THE UNIVERSITY OF MANITOBA

Characterization and Drying of Tomato Paste Foam Utilizing Hot-Air and Microwave Energy

by

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A Thesis

Submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the
Degree of Master of Science

Department of Food Science

Winnipeg, Manitoba

May, 1976

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ACKNOWLEDGEMENTS

The author would like to extend his sincerest appreciation and thanks to Drs. M. A. Rzepecka and M. B. McConnell, Departments of Electrical Engineering and Food Sciences, University of Manitoba, for their valuable direction, advice and encouragement accorded throughout the project. Special thanks are also due to Dr. R. A. Gallop, Head, Department of Food Sciences, for serving on the examining committee.

The author also wishes to acknowledge the cooperation received from the graduate students of the Food Science Department, University of Manitoba. Here, sincerest appreciation is extended to Mr. D. Y. Fung, for the photography, and Mr. L. B. Carvalho, for the computer work.

In addition, the author wishes to extend appreciation to Martha Banias and Lesia Pawlowsky for their assistance in the typing and editing of this thesis.

A very special thank you is accorded to Mrs. Lidia Brygidyr for her unending support and encouragement, without which this work would not have been possible. This thesis is dedicated to her in recognition of this.

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ABSTRACT

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Tomato paste (27% total solids) purees containing a 90% mono, 10% diglyceride stabilizer (concentrations from 1% to 3%) were whipped in a blender (whipping time 0-11 minutes). Various characterization studies were performed on these foams such as density, bubble size index and stability. Such data was considered significant in producing foams suitable for foam-mat drying.

Foams prepared under controlled conditions were dried separately using either hot-air or microwave energy. The two common parameters used in these dehydration experiments were different densities (0.34, 0.38, 0.45 amd 0.50 g/cm^3), and different foam thicknesses (3.2, 6.3, 12.7 mm). Hot-air studies, however, were done at three drying air temperatures (71, 77, and 82^{o}C), while the microwave energy experiments were carried out at five forward power settings (150 to 350W at 50W increments). Hot-air dehydration experiments were also carried out at different stabilizer levels (1.0 to 3.0% at 0.5% increments).

The dried foams were evaluated via their moisture uptake (equilibrium moisture content vs relative humidity), rehydration rate and colour.

CHAPTER I

INTRODUCTION

Production of dehydrated foods in the United States and Canada expanded vigorously after World War II until the early 1960's. Commodities which enjoyed a large market growth during this period were non-fat dry milk, potatoes, onions, and garlic. In general, the commodities with the most market growth were those that did not have to compete with alternative processed products (White 1973).

Since 1966, the total production of the industry has been relatively stable, with an increase in some commodities, especially dried eggs, and a decline in production of other commodities, such as non-fat milk. Dairy products, however, have accounted for about 60% of the total dry weight of dehydrated foods since 1966. In 1970, over 3,776 million pounds of dehydrated foods were produced (dry weight basis) with a wholesale value exceeding $ 1.4 billion.

About half of the dehydrated foods produced are used by manufacturers whose principal customers are the food service outlets (USDA 1969). The food dehydration industry also supplies dried food directly to food service outlets, as well as to retail markets for use in households and for campers and other sportsmen. The federal government purchases dehydrated foods for the military and for federal food distribution programs. Some of the advantages of dehydrated foods are: 1) lower transportation and storage costs; 2) no refrigeration costs in comparison with fresh or frozen foods; 3) prolonged shelf life; and 4) compatibility with other ingredients in dry food mixes.

There are various types of drying systems used today. Drum driers are one of the most economical (drying cost about 1¢ to 2¢ per pound) and popular. They are generally used to dry high solid materials such as liquids, slurries, pastes and mashed products. However, because of high surface temperatures, heat sensitive products become scorched.

Vacuum driers are employed wherever cost permits, improved quality is required (eg flavour and colour retention), or lower moisture contents are demanded. High equipment operation and maintenance costs however limit the use of vacuum driers. Coffee, tea, fruit juices and milk are the most frequently dried products (Tape 1970).

The most common method of drying liquids is spray drying. It is used primarily for milk products, egg products, coffee and tea concentrates. However, it is limited to liquids with low solid content since high solid content liquids tend to clog nozzles.

Fluidized bed drying is useful for granular material such as potato granules, grain, peas, lentils, soya flakes and bulgar wheat. Its use, however, becomes limited when slurries, pastes and liquids are to be dried.

Freeze drying or lyophilization produces excellent quality product but at a very high processing cost (7¢ to 15¢ per pound). As a result it can only be used economically for high cost foods where maximum quality is required. The products dried by this method are coffee, chicken parts and mushrooms.

Batch or continuous atmospheric hot air dryers are widely used for dehydrating fruits and vegetables. Product quality is generally good, but the drying rate is very slow due to the heat and mass transfer limitations.

Foam-mat drying, which utilizes hot air on a foamed slurry, greatly reduces the mass transfer problem. Consequently, there is a shorter residence drying time and generally a better product than with the batch or continuous atmospheric hot air dryers. The two drawbacks to this system, however, are that 1) the product must be altered in shape and consistency, and 2) the heat transfer problem mentioned earlier is still existent. At present, heat sensitive products such as orange and tomato purees are being dried using the foam-mat technique.

The use of microwave energy in dehydration has just recently become viable. The unique characteristics of microwaves is their ability to generate heat instantaneously and volumetrically within the product. This significantly reduces the problem of heat transfer previously mentioned. Microwave energy drying is expensive as compared to other dehydration techniques. However, at this stage it would seem that the biggest drawback to widescale application is the lack of sufficient knowledge to proceed with confidence.

The purpose of this thesis was to take advantage of the foam-mat and microwave systems and apply them to the dehydration of a heat sensitive product. The product used for this study was tomato paste. The scope of the thesis was to 1) investigate the optimal parameters involved in the production and evaluation of foams for foam-mat drying; 2) to compare microwave energy dehydration with hot-air drying of foams within certain physical parameters; 3) to evaluate the quality of the final product produced by the systems mentioned in 2) above.

CHAPTER II

REVIEW OF LITERATURE

2.1 Introduction

There are two fundamental processes which occur simultaneously in the dehydration process (Williams-Gardner 1971; Komanovsky et al 1964): 1) transfer of heat to raise the wet solids temperature and to evaporate the moisture (heat transfer); and 2) transfer of mass in the form of internal moisture to the surface of the solid and its subsequent evaporation (mass transfer). Heat transfer in the drying operation occurs through three basic mechanisms: convection, conduction or radiation. In some cases, it occurs as a result of a combination of any of these efforts.

Industrial driers differ in type and design and are dependent on the principal method of heat transfer employed (Holdsworth 1971; McCormick 1970; Borgstrom 1971; Tape 1970; van Arsdel et al 1973). Regardless of the type that is utilized, heat is required to be transferred to the surface of the solid and thence to its interior. The one exception is when a high frequency (microwave) drier is used, in which case heat is generated within the solid and then flows to the exterior surfaces (Copson 1962).

Mass transfer in the drying of a wet solid depends on two mechanisms (Potter 1968; Williams-Gardner 1971; Borgstrom 1971). These are 1) movement of moisture internally within the solid, which is a function of the internal physical nature of the solid and its moisture content; and 2) movement of water vapour from the material surface, which is a result of external conditions such as air temperature, humidity, air flow rate, area of exposed surface and supernatant pressure.

When foods are dehydrated, they do not lose water at a constant rate all the way down to bone dryness. On the contrary, as drying progresses, the rate of water removal drops off under any fixed set of conditions. The curve illustrated in Figure 1 is a plot of moisture content at any time in a given material undergoing drying. The drying curve, its various meanings and implications are well reviewed (Potter 1968; Chen 1973; McCormick 1970; Williams-Gardner 1971; van Arsdel et al 1973).

The properties of foam-mat drying greatly reduce the mass transfer problem and thereby decrease the time intervals of the warm-up, constant rate and falling rate periods. Consequently, drying time is substantially reduced. This drying technique, therefore, presents substantial advantages in processing and thus warrants further investigation.

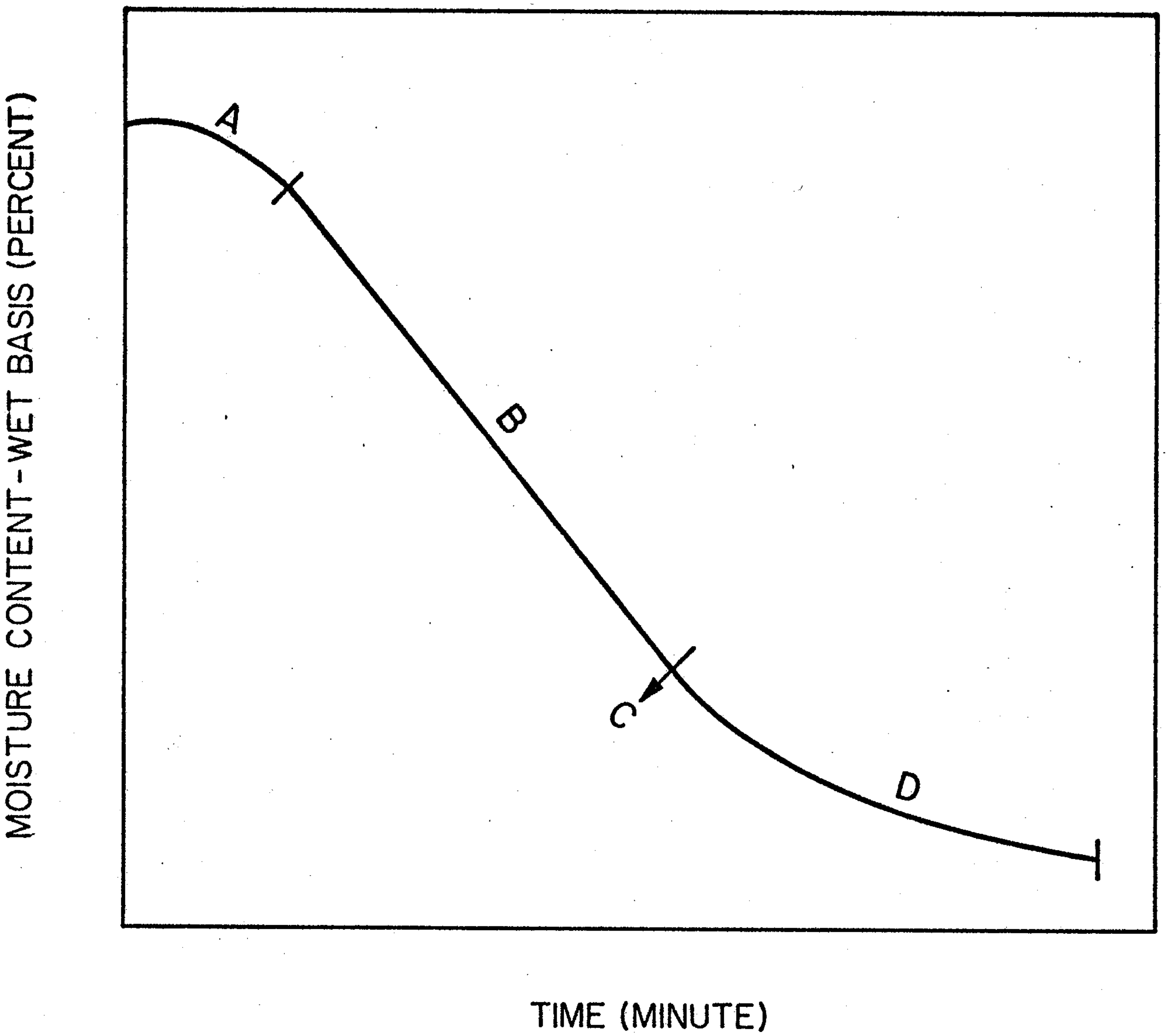
Figure 1: Typical drying curve depicting:

a) the warm-up period

b) constant drying rate period

c) critical moisture content

d) the falling rate period


MOISTURE CONTENT-WET BASIS (PERCENT)
A
B
C
D
TIME (MINUTE)

2.2 The Foam-mat Process

The foam-mat drying process was developed by A. Morgan and others at the U.S. Department of Agriculture (Noyes 1969). It is a simple and inexpensive process operating at atmospheric pressure and essentially involves the following steps (A. Morgan Jr. et al 1961): 1) forming a stable foam from a puree of sufficient total solids content by the use of additives and gas injections; 2) drying the foam to form a thin porous sheet or mat. Other foam-mat process have been patented and comprehensively described (Morgan et al 1960; Morgan et al 1961; Eolkin 1962; Graham 1963; Gunther 1964; Berry et al 1968; Anonymous 1962; Bissett et al 1973; Hart et al 1963; Bates 1964).

2.2.1 Preparation of Foams for Foam-mat Drying

A foam consists of basically a dispersion of a gas in a liquid or solid film. In other words, a foam is an agglomeration of gas bubbles separated from one another by thin films (Bikerman 1953). In preparing such a foam, a surface active agent is added to the juice concentrate and air or other non-toxic gases such as nitrogen, carbon dioxide, nitrous oxide, helium, propane, dichlorofluoromethane, n-butane, isobutante, etc are incorporated (Noyes 1969). The surface active agent (or surfactant) is added in order to keep such a system stable. This reduces the surface tension of the liquid or solid phase, thus increasing the dispersibility of the system (Glicksman 1969).

The proportion of surface active agent added varies, depending on the properties of the juice concentrate, and the properties of the agent in question. Chandak and Chivate (1972) state that in general the proportion of surfactant may vary from 0.1% to 2.0% by weight based on the weight of the total solids in the concentrate. It is more efficient to use the lowest proportion of surfactant compatible with production of a stable foam.

Incorporation of the gas into the juice concentrate (containing added surfactant) may be accompanied by any of the available conventional methods, ie whipping, mixing or agitation. One of the simplest and most popular techniques is to subject the juice concentrate to a rotating wire whip. This beats or injects air into the material and thus produces a foam (Berry et al 1965; Berry et al 1967; La Belle 1966; Beck 1968). Air injection proceeds until optimum density and gas bubble size are achieved. The whipping time required for the optimum foam varies from product to product (La Belle 1966; Berry 1965; Noyes 1969).

2.2.2 Foam Evaluation

Ward (1976) has reviewed the techniques developed for analyzing foams produced for foam-mat drying. These include measuring 1) changes of surface viscosity and elasticity (MacRitchie and Alexander 1961); 2) foam drainage as related to surface and bulk viscosities (Davies 1961); and 3) foam drainage in a graduated centrifuge tube at room temperature (La Belle 1966) and at elevated temperatures (Miles and Shedlovsky 1944). Other systems included measuring bubble size change in the foam, and determining changes in foam densities with time (Berry et al 1965; Chang et al 1956).

2.2.3 Foam-mat Drying

One of the conventional methods used to dry foams involves the use of hot-air systems (Morgan et al 1961; Berry et al 1972; Noyes 1969; Ginnette et al 1963). The procedure utilized in these systems involves the following steps: 1) spreading the foam in thin layers (3-13 mm) on perforated plates; 2) subjecting the foam to hot-air until the desired moisture content is reached; and 3) removing the dried product from the sheets for packaging.

2.2.4 Theoretical Aspects of Foam-mat Dehydration

According to Hertzendorf and Moshy (1970) the foaming of materials significantly alters the mechanism and mode of dehydration. Foaming a fluid material reduces its fluidity, often converting it to a semi-solid. This alters the materials support system requirements for hot-air drying.

The expanded surface areas of foams affect the mass and energy transport phenomena to and from the surface of the material. The foam structure has the property of decreasing the rate of energy transfer into the centre (insulating effect). However, the greatly increased area exposed to dehydration increases the mass transfer rate. The overall effect of these phenomena is a substantially increased rate of dehydration when utilizing the hot-air foam-mat system. These factors play a significant role in the warm-up and constant rate sections of the drying curve (Potter 1969; Borgstrom 1971). This therefore enables the dehydration of heat sensitive products such as tomato paste to become viable.

As noted above, utilizing foams for drying has a distinct disadvantage when relating to heat (energy) transfer (Hertzendorf and Moshy 1970). This disadvantage could be made less critical if the heat would be generated within the product itself. Adapting microwave energy to this process could overcome this problem.

2.2.5 Industrial Applications of Hot-Air Foam-mat Dehydration

Current industrial applications of hot-air foam-mat systems although not many are increasing in popularity. Berry et al (1972) describe two new corporations, namely Foam-mat Corporation in Corvallis, Oregon and Citrus World Incorporated in Lake Wales, Florida, which are involved in the production of citrus powders via the foam-mat system.

Anonymous (1962) describes the production of tomato powders by the Patterson Company in northern California. All three operations are economically viable at this time (Ward 1976).

2.3 Microwave Power Systems

The phenomena of heating objects by means of high frequency electric fields has been known since the late 1800's. It was not until the development of radar, however, that serious attention was turned to the possibility of industrial heating and dehydration with microwave energy. First microwave systems appeared in the 1950's, but industrial development was delayed until the 1960's when more efficient power tubes were developed. The past five or six years have seen the most rapid increase in the number of industrial microwave installations.

2.3.1 Properties of Microwaves

Microwaves are electromagnetic radiations with frequencies ranging from about 100 MHz to 300 GHz and corresponding wavelengths from 3 mm to 1 mm. In the electromagnetic spectrum they lie between radio frequencies and infrared radiation. From the broad range of microwave frequencies available, a few are designated for industrial, scientific and medical applications (ISM). As a result, utilization of specific microwave frequencies comes under the regulations of the Federal Communications Commission. For food applications, the most frequently used