4 setting on mixer), foam formation was superior to either slower or faster whipping. The shortest whipping time required to produce a foam of acceptable stability (characterized by foam quality and a range of foam densities) was termed the optimum whipping time.

3.5 Characterization of Foam

3.5.1 Foam density

Foam density was determined by filling a 40 ml glass graduated cylinder from a syringe, taking care to exclude accidental voids. Density was calculated as

TABLE 4: LEVELS OF STABILIZER ADDED TO PUREE

Total Solids in Puree	Weight of Stabilizer (10% wt/wt Dispersion) Added to Maintain the Level of Stabilizer At			
	1.0 %	1.3 %	1.5 %	2.0 %
11 %	-	-	-	9.5 %
19 %	8.6 g	11.0 g	13.7 g	-
24 %	12.5 g	14.8 g	18.0 g	-

$\frac{\text{Wt of foam}}{\text{40 ml}}$ and reported as g/ml. Foam density was determined at every 2-minute interval during whipping.

3.5.2 Foam Volume

Unit volume graduations were marked on the mixing bowl to signify the volume change during whipping. Foam volume was used only as an approximate guideline for accepting or rejecting a foam. Foams with a volume increase of less than 2X were deemed unacceptable.

3.5.3 Oven Stability

A method for determining oven stability was described by Ward (1976). Several strips of foam (1/8 in diameter) were extruded from a syringe onto a stainless steel screen (Tyler #10). They were then placed in the Blue M Power-O-Matic oven at 97°C with cross-flowing air for 5 minutes. Foams that retained their structure well or showed only a slight degree of collapse were deemed acceptable for drying.

3.5.4 Foam Quality

Foams were appraised subjectively as to their smoothness, evenness, consistency, and their ability to withstand mechanical operations such as spreading and cratering. Using the foam spreading apparatus (Figure 2), foams were checked to see whether they spread easily or run through the holes in the drying plates. The thickness of the foams was controlled by adjusting the span on the apparatus.

Since cratered foams were used in hot air drying, it was necessary to determine the cratering properties of oven stable foams. Foams were loaded onto cold rolled steel plates (0.032 cm x 25 cm x 25 cm), perforated with staggered 3.2 mm diam. holes on 4.8 mm centers. The loaded trays were cratered in the apparatus described by Ward (1976) by blasting a jet of air at the bottom of the trays. The laboratory-line compressed air was carefully controlled so that the foams were perforated around the holes and not splattered off the trays. The cratered foams that maintained their perforated forms without collapsing were said to have good cratering properties.

During the drying study, foams were cratered at the bottom of the Aeromatic fluidized-bed dryer instead of the cratering apparatus. The air velocity was carefully selected to avoid splattering.

3.6 Drying Study

Only oven stable foams of good quality were used in the drying studies. Two methods of drying were investigated: (1) Hot air drying; (2) Microwave drying. Several parameters such as drying temperature, foam thickness, foam density, and microwave power level were studied.

3.6.1 Hot Air Drying

A preliminary drying study was performed using the Blue M Power-0-Matic convection oven. Plates of cratered and non-cratered foams were dried in cross-flow air with varying temperatures. Drying rates were found to be slow at practical temperatures (60°C —— 80°C), and pinking was extensive. The Convection Oven was abandoned in favor of the more efficient Aeromatic Dryer.

The drying rates of foams containing 11%, 19% and 24% solids were studied. The foam was spread 6.4 mm (1/4") or 3.2 mm (1/8") thick onto a perforated steel plate and then dried at 60° ± 2°C or 70° ± 2°C in an Aeromatic Batch type STS 5 Fluidized Bed Dryer (manuf. Aeromatic Ltd., Basle, Switzerland). An air flow rate of 9.4×10^{-2} m^3/sec (190 cfm) was used which also facilitated cratering of the foam. The drying rate was monitored by weighing the sample at 5 minute intervals on a Sartorius top loading balance (Model 2253). Drying was terminated when the sample weight remained constant.

3.6.2 Microwave Drying

Only foams of 11% solids (i.e. no dextrin) were studied. The stiff foam was spread 6.4 mm (1/4") or 12.7 mm (1/2") thick onto fiberglass teflon coated mesh sheets. Cratering was not necessary because of the nature of microwave heating. The foam was dried in a Gerling-Moore microwave cavity equipped with an air blower (flow rate = 8.6×10^{-2} m^3/sec or 173 cfm). A Varian Industrial Systems Model PPS - 2.5A power pack which operated at 2450 MHz with a continuous adjustable power output range of 0 - 2.5 kW was used as the power source. The power

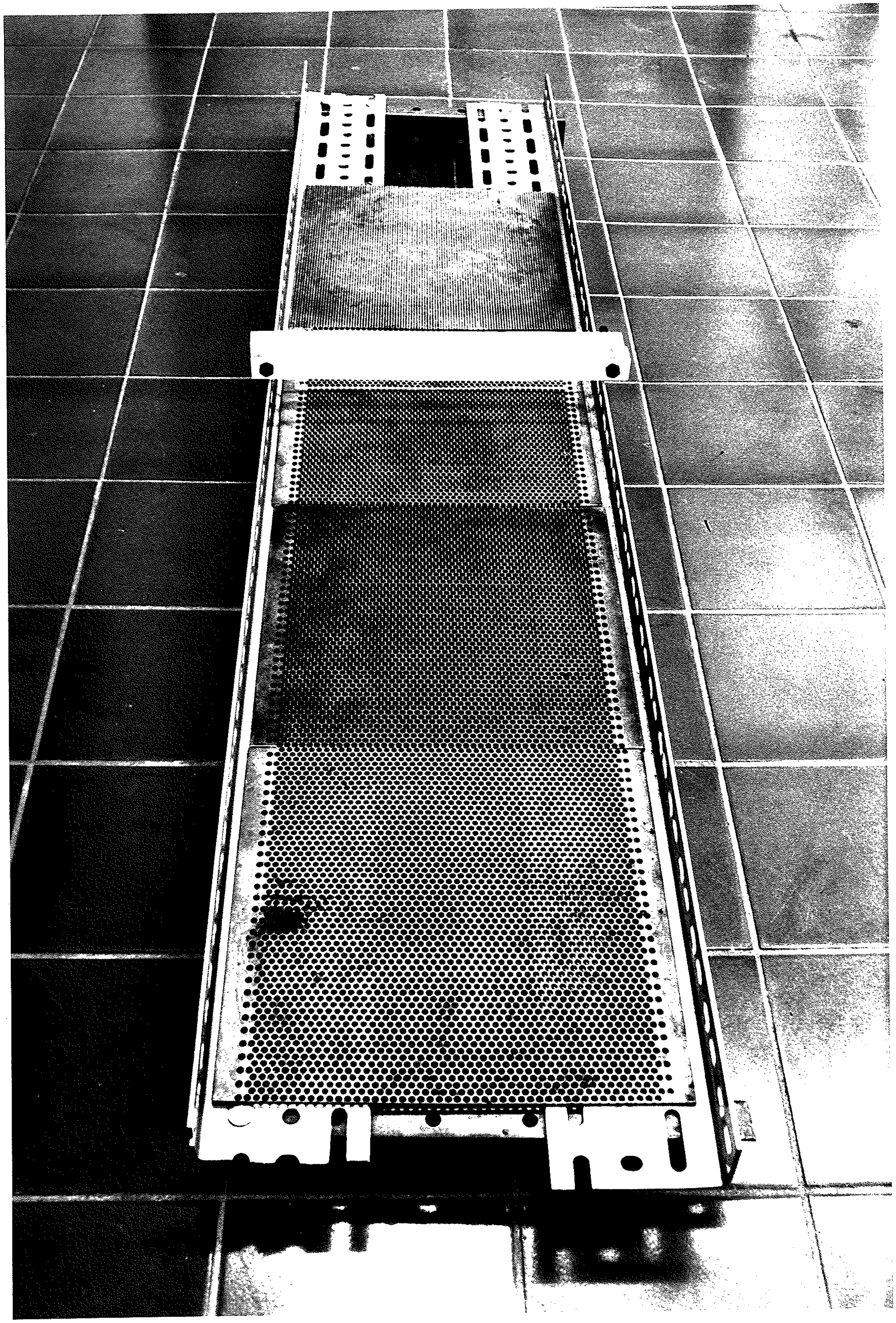

Figure 2. The Foam Spreading Apparatus.

delivered into and reflected from the microwave cavity was monitored by a Varian EW3 - DPM3S power meter. An external view of the microwave drying equipment is shown in Figure 3. Several power levels were tested initially, and the levels of 1.0 kW and 1.5 kW were found to be most practicable. The drying rate was monitored by weighing the sample every 2 minutes until a constant weight was attained. Towards the end of the drying cycle when the reflected power reached the level of 0.45 - 0.5 kW, it was necessary to reduce the forward power down to 0.5 kW to prevent the high dose of reflected power from damaging the magnetron. The surface temperature of the samples was measured qualitatively by using Tempilabels. These temperature indicators are strips or labels impregnated with dots of heat sensitive materials which undergo color change when specified temperatures are reached. The humidity of the drying air was measured by a Taylor sling-shot wet bulb/dry bulb Hygrometer. The finished product was removed from the trays and stored in plastic Lab-Tek containers at room temperature.

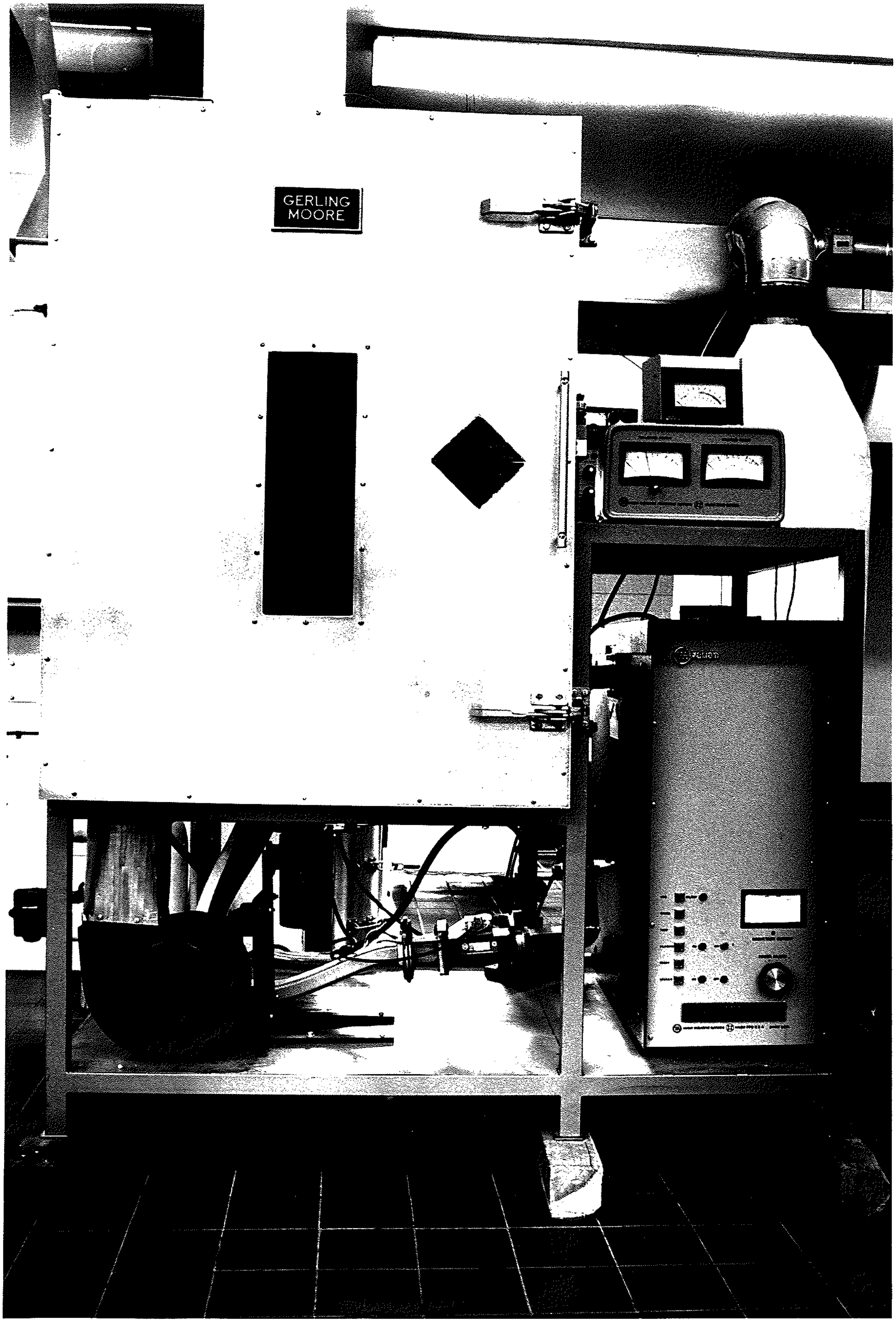

Figure 3. External view of the Microwave Drying System.

3.7 Product Study

3.7.1 Moisture Content

The moisture content in the finished product was determined by drying under vacuum (70°C, 100 mm Hg, 6 hours) as given in the Official Methods of the American Dehydrated Onions and Garlic Association (ADOGA). The determinations were done in duplicates.

3.7.2 Color

The color of the dried product was analysed by tristimulus colorimetry using a Hunterlab Model D25 Color and Color Difference Meter. The procedure was described in 3.2.3 for measuring the color of puree. Each sample was measured in triplicate and the results were reported as average readings.

3.7.3 Reconstitution Study

Ward (1976) reported a method for measuring reconstitution. A weighed sample was poured quickly into a beaker of heated water (80°C) of known weight. The mixture was stirred until fully rehydrated. The time interval between the addition of sample and full rehydration was timed and reported as reconstitution time.

3.7.4 Aroma Study

The Chemical Oxygen Demand (COD) method for evaluating onion aroma as modified by Saguy et al (1970) was used to monitor the pungency of the onion puree, the hot air dried onion powder, and the microwave dried onion powder.

To a sample of 10.0 g (moisture free basis) of onion or onion product 100 ml of distilled water were added into a 500 ml distillation flask. The slurry was left for 15 min with occasional stirring at room temperature and then distilled slowly on an heating plate. The first 10 ml were collected. To the 10 ml distillate 5 ml of 0.25 N potassium dichromate were added in a 100 ml flask and stirred carefully. During stirring 15 ml conc. phosphoric acid were slowly added. After reflux for 10 min the mixture was brought to room temperature in a water bath. The percent transmittance was determined at 650 nm in a Unicam SP600 Series 2 Spectrophotometer. As a blank, distilled water was used after adding the oxidizing mixture and refluxing as noted before. A standard Calibration Curve was prepared by oxidizing 10 ml sucrose solutions of known concentrations. The results were expressed as ppm COD or ppm volatiles.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The purpose of this thesis was to study the application of the foam-mat drying process on a heat sensitive product - onion. In this study, several areas of concern were investigated. These were:

(a) The various factors affecting the production of stable foams from onions.

(b) Characterization of such foams.

(c) A time - temperature study on the foams by utilizing the hot-air convection drying method, and the micro-wave radiation drying method.

(d) Evaluation of the foam-mat dried product.

4.2 Evaluation of puree preparation

The preparation of puree was the first step in the foam production process. Fresh onions were blended in order to achieve a liquid or semi-liquid form. The liquid puree was maintained at a certain consistency and homogeneity before whipping or foaming.

The consistency of the puree determines its whipping or foaming properties. The more fluid the system the easier it can be whipped. On the other hand, Hart et al (1963) and Bates (1964) found that the more viscous or the higher the fiber content present in the puree, the lower the solids content that is necessary for the production of a stable foam. The total solids contents of the onions used were found to fall within 11 ± 0.5 %. A liquid containing this level of solids is generally considered to be too thin for whipping. However, the large amount of pulp present in the system enabled the puree to be foamed successfully. Two levels of corn dextrin were added to the puree in order to bring the solids content from 11% up to 19% and 24% respectively. On visual inspection, the consistency of the puree remained fairly constant after the addition of dextrin.

The color of the onion puree was measured by the Hunterlab Color Difference Meter (see Table 9, section 4.6.3). The puree had a light yellow appearance when freshly blended. On standing, some of the onion juice became separated from the pulp and the yellow color appeared more intense. Pinking or other discoloration was not observed even after 1 hour of maceration.

4.3 Evaluation of foam production

4.3.1 Stabilizers

Two foaming agents or stabilizers were chosen for the foam characterization study. These were, (a) Myverol 18-00, a monoglyceride (GMS), and (b) Admul 1405, a polyglycerol ester. Three levels of stabilizers (1.0%, 1.3%, 1.5%) based on the dry weight of the puree were used in trials where dextrin was added; and a 2% level was used in trials where no dextrin was added.

Both stabilizers had similar procedures of preparation and required stringent temperature control and agitation to attain the smooth and homogeneous dispersions. The two stabilizers were judged according to their foaming properties, foam development times, foam stabilizing properties, and effects on foam quality.

Myverol 18-00 and Admul 1405 were found to have excellent foaming properties when used in low concentrations. Both stabilizers could produce stiff, dry, and low density foams which were suitable for spreading, cratering and drying. By holding the total solids content constant and increasing the foam stabilizer concentrations, foams of progressively lower densities were produced (Figures 4 - 7).

Myverol 18-00 was found to promote faster foam development than Admul 1405 in most trials. In the puree systems (19% T.S., 24% T.S.) where dextrin was added, good quality foams were produced within 6-10 minutes of whipping when the former stabilizer was used. In the puree systems (11% T.S.) containing no corn dextrin, a higher proportion of stabilizer was required to produce foams of good quality. A 2% level of Admul 1405 was found to perform better than the same amount of Myverol 18-00 (Figure 8). It was this finding that prompted the selection of Admul 1405 in the drying studies.

4.3.2 Foam Temperature During Whipping

Hart et al (1963) found that in most cases, less foam stabilizer was required at low temperatures. It was reasoned that purees or concentrates tended to become more viscous at low temperatures and could be foamed more easily. In this study, foaming or whipping was done at ambient room temperature ($21^{o} \pm 1^{o}C$). The temperature of the foaming system could only be varied by varying the

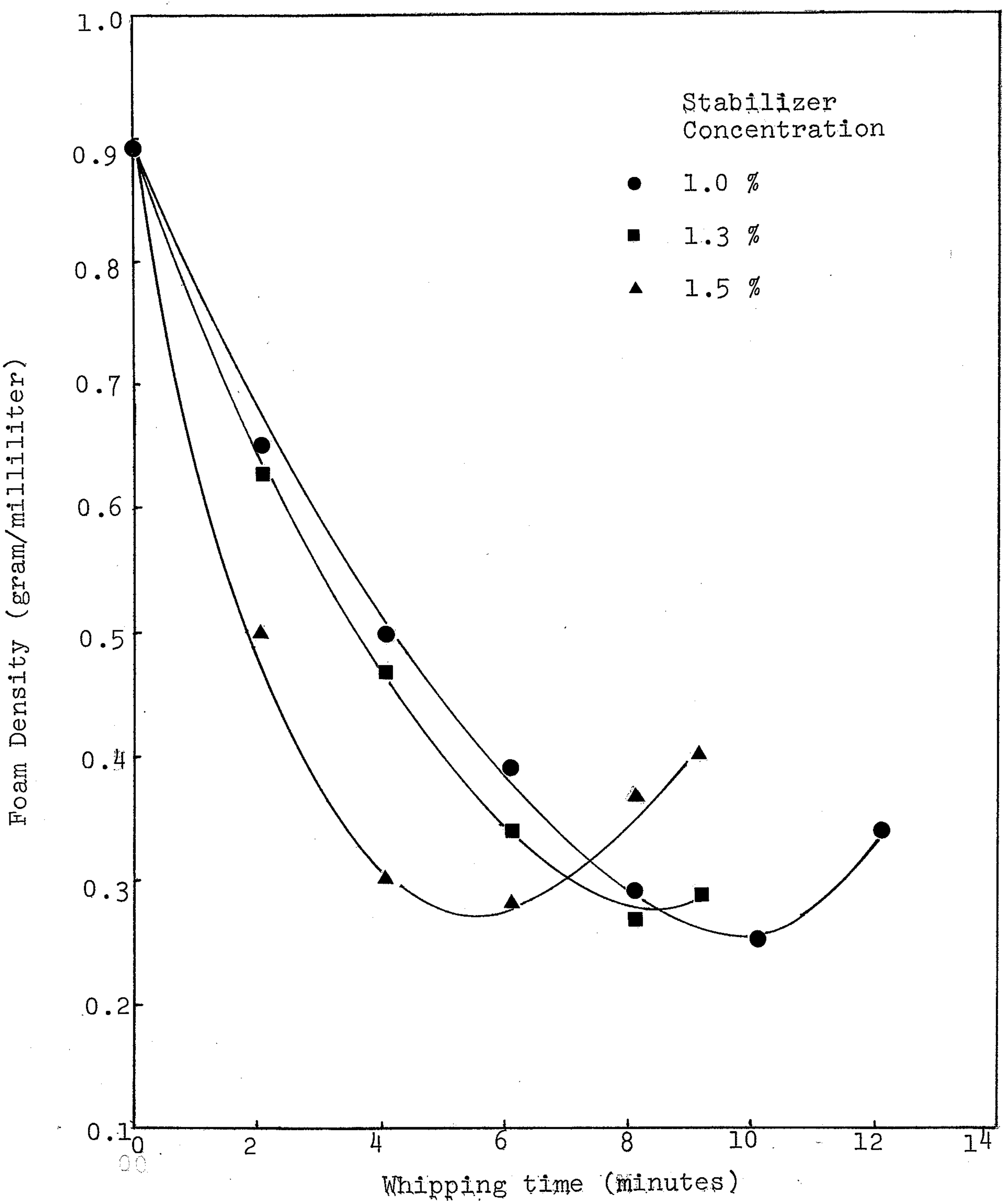

Figure 4. Effect of Stabilizer (Myverol 18-00) Concentration on Foam Formation (19% Total Solids)

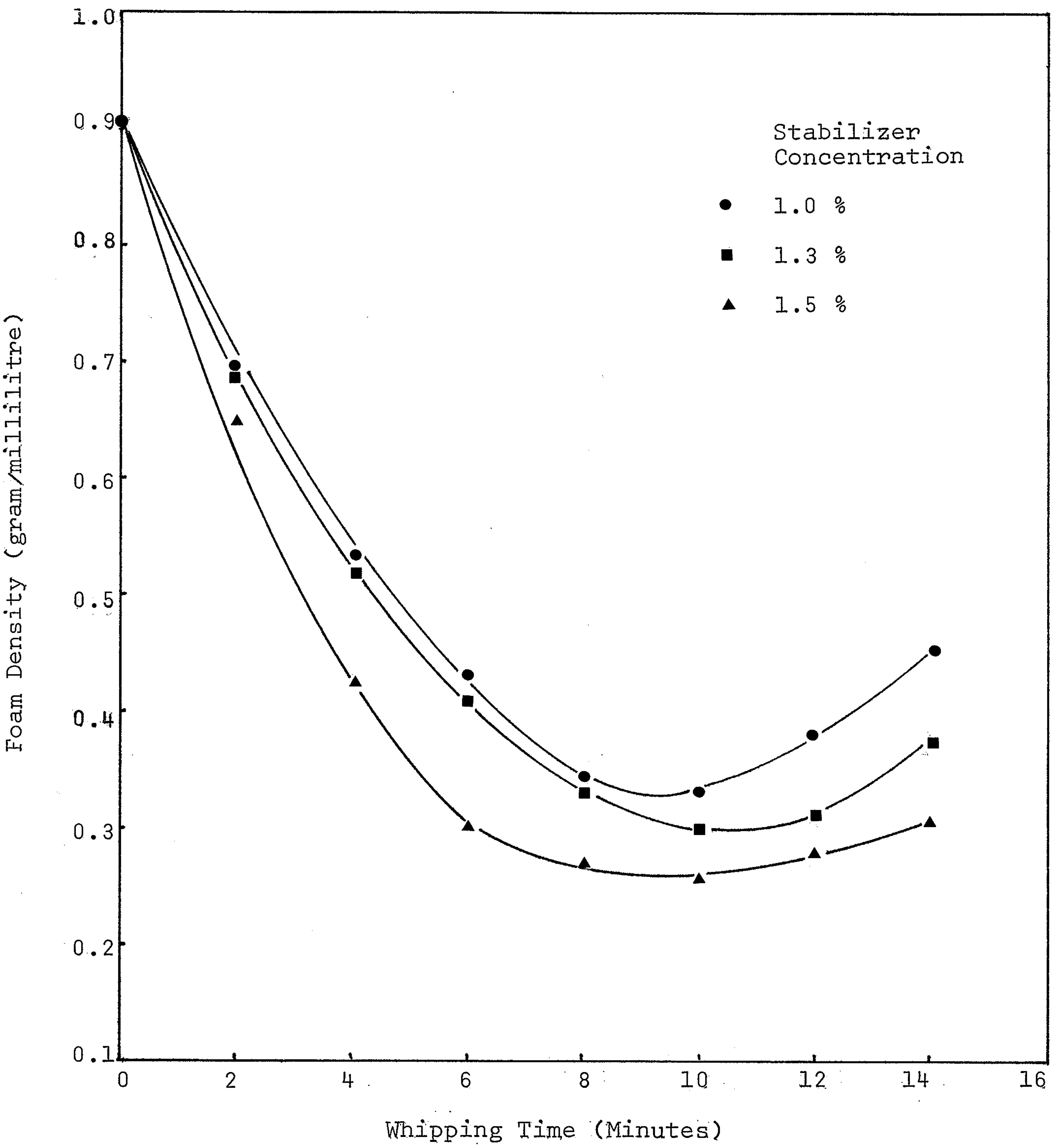

Figure 5. Effect of Stabilizer (Myverol 18-00) Concentration on Foam Formation (24% Total Solids)

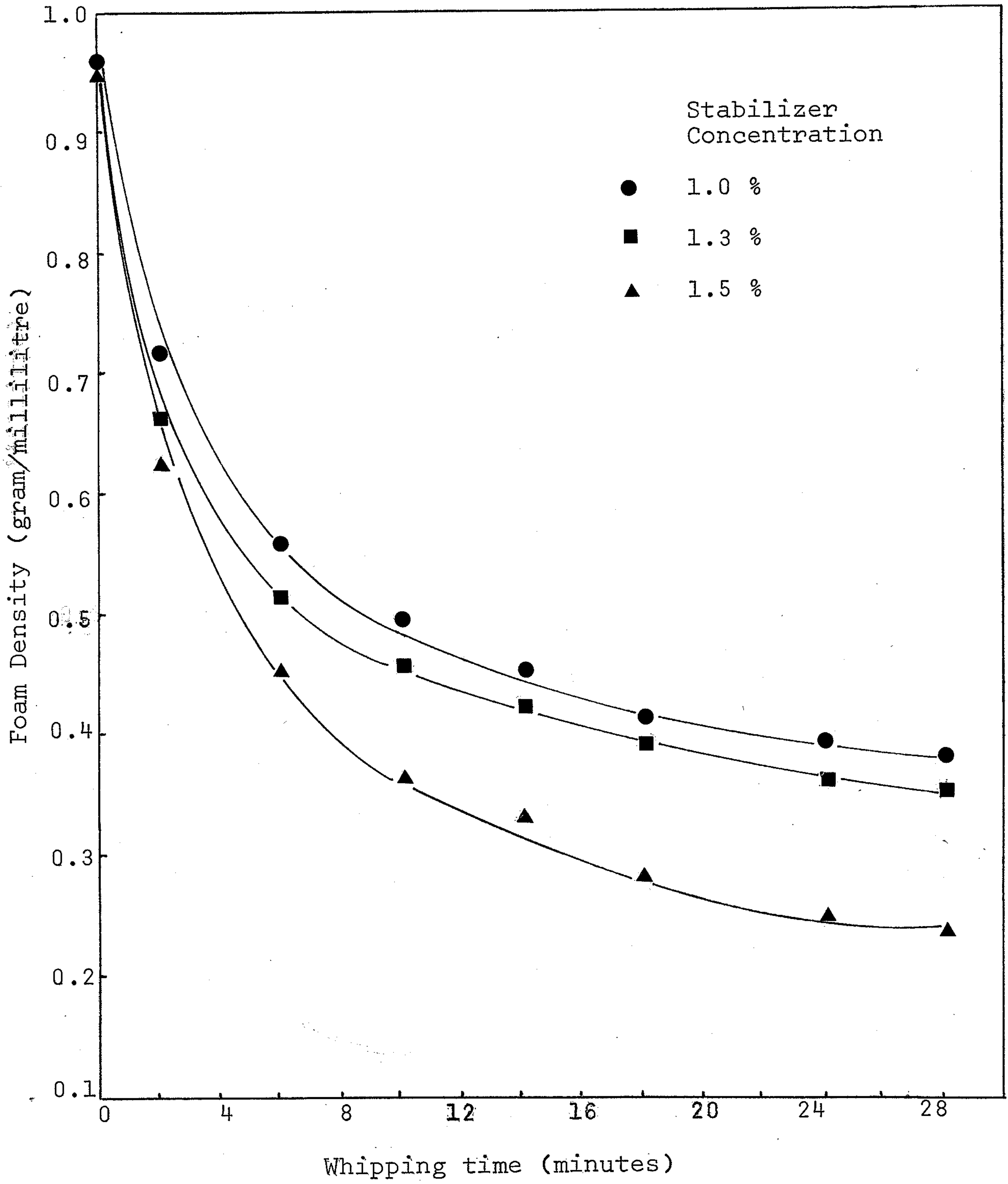

Figure 6. Effect of Stabilizer (Admul 1405) Concentration on Foam Formation (19% Total Solids)

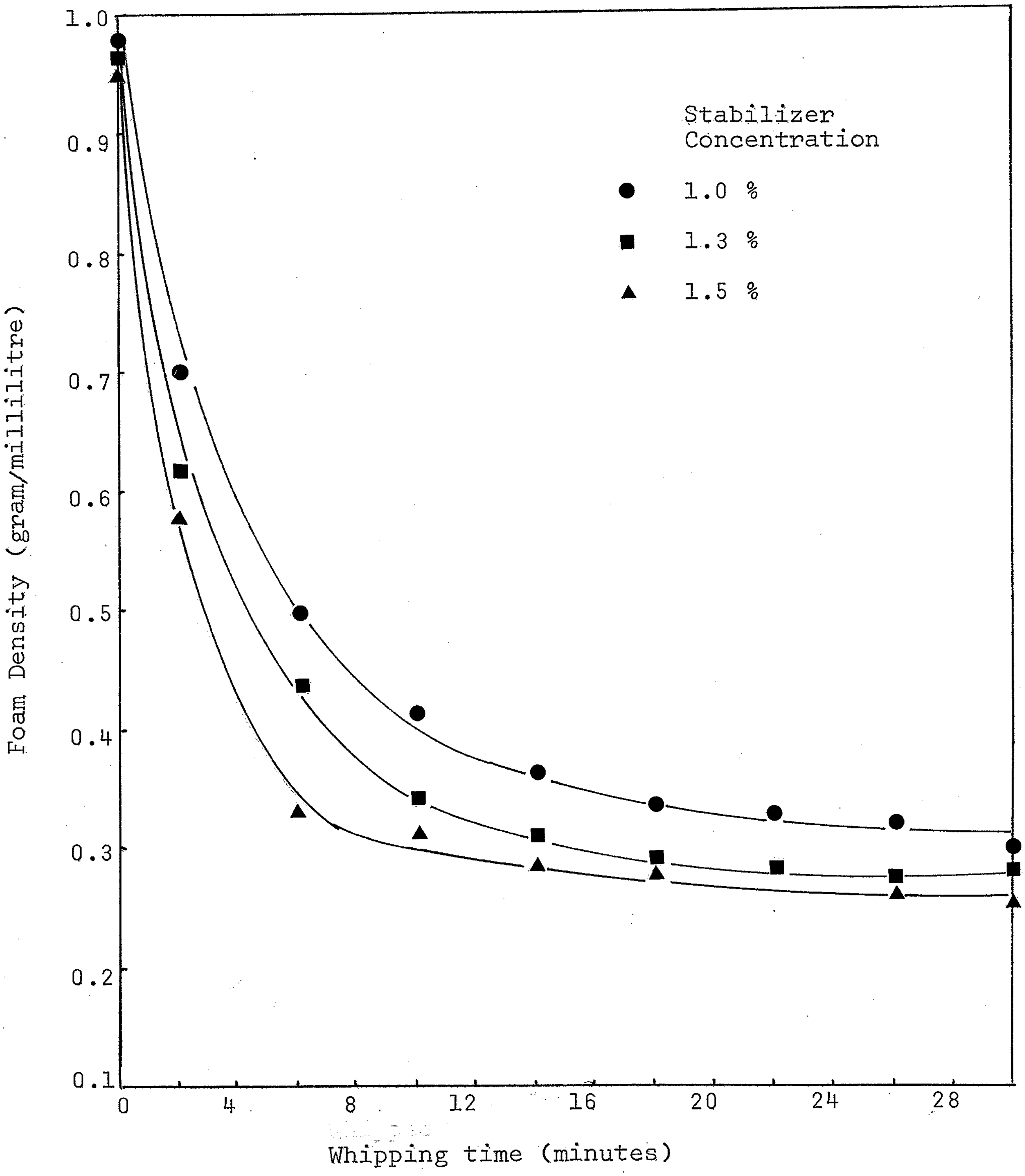

Figure 7. Effect of Stabilizer (Admul 1405) Concentration on Foam Formation (24% Total Solids)

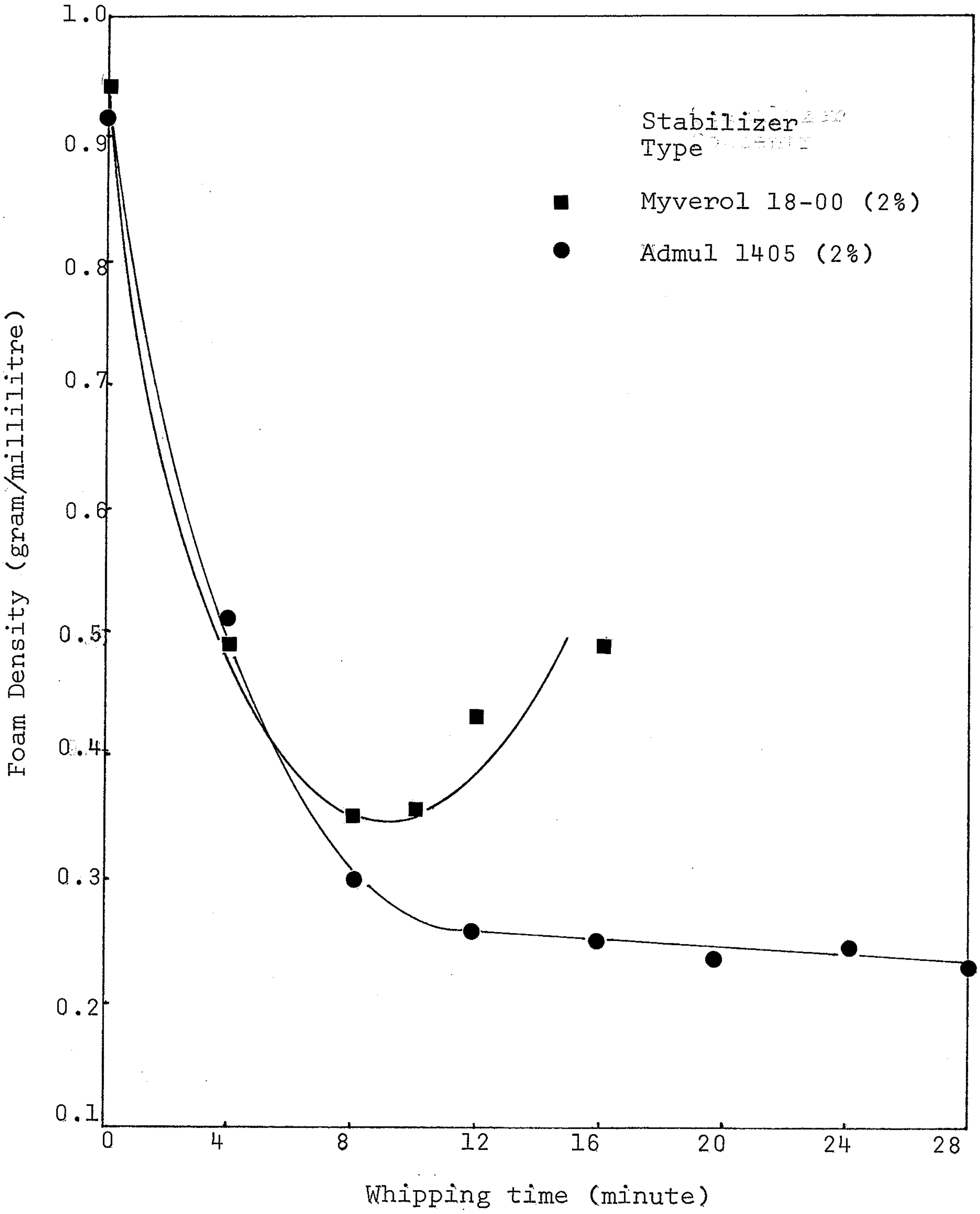

Figure 8. Effect of Stabilizer Type on Foam Formation
(11% Total Solids)

temperature of the starting material. Since onion was considered to be a heat sensitive product, high temperature foaming experiments were ruled out. Experiments were performed by using two sets of foaming temperature. In set 1, onions were removed from cool storage (4.4°C), pureed, and whipped immediately. The foaming temperature increased slowly from 10°C (50°F) just before whipping to 20°C (68°F) at the end of whipping when the foam started to equilibrate with the ambient temperature. In set 2, onions were removed from storage and allowed to equilibrate to room temperature before whipping. It was found that foaming was slightly better at set 1 conditions. Subsequent foaming trials were practised under set 1 conditions.

4.3.3 Whipping Speed

Hart et al (1963) found that foam formation was affected by the amount of agitation or whipping speed. In some instances, excessive whipping speed was noted to produce a coarse foam or prevent foaming altogether. Hart et al recommended a fast whipping speed for products of high viscosity (tomato paste, pumpkin, apricot) and a slow whipping speed for products of low viscosity (orange juice concentrate). The onion puree used in foaming was considered to be fairly high in consistency but low in total solids (11% - 24%). Thus, several whipping speeds were tested in order to establish an optimum one. When onion purees incorporated with different levels of dextrin and stabilizers were whipped at high speeds (#8, and #10 setting on Hobart Kitchen Aid Mixer), foam formation failed to occur. When a #6 setting was used, a small increase in volume was observed. When whipping was done on the #4 setting, foam formation was rapid and consistent over the concentrations of stabilizers used. The speed correlated to the #4 setting was equal to 145 rpm. Foaming did not occur at slower whipping speeds.

4.3.4 Whipping Time

The length of whipping time was found to vary according to the product, stabilizer type,and stabilizer concentration. Low viscosity products such as apple and orange juices required a lengthy residence time to permit the development of the finely - divided stiff foam; whereas prolonged whipping of some foams (e.g. tomato pastes with GMS) could cause them to collapse (Hart et al 1963).

Two different patterns of onion foam development were observed. In the Myverol 18-00 system, foam density decreased rapidly during the initial 6-10 minutes and the foam volume reached a maximum. On prolonged whipping, the foam collapsed just as rapidly as it was formed. Foam density increased although it never reached the original puree density. When the change in foam density was plotted against the whipping time, a parabolic relationship was obtained. This pattern shifted somewhat when dextrin and different proportions of stabilizer were used (Figures 4 & 5) but the shape generally remained the same.

In the Admul 1405 (polyglycerol ester) system, foam development was slightly slower. Foam density decreased rapidly over the first 8-10 minutes and then tapered off when whipping continued. On prolonged whipping, the foam density remained almost constant (in most cases, a slight decrease), and the foam also maintained its maximum volume. The graph of foam density versus whipping time showed some shifts when dextrin and different proportions of stabilizer were used (Figures 6 & 7). The ability of the Admul 1405 stabilizer to maintain foam integrity upon prolonged whipping was another reason that it was chosen for the drying study.

4.4 Characterization of Foams

4.4.1 Foam Density

The foam density at various stages of whipping was measured by filling a short-stem glass cylinder of known volume. The density of the starting mixture (puree with or without dextrin plus stabilizer dispersion) was measured just prior to whipping. As whipping progressed, the starting mixture entrapped more air and became lighter, its density decreased rapidly and its volume increased. At some stage of whipping, the particular foam acquired a minimum density and a maximum volume. Further whipping could only cause the foam to collapse, and hence cause an increase in density.

Foam density was found to depend on the solids content and the amount of air entrapped in the foam. Thus, foams of different solids content but having the same foam density were found to differ in many respects. The most noticeable difference was their fluidity or consistency. This parameter was not measured experimentally.

In this study, a foam was found to be stable when it attained a certain range of foam densities. This range of foam densities was used for characterizing foams of various solids content (Table 5).

TABLE 5: CHARACTERIZATION OF FOAMS BY DENSITY RANGE

TOTAL SOLIDS CONTENT	Range of densities required for foam stability
11 %	0.27 g/ml and lower
19 %	0.30 " "
24 %	0.35 " "

As was discussed in section 4.3.1, the amount of stabilizer used affected the rate of foam formation and the eventual foam density that could be achieved. By characterizing foam stability as described above, the optimum level of stabilizer that would affect foam formation and stability could be determined.

4.4.2 Foam Volume

The onset of foam formation was observed through an increase in foam volume. A rough estimate of foam volume was done by reading the unit volume graduations on the mixing bowl. The rate of change of volume resembled that of foam density, with the trend reversed. In general, the maximum foam volume was attained after 6-10 minutes in the Myverol system; and 8-10 minutes in the Admul system. Since foam volume could not be measured with accuracy, it was used solely as a visual aid in judging foam stability.

4.4.3 Oven Stability

In the foam-mat drying process, it is important for the foam to maintain as much as possible its original honeycombed structure during drying. Foams that collapsed during drying are deemed undesirable due to the longer drying times incurred.

Foams of various densities and solids contents were tested for oven stability (section 3.5.3). This method was qualitative and not quantitative in nature, since the rate and extent of foam collapse were difficult to assess. It was found that foams that were characterized as stable after whipping displayed good overall oven stability. Foams of lower solids content generally showed slightly more shrinkage than those of higher solids content. This was due mainly to the amount of moisture released. Foams that were under— or overwhipped showed the greatest amount of collapse. On heating, these foams tended to revert back to the original puree structure. In addition, pinking and heat damage developed rapidly. The type and concentration of stabilizer did not seem to have an appreciable effect on the oven stability of foams.

4.4.4 Foam Quality

A foam was described as having good foam quality when it displayed a combination of stiffness, smoothness, dryness, and stability. All the foams that were previously characterized to be stable showed good foam quality. Due to the inclusion of the pulp fraction, the foams produced were not as smooth as whipped cream. The coarser texture, however, did not affect the overall foam quality.

The foams containing higher solids (more dextrin) appeared more dry and rigid than those containing less solids. Similarly, low density foams were rated better quality wise than high density foams. The foams that were too light or too fluid had poor cratering and spreading properties. A light foam was easily blown off the tray during cratering; and a foam that was too fluid tended to drip through the holes in the tray during spreading. The author failed to notice any distinct quality differences among foams produced by the two stabilizers. Ward (1976), however, described the foams produced by the polyglycerol ester as less "cohesive", less dry, and less "brittle" than foams produced by the monoglyceride stabilizer system.

4.5 Evaluation of Drying Methods

Foams made from onion purees were dried by two different methods of dehydration: (a) hot-air convection method; (b) microwave heating method. The aim of the drying study was to identify the drying characteristics of the onion foam system. Basically, a time-temperature study by monitoring the sample weight loss was performed. Other variables that affected drying rates such as sample thickness, density, solids content were also studied.

4.5.1 Hot-air Convection Method

A preliminary drying study was done using a Blue M constant temperature convection laboratory bench oven. Ward (1976) reported the use of such an oven in his study on foam-mat drying of tropical root crops. Both cratered and non-cratered onion foams of 2 thicknesses (3.2 mm & 6.4 mm) were dried at various temperatures. The drying rates of these foams were found to be slow and pinking was significant. It was speculated that the air flow rate circulated through the oven was not enough for efficient drying to be accomplished. Subsequently, a decision was made to use an Aeromatic Fluidized-Bed dryer for further study.

Although a batch-type fluidized-bed dryer was not conventionally used for foam-mat drying, it nonetheless offered several features such as variable temperature control, through circulation, and variable air velocity control. In addition, the perforated bottom of the dryer was an excellent device for foam cratering. The air velocity was adjusted to 2.90 m/sec (570 ft/min) so that foam splattering was avoided during cratering and the subsequent drying. The air flow rate as measured by a

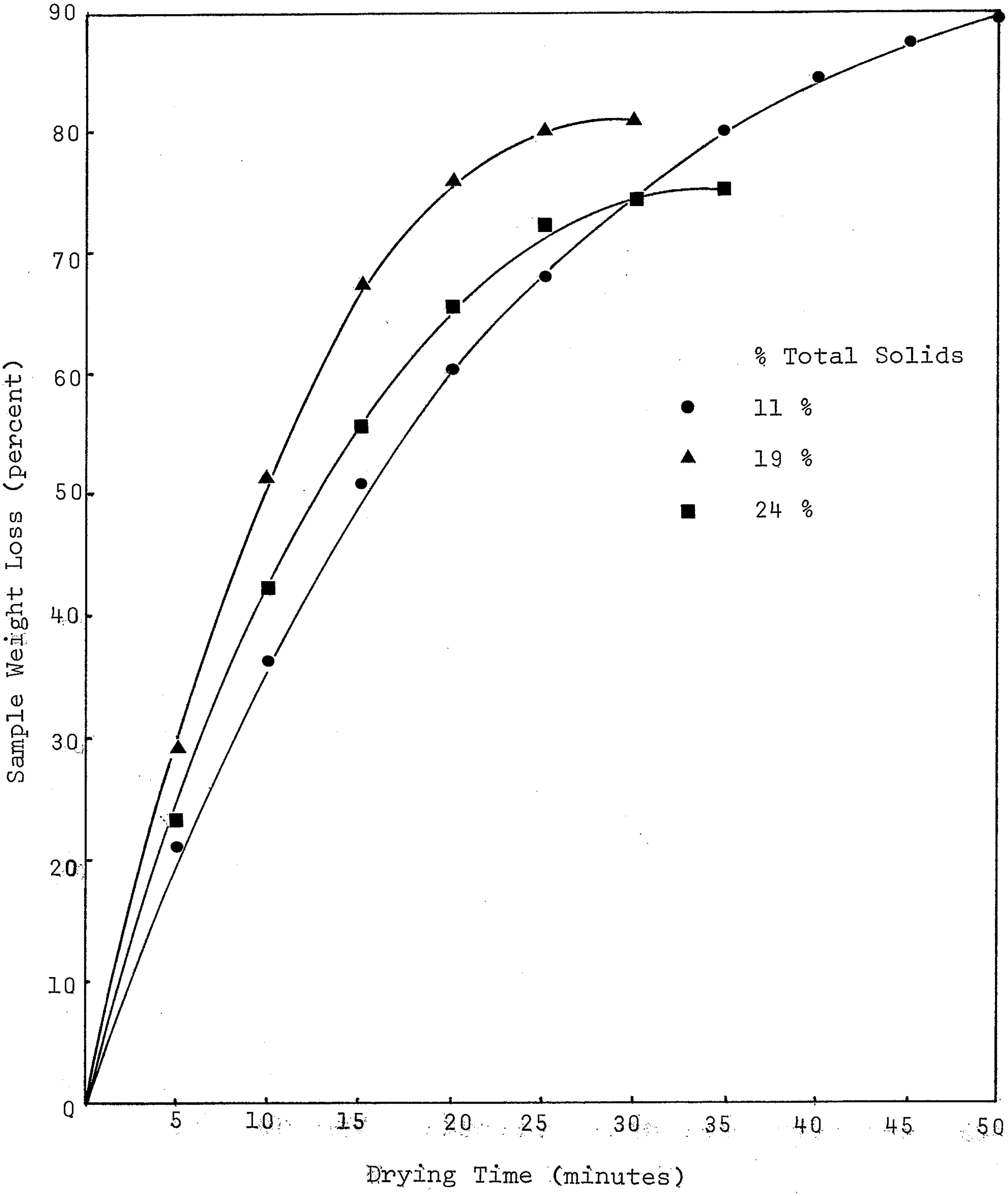

Figure 9. The Rate of Sample Weight Loss During Dehydration (Drying Temperature = 60°C)

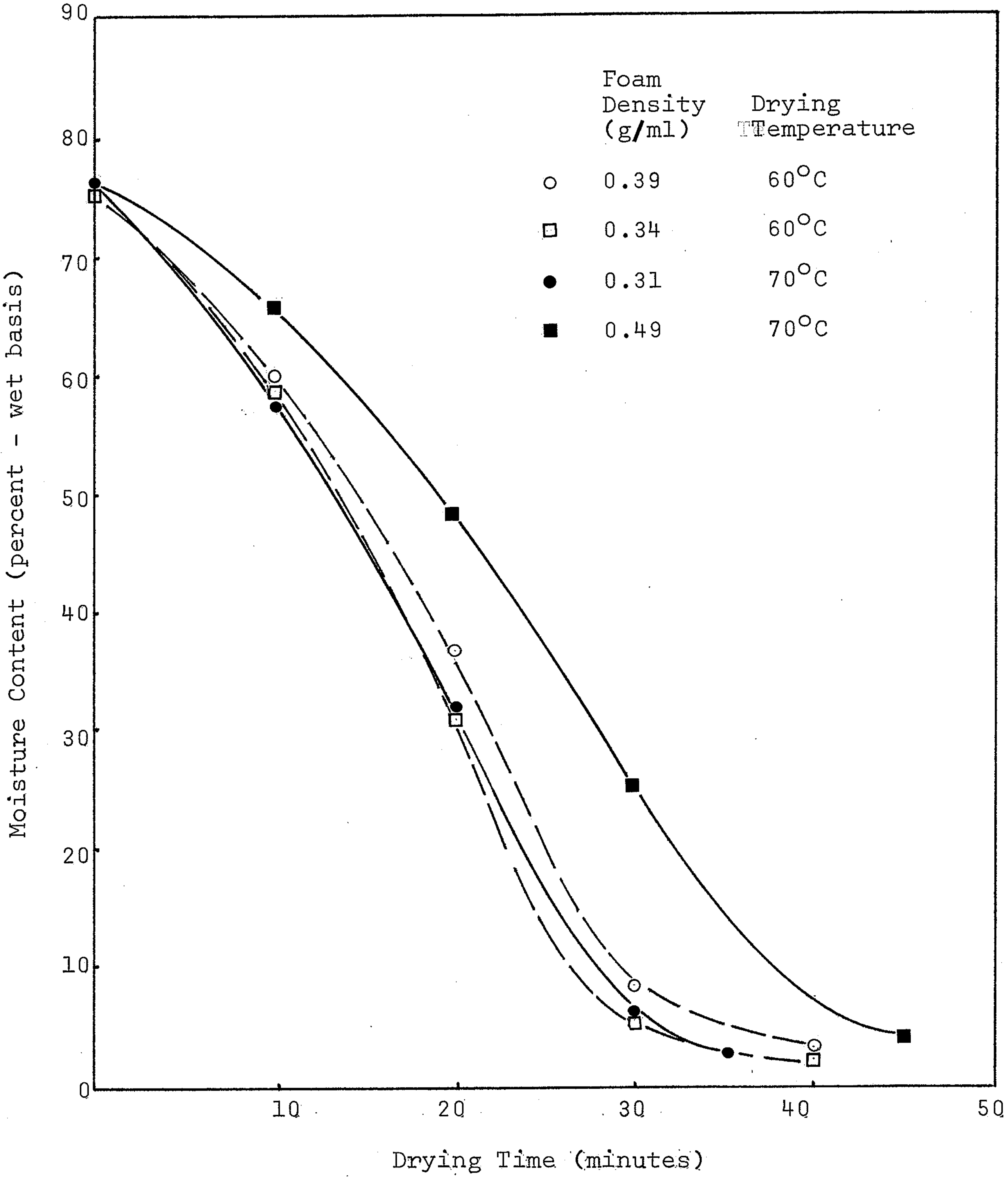

Figure 10. Drying Curves For Onion Foams (24% Total Solids, 6.4 mm Thickness)

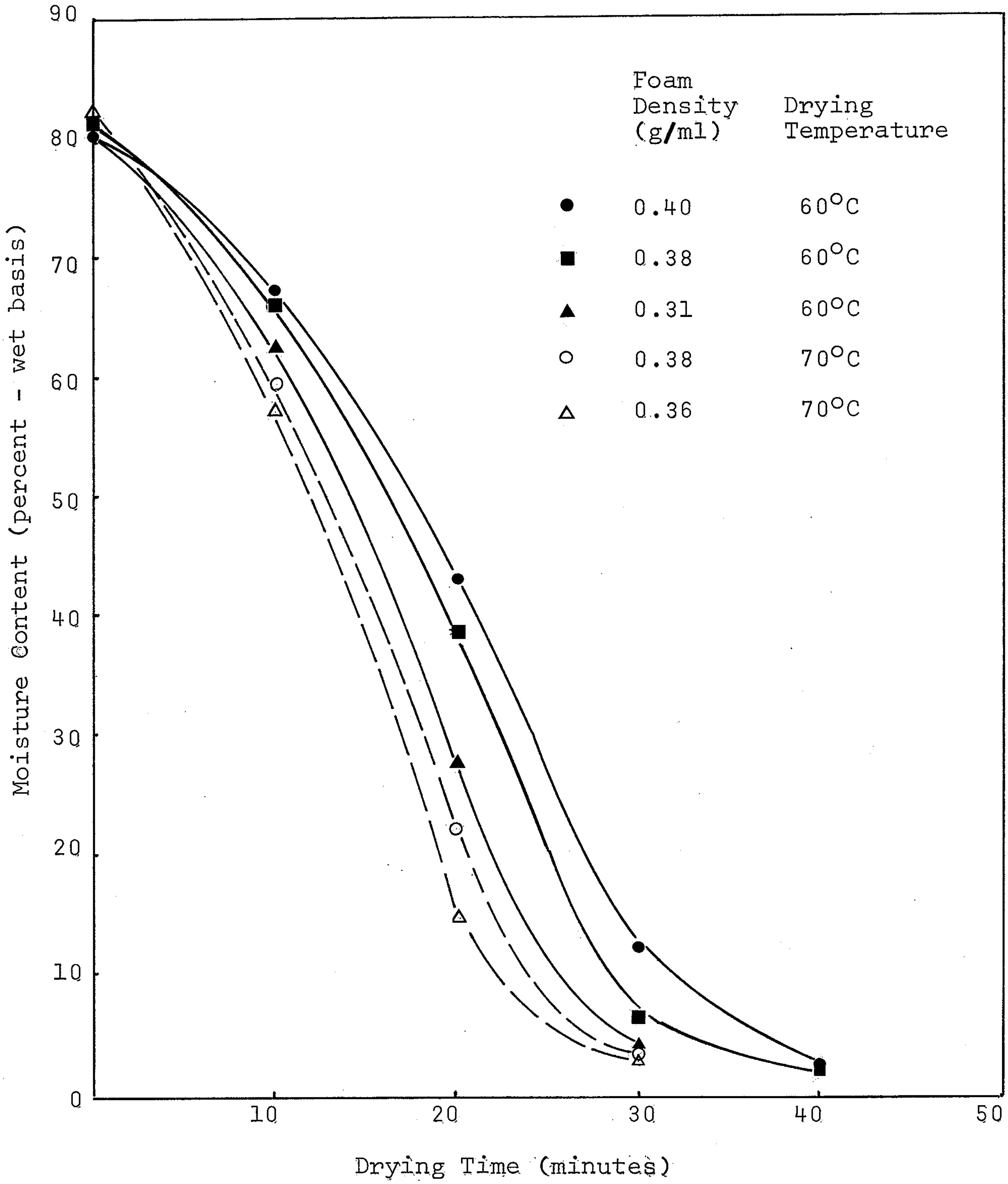

Figure 11. Drying Curves for Onion Foams (19% Total Solids, 6.4 mm Thickness)

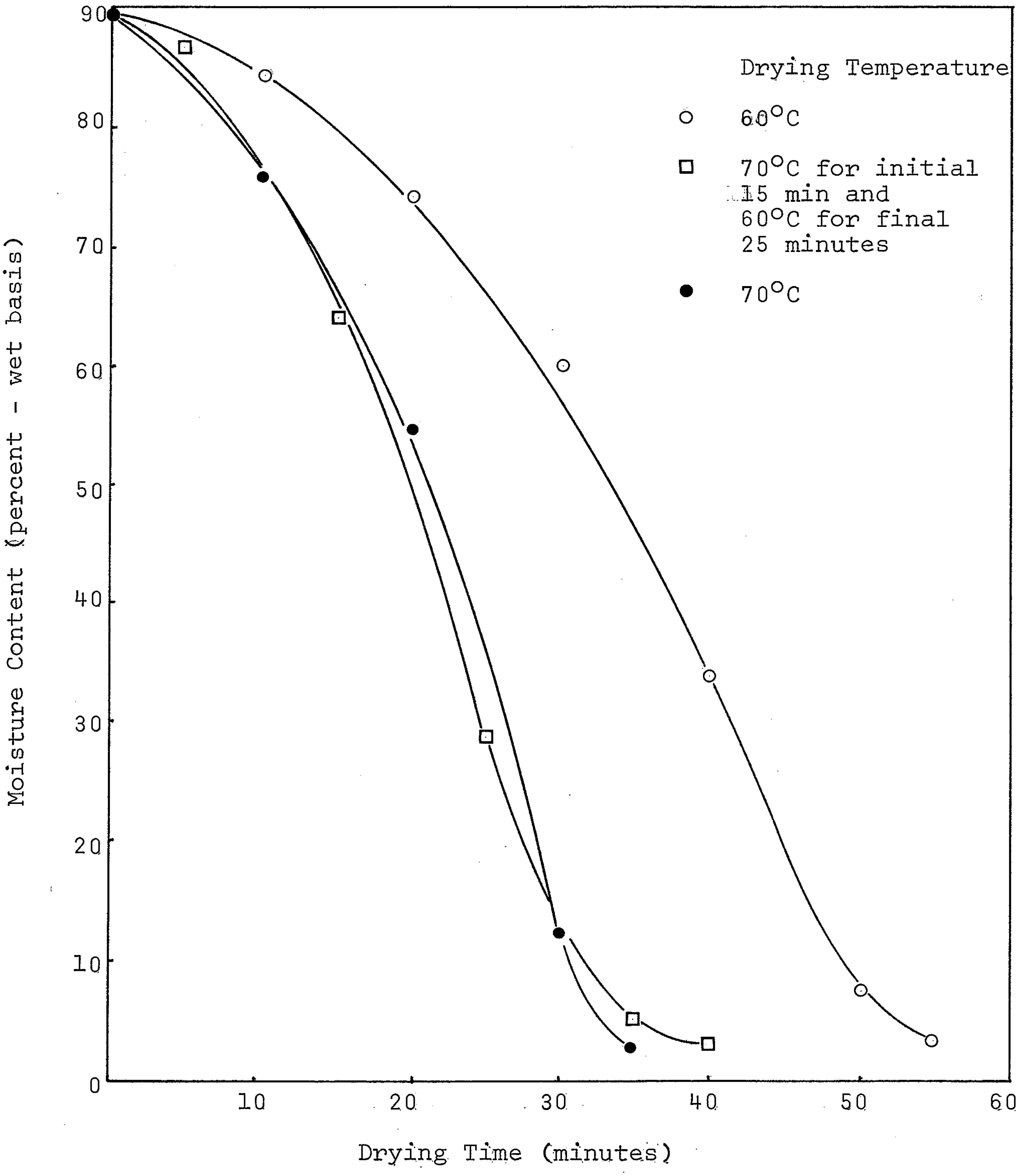

Figure 12. Drying Curves for Onion Foams (11% Total Solids, 6.4 mm Thickness)

Thermo-Anemometer was 9.4×10^{-2} m^3/sec or 138 cfm. The foam area exposed to drying was kept constant wherever possible. The weight of foam on each tray varied according to the thickness of foam, solids content, and foam density.

The foams made from onions had to be dried rapidly at low temperatures to prevent pinking. It was found that the temperature range of 60°C to 70°C was appropriate for dehydration. The drying rates of onion foams were obtained by monitoring the change in sample weight at 5 minutes intervals. Drying was terminated when the sample weight remained constant. A plot of percent weight loss versus time shows that the rate of moisture loss was non-linear. Figure 9 shows that the weight loss was most rapid at the beginning of the drying period and then tapered off towards the end. Figures 10 to 12 illustrate the drying curves of foams of various solids contents and densities at 60°C and 70°C. Foam density is known to affect the heat and mass transfer characteristics of foams. Thus, the increased drying rates observed among lighter foams may be attributed to the larger surface areas and faster moisture diffusion rates offered by the low density foams. The foam density could be controlled by whipping the puree of the same solids content with different levels of stabilizers. This was important in determining the optimum drying rate and throughput during large-scale or commercial production.

Another factor that affected drying rates was the amount of solids present in the foam system. Foams containing dextrin were observed to have faster drying rates than foams without dextrin. Dextrin was used primarily as a bulking agent in order to improve the whipping property. Its use appeared to facilitate faster drying as well. One possible explanation is that foams containing dextrin had better oven stability, i.e. they maintained a more rigid structure and had less tendency to collapse during drying. Consequently, the mass transfer rate was improved and faster drying resulted. However, when too much dextrin was added, the drying rates were found to decrease slightly. This may be due to the water-binding property exhibited by dextrin that hindered the release of free moisture.

When the rate of heat transfer to the foams was increased by increasing the drying temperature from 60°C to 70°C, the drying times were shortened. A further increase in drying temperature proved to be deleterious to the final products, causing such side effects as pinking, scorching, and an absence of flavor. The drying temperature also affected the equilibrium moisture content of the product, although this was not significant in the temperature range employed (60°C - 70°C). Perhaps the drying rates were affected most dramatically by the foam thickness. Figure 13 illustrates the marked difference in drying rates exhibited by the 3.2 mm and 6.4 mm thick foams. The increase in foam thickness lengthens the center-to-surface distance that the moisture must now travel. Since foam drying is generally described as a mass transfer limiting process, the drying rate is not expected to vary linearly as the foam thickness. Komanowsky et al (1964) reported that the drying time between two given moisture contents varied as the square of the slab thickness. The same authors also reported that the drying curves showed no detectable constant rate period. This claim was contrasted by Chandak and Chivate (1972) who reported the presence of multiple constant rate periods which might be due to periodic bursting of successive layers of foam bubbles, thus exposing new surfaces for heat and mass transfer as drying progressed. No attempt was made in this study to demonstrate the occurrence of the various drying periods. It would appear that the falling rate period was dominant in hot air drying.

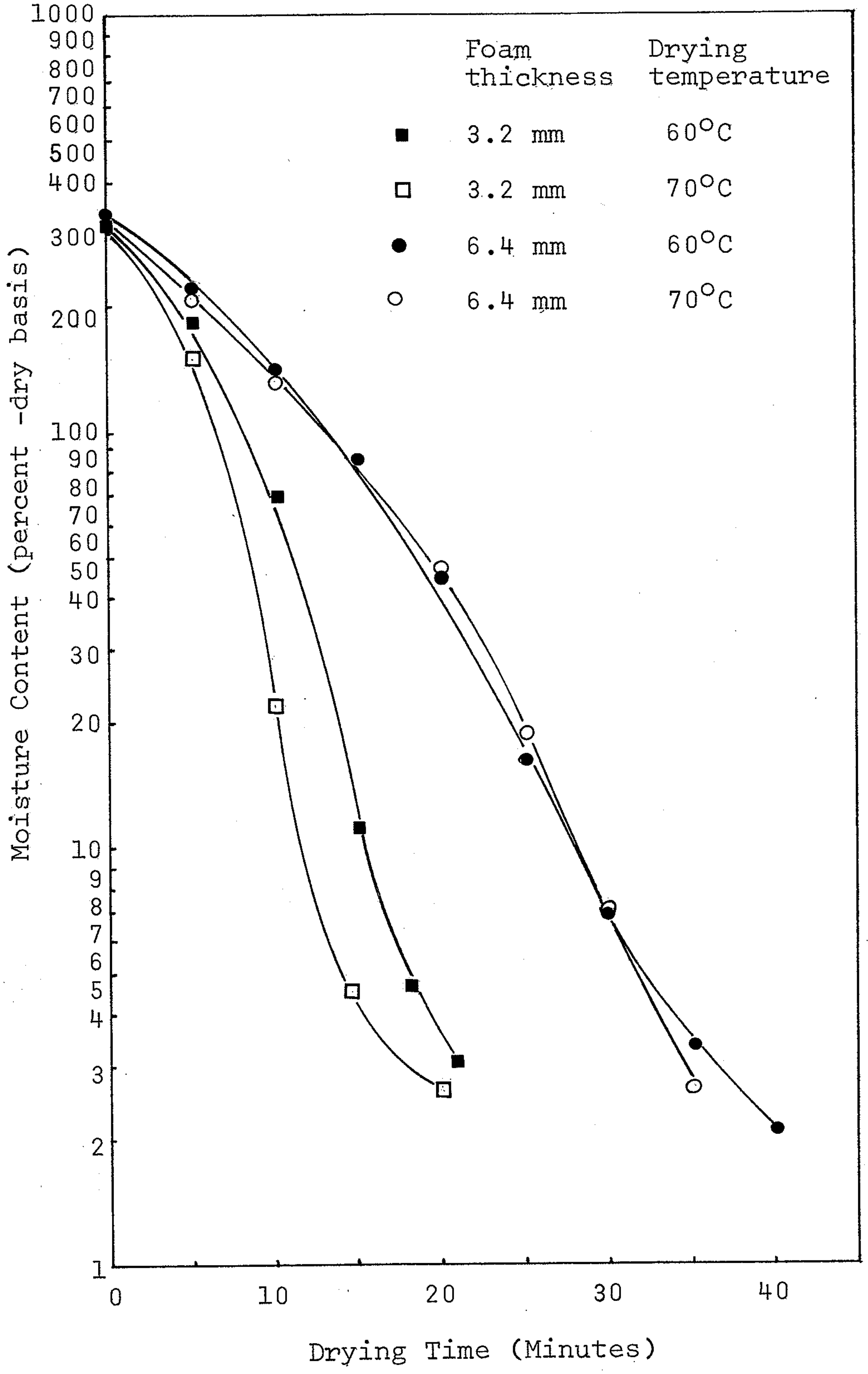

Figure 13. Effect of Foam Thickness on Drying Rates of Foams (24% Total Solids)

The time required to dry onion foams depended on the densities of these foams (Table 6).

TABLE 6: RANGE OF DRYING TIMES FOR HOT AIR DRIED SAMPLES

	Drying Time (minutes) At			
Total Solids	60°C		70°C	
	1/4"	1/8"	1/4"	1/8"
11 %	50-60	20-25	30-35	15-20
19 %	30-40	15-20	25-30	15-20
24 %	35-40	20-25	35-45	15-20

4.5.2 Microwave Drying Method

Rzepecka et al (1975) studied the foam-mat dehydration of tomato paste using microwave energy. Their findings demonstrated the advantages of microwave dehydration primarily in improving the drying rates. In this project, the drying rates of onion foams (11% T.S.) of two thicknesses (6.4 mm and 12.7 mm) were investigated. A preliminary test showed that the forward power levels

(150 kW - 350 kW) used by <u>Rzepecka et al</u> were too low for effective drying. This was due to the heavier samples that were used in this study (150 g - 350 g versus 112 g[*] maximum). The forward power levels of 1.0 kW and 1.5 kW were found to be more appr~~e~~opriate. In order to demonstrate the effect of microwave heating, the microwave cavity (drying chamber) was kept at ambient temperature and relative humidity (20°C, 50% R.H. or an absolute humidity = 53 grains water/lb dry air). An air flow of 8.6×10^{-2} m^3/sec or 175 cfm was circulated through the cavity to remove surface moisture. Two other precautions were also taken in the microwave drying system; (1) the foams were not cratered in order to emphasize the sole effect of microwave heating; (2) only foams that contained no dextrin (i.e. 11% T.S.) were used. This was necessary to prevent any possible gelatinization from taking place as a result of the high temperature incurred by microwave heating.

The foams were dried according to the following scheme:

Foam Thickness	Forward Power Levels	
12.7 mm (1 sheet)	1.0 kW	1.5 kW
6.4 mm (2 sheets)	1.0 kW	1.5 kW
6.4 mm (1 sheet)	1.0 kW	—

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[*] This figure was calculated based on the size of the tray, the maximum thickness of the foam used, and the foam density reported.

The purpose of using 2 sheets of 6.4 mm foam was to keep an equivalent amount of sample as 1 sheet of 12.7 mm foam in the drying chamber. The sheet(s) of foam was(were) placed at the geometric center of the microwave cavity to receive even heating. Several temperature sensitive labels (Tempilabels) were placed on the central parts and edges of the foam surface to record temperature changes. The more commonly used and precise temperature measuring devices such as thermocouples were unsuitable because they might be interfered with in the presence of an electric field. An approximate rate of temperature change of the foams (12.7 mm) during drying is shown in Figure 14. This graph illustrates the instantaneous heat generation property possessed by microwaves as the surface temperature was recorded to have jumped from 20°C to over 70°C during the first 2 minutes. The product temperature continued to climb slowly until a maximum was reached. This "inside-out" temperature gradient also exerted a pumping action to increase mass transfer. As the product became drier, the amount of microwave energy absorbed by the product became proportionately less. This was evident when the total reflected power increased rapidly while the forward power was kept constant. Figure 15 shows the change in total reflected power during drying. This decrease in microwave

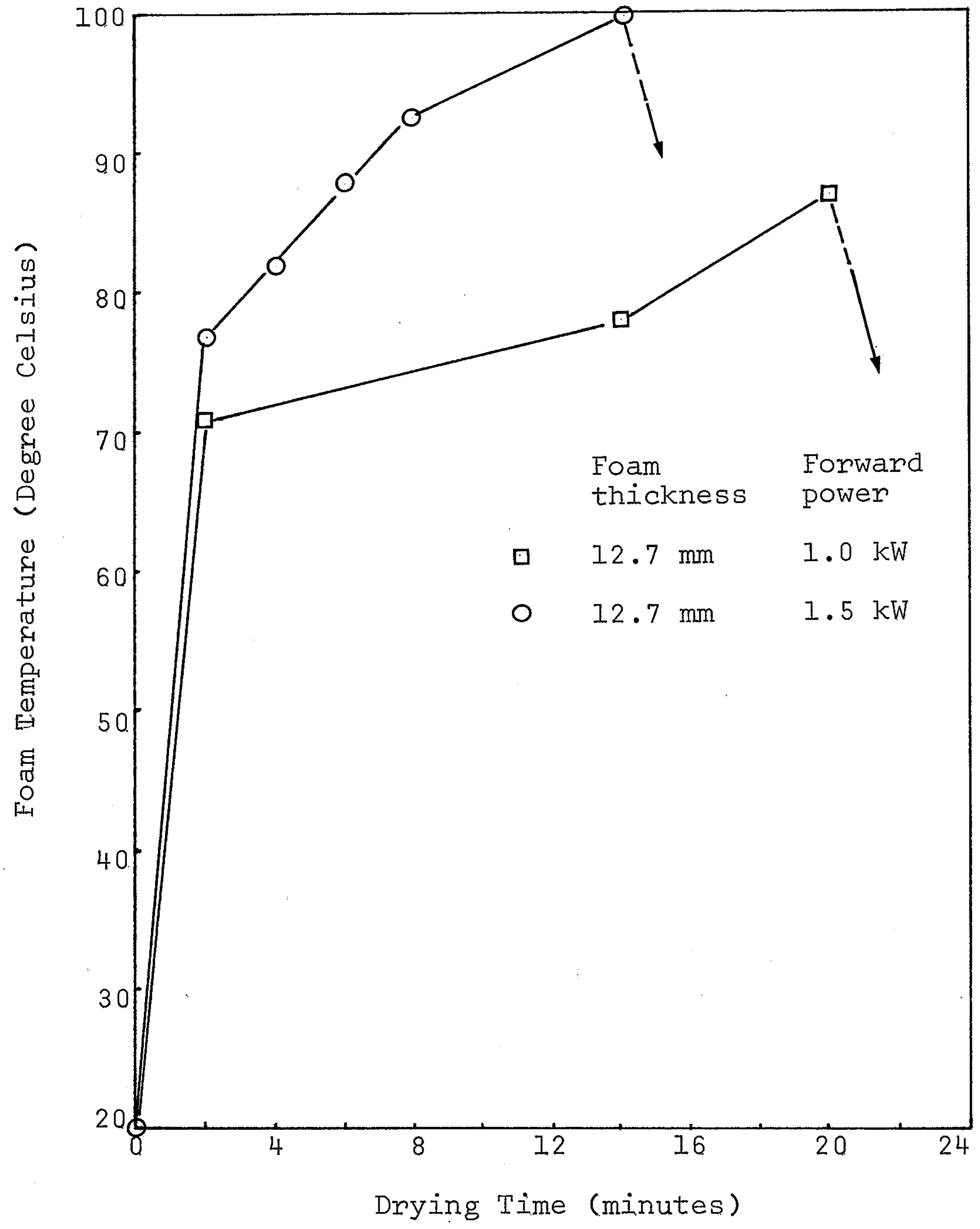

Figure 14. The Rate of Change in Foam Temperature During Microwave Dehydration (11% Total Solids)

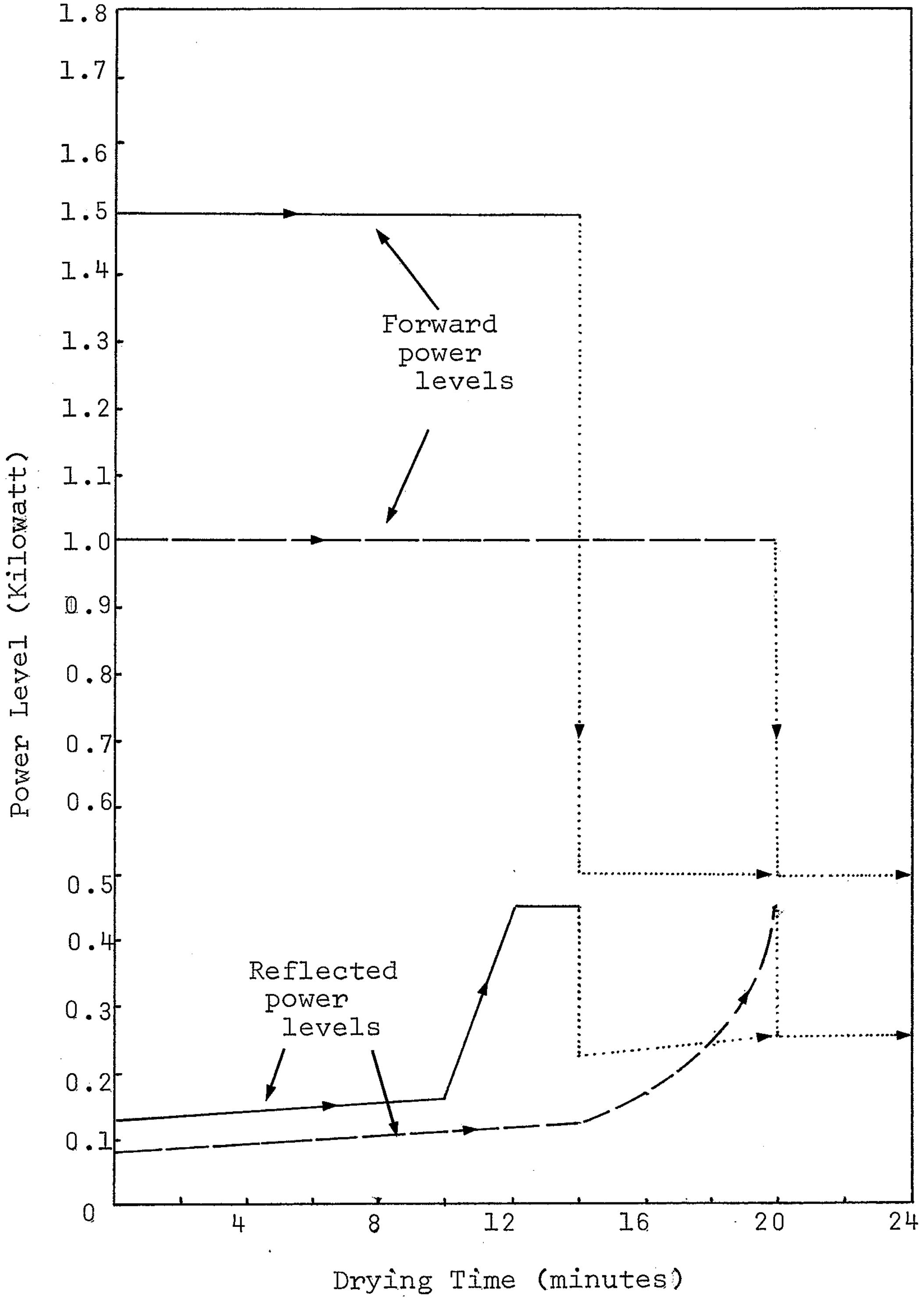

Figure 15. The Change in Total Reflected Power as Monitored During Dehydration

energy absorption by the sample at the late stages of drying also caused the sample temperature to drop. This was in sharp contrast to conventional heating where the product could only attain the dry-bulb temperature of the drying air slowly.

Figure 16 shows the drying rates of foams of two thicknesses (6.4 mm, 12.7 mm). Since microwave heating practically eliminated the heat transfer problem inherent in foam drying, the discrepancy in the drying rates demonstrated that foam drying was largely a mass transfer limiting process. Figure 16 also shows that the drying rates could be increased by raising the forward power levels. This increase in power was accompanied by further rise in product temperature which provided the driving force in aiding the moisture to escape. The use of higher power levels was restricted by the product's tolerance to high temperatures. At 1.5 kW, the product temperature was observed to have reached 100°C, causing the foam to boil.

As mentioned previously, the amount of microwave energy absorbed by the sample was related to the amount of moisture present. This was due mainly to the selective energy absorption by the polar (water) molecules.

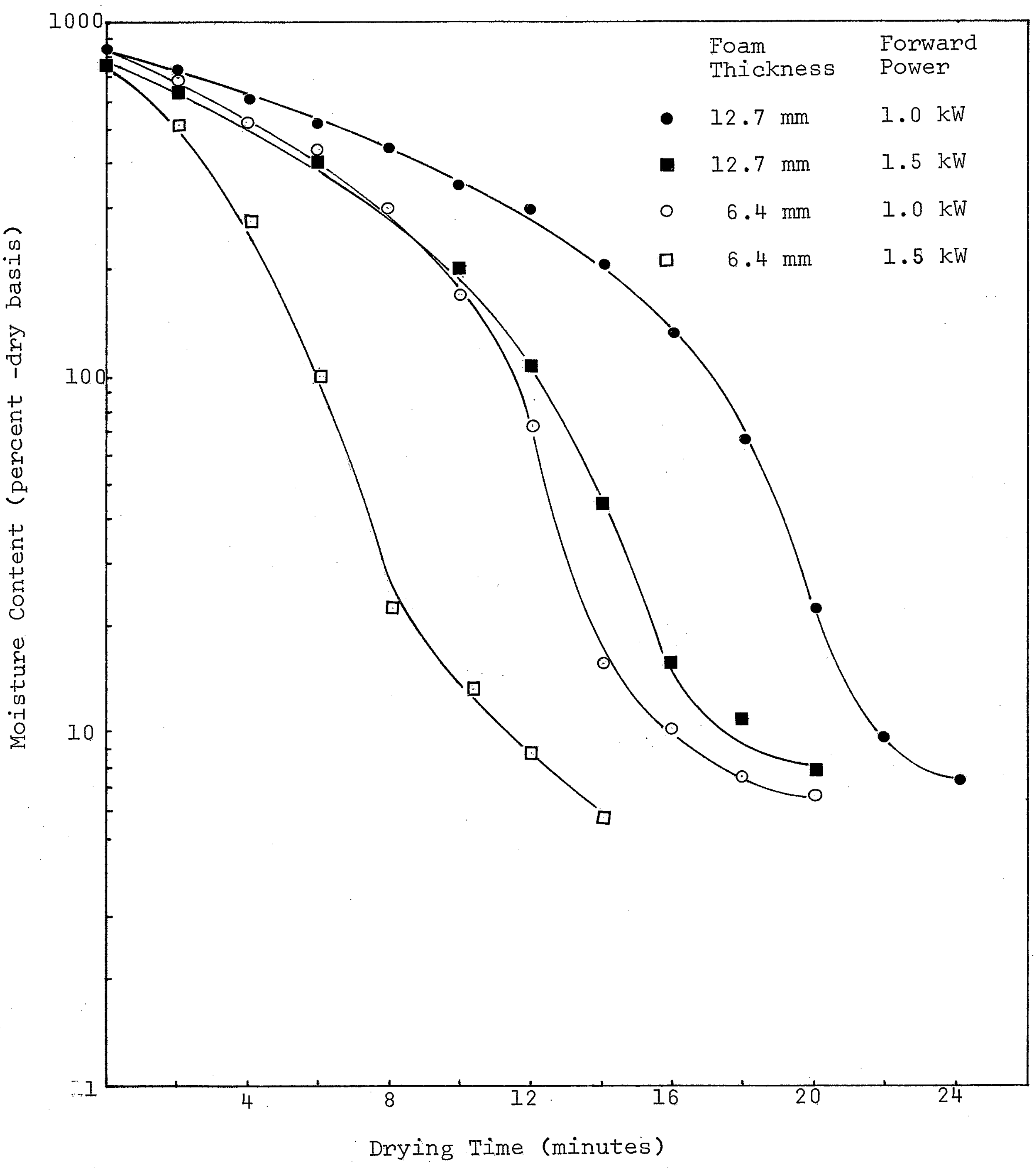

Figure 16. Effects of Foam Thickness and Forward Power on the Drying Rates of Onion Foams (11% Total Solids)

Theoretically, the power dissipated in the sample is equal to the difference between the forward power and the reflected power. The total energy dissipated in the sample is numerically equal to the power dissipated multiplied by the total drying time. Table 7 shows the total microwave energy dissipated in the foam samples, and the total energy required to remove one gram of water from each different sample. The computation of the latter data are illustrated in Appendix 3. The amount of energy dissipated was proportional to the sample weight, the forward power, and the total drying time. As the drying time was lengthened, the energy dissipated increased proportionately. Theoretically, the energy dissipated per gram of water removed should be constant for each sample. The discrepancy in values when different foam thicknesses were compared could be due to the heat loss to the surroundings and the mass transfer problem. A thinner foam showed less mass transfer restrictions but more heat loss because of its larger surface area. A thicker foam conserved more heat yet it imposed a greater mass transfer problem.

Table 8 shows the efficiency of drying of some of the samples at different sample loads, thicknesses, and forward power levels. The drying efficiency is concerned

TABLE 7: COMPARISON OF THE TOTAL MICROWAVE ENERGY DISSIPATED IN THE SAMPLE FOR DIFFERENT FOAM THICKNESSES AND FORWARD POWER LEVELS

Foam Thickness (mm)	Power Forward (kW)	Average Sample Weight (gram)	Weight of water Removed (gram)	Average* Drying Time (min)	Temperature Attained (°C)	Energy Dissipated (kW min)	Energy Dissipated per gram of water Removed (W min/g)
6.4	1.0	129.2	105.3	16	82	9.30	88.3
6.4	1.0	148.2	120.8	16	82	9.50	78.6
6.4	1.0	172.9	141.2	20	82	10.36	73.3
6.4	1.0	238.9	194.0	22	77	15.04	77.5
6.4	1.0	268.8	217.5	24	77	16.60	76.3
12.7	1.0	338.4	273.1	26	82	18.50	67.7
12.7	1.0	345.6	280.3	26	82	19.52	69.6
12.7	1.0	364.3	297.7	26	82	20.98	70.5
6.4	1.5	203.6	165.3	14	88	11.48	69.4
12.7	1.5	338.6	276.1	22	100	20.44	74.1

* Time required to dry the sample to 7.5% moisture.

TABLE 8: COMPARISON OF THE DRYING EFFICIENCY AT DIFFERENT SAMPLE LOADS, THICKNESSES, AND FORWARD POWER LEVELS.

Foam Thickness (mm)	Forward Power (kW)	Average Sample Weight (gram)	Drying Time (min)	Energy Dissipated (Experimental) (kW min)	Energy* (Theoretical) Required to Remove the Same Amount of Water (kW min)	Drying** Efficiency (%)
6.4	1.0	129.2	16	9.30	4.45	47.8
6.4	1.0	172.9	20	10.36	5.98	57.7
6.4	1.0	268.8	24	16.60	9.16	55.2
12.7	1.0	338.4	26	18.50	11.58	62.6
12.7	1.0	364.3	26	20.98	12.62	60.2
6.4	1.5	203.6	14	11.48	7.08	61.6
12.7	1.5	338.8	22	20.44	12.09	59.1

* See Appendix 5.

** $$\text{Efficiency} = \frac{\text{Energy (Theoretical)}}{\text{Energy (Experimental)}} \times 100\%$$

only with the energy utilized in moisture removal and does not account for the processing criteria of the product, such as color and aroma retention. The choice of processing conditions, therefore, must take into consideration the overall compatibility between the product and the process.

A comparison of the drying rates of foams (6.4 mm, 11% T.S.) as dried by the hot air convection method, and the microwave method is shown in Figure 17. In the hot air system, the drying times were in the range of 35-55 minutes. In the microwave system, the foams of the same thickness had drying times of 12-20 minutes. The reduction in drying time was attributed to the ability of the microwave system to overcome the heat transfer problem by generating the heat energy within the foam. In either system of drying studied, the drying rate of foams was controlled to some extent by the intangible mass transfer rate. This problem could be alleviated somewhat by using thinner foams, or other techniques such as cratering. Perhaps the most significant advantage of the microwave foam-mat drying system over that of the hot-air foam-mat drying system was the faster drying rate combined with higher product throughput. There exist other possibilities in the study of foam-mat drying, such as a combined microwaves and hot-

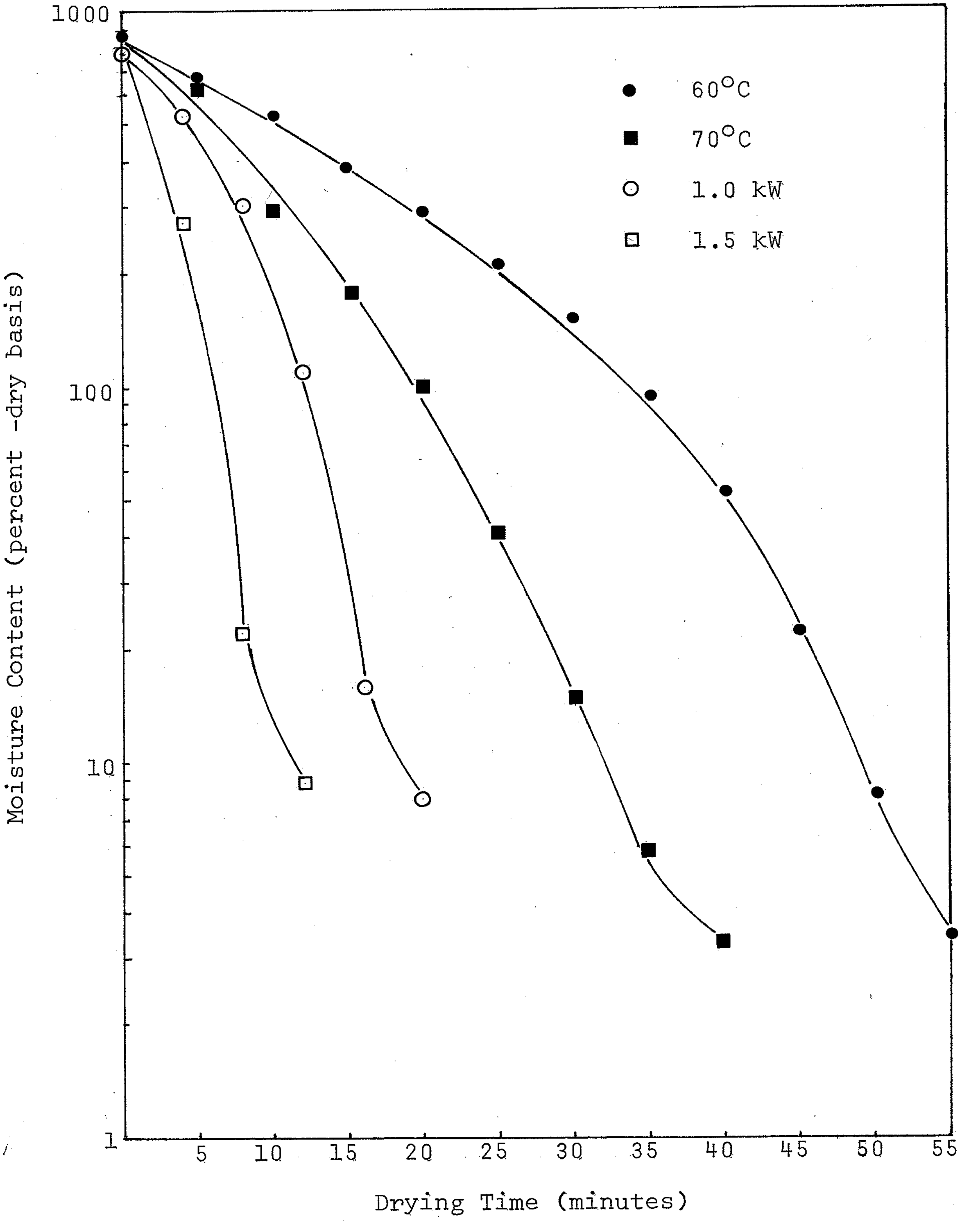

Figure 17. A Comparison of the Drying Rates of Foams (6.4 mm Thickness) as dried by hot-air and Microwaves respectively

air drying treatment, and pulsed operation. More research needs to be done in these areas.

4.6 Product Evaluation

4.6.1 Moisture Content

The moisture content of a solid is generally expressed as the moisture content by weight per unit weight of the dry or wet solid. Wet-weight basis expresses the moisture in a product as a percentage of the weight of the wet solid, whereas the dry-weight basis expresses the moisture as a percentage of the weight of bone-dry material. Another consideration in expressing the moisture content is the method by which it is determined. The meaning remains ambiguous unless the method is defined operationally. In this study, the final moisture contents of the foam-mat dried onions are expressed on the wet-weight basis using the method of determination as outlined in the Official Methods of American Dehydrated Onions and Garlic Association (1969).

When the sample weight remained constant during a drying run, the sample was removed from the tray and its moisture content determined by the method described (3.2.1). The moisture contents of the hot-air dried samples varied between 2-4%; whereas that of the microwave-dried samples varied between 6-9% (wet basis). The final moisture content of a dehydrated product was influenced by the condition (wet-bulb/dry-bulb temperatures) of the drying medium. In this study, the air circulated through the hot-air system had an average absolute humidity equal to 12 grains water/lb dry air, compared to 53 grains water/lb dry air in the microwave system. In commercial onion dehydration, the product was finish-dried by blowing warm, dehumidified air with an absolute humidity not exceeding 21 grains water/lb dry air. Thus, the difference in moisture among the foam-mat-dried onions was not caused by the difference in the drying methods, but by the moisture content of the drying medium.

The final moisture content is important in determining the product's stability during storage. Dehydrated onion is very hygroscopic, i.e. it absorbs ambient moisture readily. In order to keep the dried onion free-flowing, a final moisture below 4% is recommended. Dehydrated onion containing higher moisture levels may be subject to microbial growth, fungal attacks, color and flavor deterioration. The addition of anti-caking agents such as calcium stearate may prevent onion powder from caking. The hot-air foam-mat dried samples were noted to remain free-flowing even after storing at ambient room conditions for 30-60 days. The microwave-dried samples, on the other hand, showed considerable caking when stored under the same conditions due to the higher moisture content.

4.6.2 Reconstitution Study

One of the main advantages offered by foam-mat drying is the instant or rapid reconstitution of the product. In this study, the foam-mat dried onion samples could be reconstituted back to the puree form within 20 seconds in either hot or cold water. Foam-mat dried products are known to have the tendency to float during reconstitution due to the surface tension created by the many voids and air spaces within the products. Floating was especially significant among the samples of light bulk densities, whereas, the high bulk density samples, such as those prepared from foams containing dextrin, were observed to go into solution faster. Both the hot-air dried and microwave-dried samples showed relatively no difference in rehydration times. A 3:1 water to product ratio was used in the rehydration tests.

As mentioned in the Literature Review, a process called densification or compaction can be used to eliminate the problem of floating by increasing the bulk density. Densification also minimizes the oxidation problems during storage, and contributes more to economic packaging and handling procedures.

4.6.3 Color Evaluation

The quality of the dehydrated product is generally reflected in the color presented. Very often, this color signifies the success or failure of the processing method used. In short, the color of the final product should resemble that of the starting material as much as possible. Some exceptions are tolerated especially when a certain color denotes doneness or other desirable quality, (e.g. toasted onions). The American Dehydrated Onions and Garlic Association has issued a color standard for all types of dehydrated onions. An optical index not exceeding 105 is the standard set for white globe onions. However, no such standard is set for yellow onions, a variety normally not used for dehydration purposes. Due to this lack of color standard for yellow onions, the tristimulus colorimetry method was used for color evaluation in favor of the spectrophotometry (optical index) method.

The color of the dehydrated onion samples can be described as creamy white. However, a more technical and precise description can be obtained by using a colorimeter (The Hunterlab D25 Color Difference Meter). Three scales (hence tristimulus), lightness, redness/greenness, and yellowness/blueness, were measured for each sample. With these three scales, it is possible to define the colors of the samples by position in a three-dimensional co-ordinate system for color (Appendix 4). In this study, the author attempted to evaluate the color of the samples as presented before and after dehydration. The color of the starting material was rendered in two separate measurements: the puree and the foam (Table 9). These two measurements indicated a significant difference in color between the puree and the foam. This was presumably due to the light scattering effect of the expanded surface area after foaming. Since only the color of the dehydrated and not the reconstituted samples was measured, it is more logical to compare the color of the foam with that of the product. Therefore the color of the onion foam was the standard used for color comparison.

TABLE 9: COLOR EVALUATION FOR ONION PUREE AND FOAM

	L	aL	bL	Hue	Saturation	Total Color Difference ΔE
PUREE	73.0	-7.5	20.8	-0.36	22.1	28.6
FOAM	86.6	-4.0	12.8	-0.31	13.4	13.1

L	measures lightness and varies from 100 for perfect white to zero for black.
aL	measures redness when plus, gray when zero, and greeness when minus.
bL	measures yellownness when plus, gray when zero, and blueness when minus.

4.6.3.1 Color Evaluation for Hot-air Dried Samples

The color of the hot-air dried samples compared quite favorably with the foam color. The lightness values (L) and the greenness values (a_L) of these samples appeared to fall within the same levels as the foam, whereas, the yellowness values presented a distinct increase (Table 10). This increase in yellowness is attributed primarily to the Maillard browning reaction which is a condensation reaction between the amino acids and the reducing sugars. It is favored by high temperatures and high concentrations of the above mentioned substrates. During the course of dehydration, the samples became concentrated as they slowly attained the drying temperature. As a result, the browning reaction was accelerated. The intensity of the yellowness scale was influenced by the drying rates. In other words, it was affected by the foam densities, drying temperatures, and the foam thicknesses.

Table 11 illustrates the effects of foam density on the color of the foam-mat dried samples. As the foam density increased (0.32 - 0.39 g/ml), the samples appeared progressively darker and more yellow. For example, at 0.32 g/ml, the lightness (L) value = 87.7 and the

TABLE 10: THE COLOR RANGE FOR HOT-AIR DRIED SAMPLES

% Total Solids		Color	Hue	Saturation	Δ E
11 %	L =	88.2→84.6	-0.31→-0.36	15.4→19.4	14.1→19.2
	aL =	-4.9→-6.1			
	bL =	14.5→18.5			
19 %	L =	87.0→84.5	-0.25→-0.31	15.6→17.2	14.8→16.8
	aL =	-3.8→-4.8			
	bL =	14.8→16.5			
24 %	L =	88.8→84.2	-0.16→-0.28	13.2→16.3	11.5→16.9
	aL =	-2.6→-3.7			
	bL =	12.7→16.1			

TABLE 11: COLOR EVALUATION FOR HOT-AIR DRIED SAMPLES (24% T.S., 60°C, 6.4 mm THICKNESS) AT FOUR DENSITY LEVELS

Foam Density g/ml	Color	Hue	Saturation	Total Color Difference ΔE
0.32	L = 87.7 aL = -3.4 bL = 13.5	-0.25	13.9	13.0
0.33	L = 86.6 aL = -3.5 bL = 13.9	-0.25	14.3	13.9
0.34	L = 86.9 aL = -3.6 bL = 14.0	-0.26	14.4	14.0
0.39	L = 86.3 aL = -3.6 bL = 14.6	-0.25	15.0	14.6

yellowness (b_L) value = 13.5, while at 0.39 g/ml, L = 86.3, b_L = 14.6. Likewise, the saturation values increased from 13.9 to 15.0. The greenness (a_L) values appeared to be less affected by the change in foam density, and the hue values remained fairly constant. Lastly, the Total Color Difference (ΔE) values showed some increase. As it was discussed in section 4.5.1, an increase in foam density would extend the total drying time by restricting the mass transfer. Consequently, the foam was exposed longer to the hot-air, allowing for more browning to occur.

The drying temperature was another factor that affected the color of the dehydrated products. Table 12 presents a comparison between the color of the onion samples dried at two temperatures, and at two thicknesses. When the drying temperature was increased from 60°C to 70°C, the yellowness (b_L) scale seemed to be affected the most. For example, at 3.2 mm thickness, the b_L values increased from 14.5 to 15.6. The ΔE values confirmed the difference in color between the samples (ΔE = 14.1 versus ΔE = 15.5). The browning reaction then, was favored at high temperatures even if the drying rates were improved.

TABLE 12: EFFECT OF FOAM THICKNESS AND DRYING TEMPERATURE ON THE COLOR OF HOT-AIR DRIED SAMPLES (11% T.S., and 19% T.S.)

% Total Solids	Thickness	Temperature	Color	Hue	Saturation	Total Color Difference (Δ E)
11 %	3.2 mm	60°C	L = 88.1 aL = -5.2 bL = 14.5	-0.36	15.4	14.1
		70°C	L = 87.0 aL = -5.1 bL = 15.6	-0.33	16.4	15.5
11 %	6.4 mm	60°C	L = 88.1 aL = -5.6 bL = 16.2	-0.34	17.1	15.6
		70°C	L = 86.4 aL = -5.5 bL = 17.4	-0.31	18.3	17.4
19 %	3.2 mm	60°C	L = 86.8 aL = -4.6 bL = 14.8	-0.31	15.5	14.8
		70°C	L = 86.6 aL = -4.3 bL = 15.8	-0.27	16.4	15.6
19 %	6.4 mm	60°C	L = 86.2 aL = -4.2 bL = 15.4	-0.27	16.0	15.5
		70°C	L = 86.1 aL = -3.8 bL = 15.2	-0.25	15.7	15.3

Since the drying rates were also affected by the foam thickness, the color was expected to vary accordingly. For example, by maintaining the temperature constant at 70°C, and varying the foam thickness from 3.2 mm to 6.4 mm, the b_L values of the samples (11% T.S.) increased from 15.6 to 17.4. The L and a_L values were only slightly affected. The total color difference (ΔE) values also varied from 15.5 to 17.4.

4.6.3.2 Color Evaluation For Microwave-Dried Samples

Table 13 shows the color range for the microwave-dried samples (11% T.S.). In general, these samples were darker and more yellow than the hot-air dried samples (11% T.S.). The drying study (section 4.5) showed that the foams when dried by microwaves attained higher product temperatures (77°C - 100°C) than when dried by hot air (60°C - 70°C). This exposure to higher temperatures resulted in products that were darker and more yellow (Figure 18).

The color evaluation for the microwave-dried samples is shown in Table 14. The parameters studied were the foam thickness and the forward power. The variation in foam density (0.26 - 0.29 g/ml) was insignificant due

TABLE 13: THE COLOR RANGE FOR MICROWAVE-DRIED SAMPLES

% Total Solids	Color	Hue	Saturation	△ E
11 %	L = 79.7 → 86.6 aL = -4.3 → -6.0 bL = 16.7 → 20.5	-0.22 → -0.34	17.6 → 21.3	16.6 → 22.6

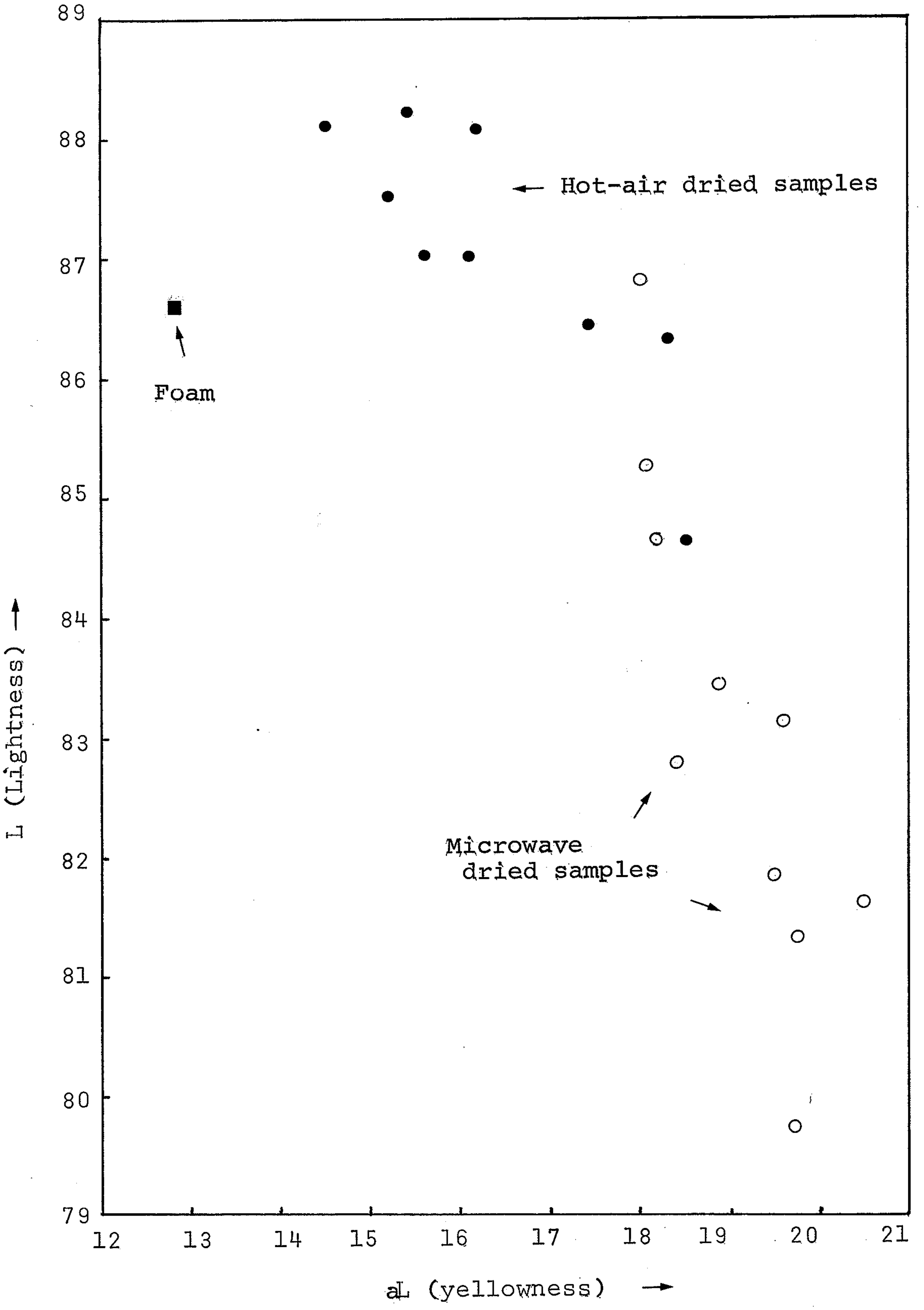

Figure 18. Graph Showing the Color of Hot-air and Microwave Dried Samples (11% Total Solids)

TABLE 14: THE EFFECTS OF FOAM THICKNESS AND FORWARD POWER LEVEL ON THE COLOR OF MICROWAVE-DRIED SAMPLES (11% T.S.)

Foam Thickness	Forward Power	Maximum Product Temperature	Color	Hue	Saturation	ΔE
6.4 mm	1.0 kW	77°C	L = 85.2 aL = -6.0 bL = 18.1	-0.34	19.0	18.6
6.4 mm	1.0 kW	82°C	L = 83.4 aL = -5.9 bL = 18.9	-0.31	19.6	20.2
6.4 mm	1.5 kW	88°C	L = 84.6 aL = -6.0 bL = 18.2	-0.33	19.2	19.0
12.7 mm	1.0 kW	82°C	L = 82.7 aL = -4.6 bL = 18.4	-0.25	19.0	19.9
12.7 mm	1.5 kW	100°C	L = 81.6 aL = -5.7 bL = 20.5	-0.28	21.3	22.4

to the use of a single stabilizer level (2%). Thus, the effect of foam density on the color of the product was not considered. When the foams of 6.4 mm thickness were dried, an increase from 1.0 kW to 1.5 kW did not affect the color of the products to any great extent. Although this increase in power was accompanied by an increase in product temperature (77°C - 88°C), the shorter drying rates may have compensated for the browning effect. However, if the product temperature was rendered too high, some degree of color deterioration could result. This effect was demonstrated among the 12.7 mm thick samples. As the forward power was increased from 1.0 kW to 1.5 kW, the product temperature was recorded to have reached 100°C, and the yellowness values rose from 18.4 to 20.5. The total color difference showed an increase of 2.5 NBS units ($\Delta E = 19.9$ vs. $\Delta E = 22.4$).

4.6.4 Aroma Evaluation

In the commercial production of dehydrated onions, the aroma or flavor of the end product is rarely evaluated. Instead, the choice of strong flavored onions suitable for dehydration is of prime importance. Several methods for onion aroma evaluation have been mentioned in the Literature

Review. One of the methods chosen for this study was the Chemical Oxygen Demand (COD) method. Fresh onions as well as the hot-air and microwave-dried samples were analyzed and their ppm COD (or volatiles) determined. One of the intentions of this study was to evaluate the products processed by the two different methods of drying. This was accomplished by comparing the ppm COD of the onions before and after dehydration.

A standard calibration curve for the COD determination was prepared by oxidizing sucrose solutions of known concentration (Figure 19). The onion samples were similarly oxidized and their respective ppm CODs were read directly from the standard calibration curve. The ppm COD was not used as an absolute measurement but merely as an index of pungency. No attempt was made to correlate the ppm COD of the dehydrated samples with subjective taste panel scores. Table 15 presents the ppm COD of the various samples as dried by hot air and microwaves respectively. The ppm COD of the hot-air dried samples showed a decreasing trend when the total solids content increased. For example, at 11% total solids, the average ppm COD of the samples dried at 60°C was 887. At 19% and 24% total solids, the samples' average ppm CODs were 617

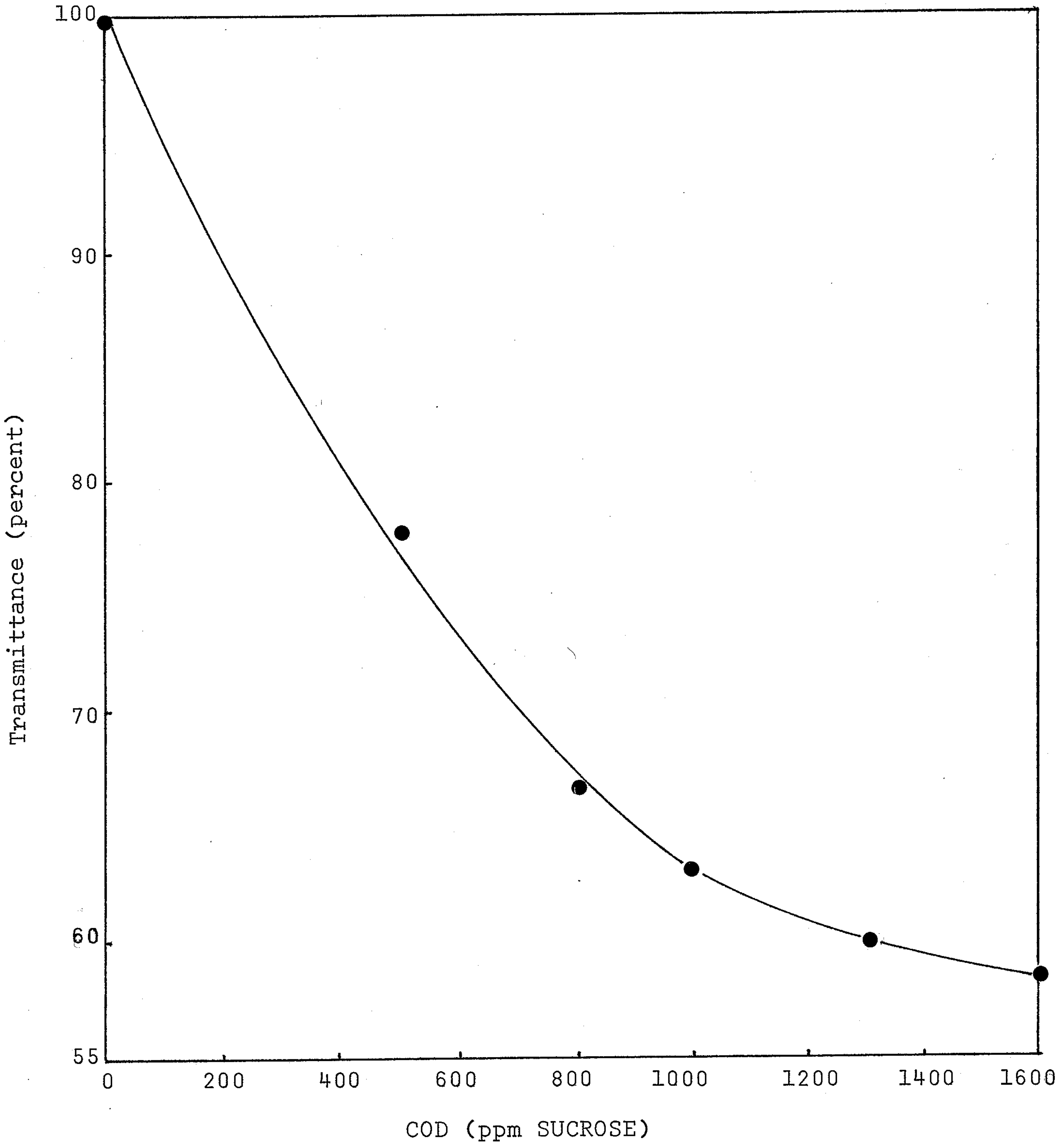

Figure 19. Standard Calibration Curve for Chemical Oxygen Demand (COD) Determination

and 302 respectively. This result was partially anticipated as the increase in total solids content was made via the addition of dextrin. Judging from these results, the addition of dextrin did little in aiding flavor retention. The drying temperature also played a role in determing the aroma content of the final products. Like color, the aroma of the samples was heat sensitive. For example, at 11% total solids, the ppm COD dropped from 887 when dried at 60°C to 792 at 70°C. The same trend was observed in samples of higher solids contents. One exception was observed when the samples were dried at an initial higher temperature and then finish-dried at a lower temperature. This was exemplified among the samples dried at 70°C for 15 minutes, and then at 60°C for the remaining 20 minutes. Their average, 1063 ppm COD, was considerably higher than the samples dried at constant temperatures of 60°C and 70°C respectively. Thus, aroma retention was favored at fast drying rates and low temperatures.

In the microwave system, the aroma retention was favored at fast drying rates. When a forward power of 1.5 kW was used, the average ppm COD of the samples was 1266 as compared to 930 at 1.0 kW. When the drying rates were slowed down by employing thicker foams, the ppm COD

TABLE 15. THE CHEMICAL OXYGEN DEMAND (COD) DETERMINATION AS AN INDEX OF PUNGENCY

% Total Solids of Starting Material	Foam Thickness (mm.)	Drying Temperature (°C)	Microwave Forward (kW)	COD (ppm)
11 %	6.4	60	-	887
		70/60*	-	1063
		70	-	792
19 %	6.4	60	-	617
		70	-	460
24 %	6.4	60	-	302
		70	-	290
11 %	6.4	-	1.0	930
	6.4	-	1.5	1266
	12.7	-	1.0	460
	12.7	-	1.5	463
11 % (fresh)	-	-	-	1791
11 % (onion flakes)	-	70**	-	675

* 70/60°C the samples were dried at 70°C for the initial 15 minutes, and at 60°C for the remaining 20 min.

** 70°C the samples were dried at 70°C in the first hour, and gradually reduced at 20°C at a rate of 10°C per hr.

dropped to 460. The samples as dried by the microwave system also displayed a higher ppm COD than the hot-air dried samples. Percentage wise, the microwave samples retained a maximum of 70% of the freshly blended onion puree, whereas the hot-air samples retained only 60%. It should be emphasized however, that much of the aroma was lost during the chopping, blending and whipping operations. This aroma loss was not accounted for in the COD determination of the freshly pureed samples. As a matter of interest, Spanish onion flakes were processed in a fluidized-bed drier using the drying conditions established by Chan (1974). These samples showed an average index of 675 ppm COD, which was a substantial drop from the original index of 1791. It was further noted however, that the onion flakes had a stronger smell than the foam-mat dried products. The extent could only be determined by subjective methods, such as a taste panel analysis.

4.6.5 Preliminary Observations For Further Research

The most noticeable difference between the onion flakes and the foam-mat dried products was the absence of a bitter taste in the former samples. The formation of a bitter substance was reviewed in section 2.6.4. This bitter taste was easily distinguished from the bitter sensation when biting into a raw onion.

Schwimmer (1967) claimed that the bitterness formation could be suppressed by means of temporary acidification of the freshly prepared onion puree. A preliminary experiment was carried out by using 1M citric acid as the acidifying agent. The puree was brought down to a pH 2.65 from the initial pH 5.5^{o}. No bitter taste in the acidified puree was detected although the strong tart flavor of citrate was prominent. The acidified puree was brought back to its original pH by adding 1M sodium bicarbonate. The tart flavor of the citric acid was neutralized and no bitter taste was detected. Since the bitter substance was a by-product of the aroma formation reaction (Schwimmer 1968), its suppression or elimination remained a problem in the foam-mat drying of onions.

CHAPTER V

CONCLUSIONS

In this study, it was found that onions with 11% total solids, when prepared in puree form, could be used as a starting material for the foam-mat drying process. The conditions for foaming this puree were established, and the drying conditions for the foam were also developed.

Two stabilizers, Myverol 18-00 (a monoglyceride), and Admul 1405 (a polyglycerol ester) were found to be effective in producing onion foams when used at a level of 2% (based of the dry weight of puree). White corn dextrin was also used in some trials to enhance the whipping properties of the puree by increasing the total solids contents to 19% and 24% respectively. The amount of stabilizer required for the dextrin-added systems were in the range of 1-1.5 %. The foams were characterized by their densities. Foams that fell within the density range of 0.35 g/ml and lower were described as acceptable for drying.

The hot-air drying study showed that the drying rates of foams were influenced by the foam thickness, foam density, and drying temperature. An increase in foam thickness or foam density would cause an increase in the total drying time, whereas an increase in drying temperature would cause a reduction in the drying time. A foam of 6.4 mm thickness could be dried to below 4% moisture (wet weight basis) within 60 minutes at 60°C. The temperature range of 60-70°C was the most effective for drying.

The microwave drying experiments showed that microwave heating was effective in improving the drying rates of foams. The same experiments also showed that the drying rates were affected by the foam thickness and the forward power level. Foams could be dried down to 7.5% moisture in 14 minutes. The final moisture content of the product was restricted by the moisture content of the drying medium.

The foam-mat dried products showed a reconstitution rate of less than 20 seconds in either hot or cold water. No distinction in reconstitution rate was evident between the hot-air and microwave dried samples.

The color of the dehydrated products was evaluated by the Hunterlab Color Difference Meter. The microwave system yielded a darker product than the hot-air system.

The dehydrated product had a more intense yellow color than the foam. The intensity of yellowness was affected by the drying rate, temperature, or power level.

The aroma of the foam-mat dried products was evaluated by the Chemical Oxygen Demand (COD) method. The results showed that the addition of dextrin did little in aiding flavor retention. In general, the microwave-dried product retained more aroma than the hot-air dried product under the respective processing conditions.

CHAPTER VI

RECOMMENDATIONS

The foam-mat drying process has proven to be applicable in the production of onion powder. Onion powder can be produced in less than 1/20 of the time required by the conventional tunnel method. The foam-mat dried product possesses an acceptable color and it can also be reconstituted in a matter of seconds. Before this process can be declared commercially feasible, several areas of research need to be considered.

1. Utilization of a Single Hot-air and Microwaves System

The drying rates can be further improved by utilizing a combined hot-air and microwaves drying system. Such a system may prove to be more efficient in terms of energy utilization. A microwave processing system usually requires a substantial capital investment and its use is generally limited to the finish-drying of the product. As high production rates can be achieved via the foam-mat process, a partial or full-scale use of microwave energy may be justified.

2. Utilization of a Continuous System

The adoption of a continuous system has proven to be an invaluable tool to many food processors. The application of this system depends mainly on the process itself. Many previous studies have shown that the foam-mat drying process can be readily adapted into continuous production. Numerous continuous systems for foam-mat drying of fruit juices are currently in operation.

3. Flavor Improvement

Perhaps the biggest problem associated with onion dehydration is the loss of aroma during processing. This problem is even more acute in the foam-mat process because virtually all the onion tissues are comminuted. In order for the foam-mat product to retain an adequate amount of aroma, some form of aroma add-back process needs to be considered. It was mentioned (section 4.6.5) that the formation of a bitter substance in pureed onions may prove to be an undesirable quality in the foam-mat product. Some research in this area is also required.

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APPENDICES

Appendix 1. Computation of total solids content and moisture content.

W_1 = Weight of dish

W_2 = Weight of dish + weight of moist sample

W_3 = Weight of dish + weight of bone dry sample

$$\% \text{ total solids} = \frac{W_3 - W_1}{W_2 - W_1} \times 100\%$$

$$\% \text{ moisture} = 100\% - \% \text{ total solids}$$

Appendix 2. Computation of Hue, Saturation, and Total Color Difference.

L = lightness

aL = redness/greenness

bL = yellowness/blueness

Hue = aL/bL

Saturation = $(aL^2 + bL^2)^{\frac{1}{2}}$

Total Color Difference

$$\Delta E = \left\{ (\Delta L)^2 + (\Delta aL)^2 + (\Delta bL)^2 \right\}^{\frac{1}{2}}$$

where L = 93.8 - L (sample)

aL = -1.1 - aL (sample)

bL = 2.3 - bL (sample)

Appendix 3. Computation of total microwave energy dissipated in sample.

Power Dissipated = Forward Power - Reflected Power

Example:

Drying Time	Forward Power	Average Reflected Power	Power Dissipated
0-2 min	1.0 kW	0.10 kW	0.90 kW
2-4	1.0	0.13	0.87
4-6	1.0	0.15	0.85
6-8	1.0	0.20	0.80
8-10	1.0	0.40	0.60
10-12	0.5	0.25	0.25
12-14	0.5	0.26	0.24
14-16	0.5	0.26	0.24

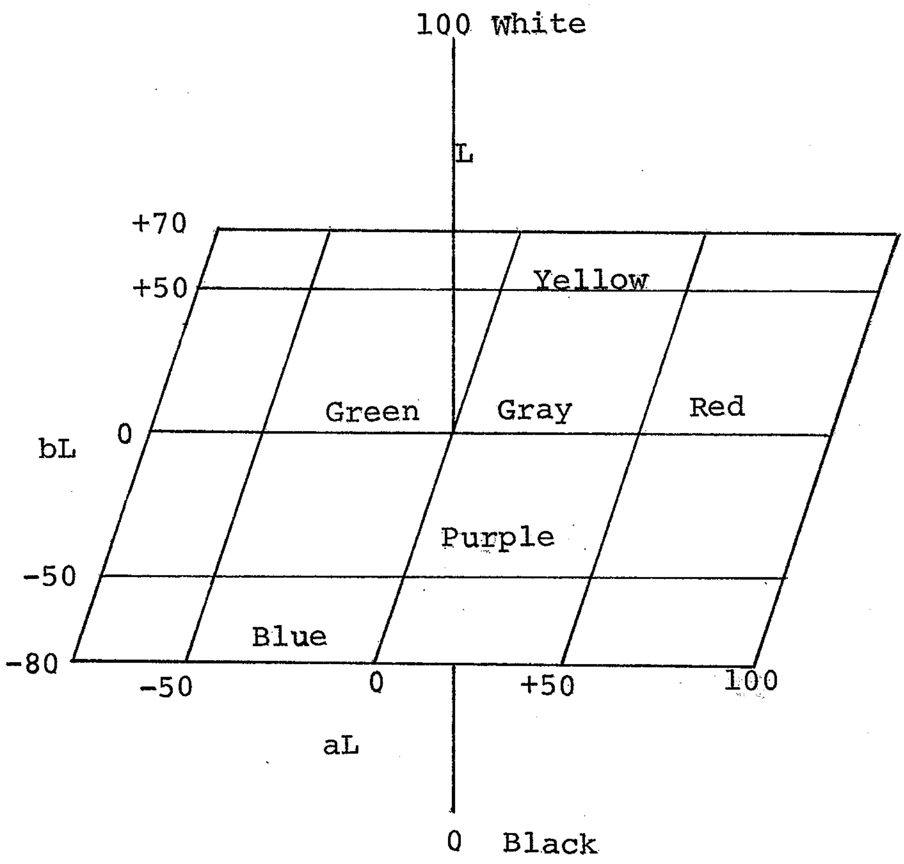
Energy dissipated = power dissipated x drying time

= (0.90)2 kW min + (0.87)2 +
(0.85)2 + (0.80)2 + (0.60) +
(0.25)2 + (0.24)2 + (0.24)2

= (4.75)2

= 9.50 kW min

Appendix 4. The L, aL, bL, color solid.



Appendix 5. Computation of the energy (theoretical) required to remove water.

Energy required to heat the sample

$$E_1(\text{kW min}) = \frac{\text{Weight of Sample}\ \text{Kg} \times \text{Specific Heat of Product}\ \frac{\text{Kcal}}{\text{Kg}^{\circ}\text{C}} \times \text{Temperature Change}\ {}^{\circ}\text{C} \times \text{Processing Time}\ \text{Minute}}{\frac{3413 \times 252}{1000 \times 60}\ \frac{\text{Kcal}}{\text{kW min}}}$$

Energy required to vaporize the water in sample

$$E_2(\text{kW min}) = \frac{\text{Weight of water Removed}\ \text{Kg} \times \text{Latent heat of Vaporization}\ \frac{\text{Kcal}}{\text{Kg}} \times \text{Processing Time}\ \text{Minute}}{\frac{3413 \times 252}{1000 \times 60}\ \frac{\text{Kcal}}{\text{kW min}}}$$

Total energy (theoretical) required to remove water from sample

$$E(\text{theoretical}) = E_1 + E_2$$