F
N
P

Journal of FOOD PROCESS ENGINEERING

Edited by

D. R. HELDMAN

FOOD & NUTRITION PRESS, INC.
WESTPORT, CONNECTICUT 06880
USA

VOLUME 4, NUMBER 4 QUARTERLY

JOURNAL OF FOOD PROCESS ENGINEERING

Journal of
FOOD PROCESS ENGINEERING

VOLUME 4
NUMBER 4

Editor: D. R. HELDMAN

FOOD & NUTRITION PRESS, INC.
WESTPORT, CONNECTICUT 06880 USA

ISSN 0145-8876

Printed in the United States of America

CONTENTS

MEETINGS

MAY 1982

May 11: **ENGINEERING DEVELOPMENTS FOR THE HANDLING OF STORAGE CEREALS.** National Agricultural Center, Stoneleigh, England. Contact: Edwina J. Holden, The Institute of Agricultural Engineers, West End Rd., Silsoe, Bedford, MK454DU, England.

May 11-13: **37th ANNUAL PURDUE INDUSTRIAL WASTES CONFERENCE.** Stuart Center, Purdue University. Contact: Dr. J. D. Wolszon, Purdue Industrial Wastes Conference, Civil Engineering Bldg., Purdue University, West Lafayette, IN 47907.

May 11-13: **7th ANNUAL POWDER AND BULK SOLIDS CONFERENCE/EXPOSITION.** O'Hare Exposition Center, Rosemont, IL. Contact: M. J. Basso, 222 E. Adams St., Chicago, IL 60606.

May 16-21: **FOOD CONFERENCE 1982.** Regional Food Science and Technology Conference. Singapore. Contact: R. A. Buchanan, PO Box 921, Kuala Lumpur 01-12, Malaysia.

May 21-26: **6th DETROP 82.** International Fair of Food-Beverages-Equipment. Thessaloniki, Greece. Contact: Sotirios Vlachopoulos, Commission Director, Thessaloniki International Fair, Thessaloniki, Greece.

May 26-28: **STOKELY-VAN CAMP SYMPOSIUM IV ON FOOD IN CONTEMPORARY SOCIETY—ENERGY—THE CRITICAL FACTOR.** University of Tennessee, Knoxville. Contact: The Department of Nutrition and Food Sciences, The University of Tennessee, Knoxville, TN 37916.

May 30-Jun 3: **CANADIAN INSTITUTE OF FOOD SCIENCE AND TECHNOLOGY, THE ANNUAL CONVENTION.** Montreal, Canada. Contact: A.H.M. Greene, Suite 38, 43 Elgon St., Ottawa K1P 5K6, Canada.

JUNE 1982

Jun 6-9: **LONDON INTERNATIONAL FROZEN FOOD TRADE FAIR.** Grosvenor House Hotel, London. Contact: British

Information Services, News Division,, 845 Third Ave., New York, NY 10022.

Jun 21-22: **IFT BASIC SYMPOSIUM: PHYSICAL PROPERTIES OF FOOD.** Las Vegas, NV. Contact: John B. Klis, Institute of Food Technologists, 221 N. LaSalle St., Suite 2120, Chicago, IL 60601.

Jun 22-25: **42nd ANNUAL MEETING AND FOOD EXPO OF INSTITUTE OF FOOD TECHNOLOGISTS.** Las Vegas Nevada Convention Center. Contact: C. L. Willey, Institute of Food Technologists, Suite 2120, 221 N. LaSalle St., Chicago, IL 60601.

Jun 27-30: **ASAE SUMMER MEETING, 75 YEARS OF AGRICULTURAL ENGINEERING, ABUNDANT QUALITY FOOD.** University of Wisconsin. Contact: Mark A. Purschwitz, American Society of Agricultural Engineers, Box 410, St. Joseph, MI 49085.

AUGUST 1982

Aug 15-18: **NATIONAL SOYBEAN PROCESSORS ASSOCIATION ANNUAL MEETING.** Pebble Beach, CA. Contact: NSPA, 1800 "M" St., NW, Washington, DC 20036.

Aug 31-Sep 3: **IFST (UK ANNUAL SYMPOSIUM).** Contact: K.C. Yates, Kellogg Company, Ltd., Stratford Manchester M32 8RA, United Kingdom.

SEPTEMBER 1982

Sep 8-10: **INTERNATIONAL SYMPOSIUM - FOOD INDUSTRY AND THE ENVIRONMENT.** Budapest, Hungary. Contact: CIIA 9 Commission Internationale des Industries. Agricoles et Alimentaires, 35, rue du General Foy, 75008 Paris, France.

Sep 12-15: **THIRD INTERNATIONAL DRYING SYMPOSIUM.** University of Birmingham, England. Contact: Program Organizer, Third International Drying Symposium, 108 Bhylls Lane, Merry Hill, Wolverhampton WV3 8DZ, England.

MICROWAVE FREEZE DRYING

J. EDWARD SUNDERLAND

Department of Mechanical Engineering
University of Massachusetts
Amherst, MA 01003

Received for Publication June 22, 1981

ABSTRACT

A critical review of recent work in microwave freeze drying of food products is presented. This is followed by a general evaluation and recommendation for future work. The major technical problems that would prevent commercial use of microwave freeze drying have been solved. Economic studies show that processing costs for microwave freeze drying are lower than the costs for conventional freeze drying. Thus there has been adequate research and development for commercialization. A discussion is presented for improving the transfer of technology to aid commercialization. Recommendations are made for additional research and development.

INTRODUCTION

Freeze drying with the assistance of microwave heating offers inherent advantages over conventional freeze drying. In any drying process that involves phase changes, very large amounts of energy are necessary per unit mass of water removed. In many drying processes there is direct or nearly direct heat transfer to the water. This is not the case in conventional freeze drying where it is necessary to transfer energy through the dried layer which has a very low thermal conductivity. In order to reduce dehydration times, the product surface is generally heated to the maximum temperature that will not cause unacceptable product damage. However, during the long time exposure commonly required, the quality of the product is diminished. Furthermore, long exposure times cause higher costs due to energy, labor and capital costs. There have been many investigations undertaken to increase the rate of heat transfer to the frozen core of foods during vacuum freeze drying. Some attempts have been made to increase the thermal conductivity of the dried region by inserting inert but high conductivity gases into the vacuum chamber. These

Journal of Food Process Engineering 4 (1981) 195-212.

efforts have not been very successful because the water vapor leaves the product with very high velocities and purges the dried layer of the inert gases. Some success was obtained by pulsing the pressure in the dryer. This process resulted in a higher average thermal conductivity of the dried layer and subsequently somewhat higher freeze drying rates occurred. Efforts have been made to conduct heat directly (almost) to the frozen core by using spikes or fins that would protrude from a heater into the food product. Rapid drying rates (3 to 4 times as fast) resulted but mechanical difficulties of inserting and especially removing the fins are substantial. In all of these processes the drying rates are directly dependent on the rate of heat transfer to the undried regions. It is the ability to supply energy to the frozen core that limits the overall drying rate, not the resistance to mass transfer of the dried region.

Microwave heating has the potentiality of fundamentally changing freeze drying processes so that they are no longer heat transfer limited. Heat is transferred directly in a distributed manner to the regions of the product that have the highest loss factors. The loss factors for the dried regions are much lower than the factors for the undried regions. Consequently heat is transferred to those regions that are still frozen and the energy needed for sublimation is conducted to the frozen regions where the temperatures are the lowest and where sublimation is occurring.

Unfortunately, there have been difficult problems to solve before microwave freeze drying could become used extensively. Ionization of gases is much more likely to occur at pressures usually used for freeze drying than at atmospheric pressures or under high vacuum. Ionization may cause discoloration and flavor damage to the food and it consumes a large fraction of the microwave energy.

Another problem is uneven heating which can be caused by several factors. Since the microwave energy distribution in the chamber is nearly uniform, unequal food sizes being dried will cause variations in energy absorbed and temperature in the frozen regions. Since loss factors increase with increasing temperature, a situation with positive feedback results. Overheating is further accelerated if local melting occurs because the loss factor for water in the liquid state is greater than the loss factor for ice. Fat present in meat has a higher loss factor than the dried region and tends to overheat.

Impedance matching between the output of the generator and the contents of the chamber (the load) is important. Since the load changes during drying, the power output must also be adjusted during drying.

These problems have seriously delayed the development of microwave freeze drying. In the past several years much progress has been made to alleviate these problems. In this paper a summary of previous work will be presented; this will be followed by a general evaluation of the subject and recommendations for future work.

REVIEW OF THE LITERATURE

General References, Reviews and Indirectly Related Publications

A general presentation of microwave heating has been written by Copson (1). He also devoted several chapters to microwave freeze drying. A very good overview is presented but the book does not go deeply into some of the theoretical aspects and the current limitations are not delineated. This book presents more information on microwave freeze drying than any other single reference.

Reviews of microwave freeze drying were presented by King (1970), Karel (1974) and Goldblith (1975). These papers are useful for determining the status of microwave freeze drying up through the early 1970's. King [1970 p. 436] stated that

> "Microwave energy is dissipated almost entirely to the bound, or unfreezable, water in freeze-drying. This fact limits the rate at which microwave energy can be absorbed by frozen foodstuffs and may also cause energy dissipation in the dry layer, to the extent that bound water is left behind by the retreating sublimation front."

It is well known that the loss factor for water is much greater than ice; consequently, foods undergoing drying that have large amounts of unfrozen water would need to be treated differently from foods with essentially all frozen water. The temperature of the frozen core can be controlled by the chamber pressure and this may in part explain why some of the more recent studies have been more successful freeze drying at lower pressures. The lower pressures also provide greater driving forces for mass transfer and reduce the fraction of unfrozen water.

Karel (1974) stated that the three major problems confronting the use of microwave freeze drying are:

1. The energy costs 10 to 20 times as much as energy from steam.
2. Glow discharge problems are severe especially at pressures between 13 and 666 Pa (0.1 and 5 torr).
3. Control problems result from the higher dielectric constant for water than for ice.

These problems are important to consider. The direct energy costs are generally offset by the faster drying and the savings that result from not operating the condenser and vacuum system as long. Karel pointed out that the discharge (ionization) problem can be reduced by lowering the chamber pressure to about 6.6×10^{-3} Pa (50μ). The control problem (uneven heating) is more difficult to solve.

Goldblith (1975) presented a general review of microwave heating of foods but did not discuss freeze drying in very much detail.

Microwave heating has been used for a wide variety of applications such as home cooking. Nykvist and Decareau (1976) presented an experimental and analytical investigation of heating roasts with microwave energy. This work was extended by Nykvist (1977) who developed a computer program for predicting the transient temperature distribution during microwave roasting of meat. Lyons *et al.* (1972) used microwave heating for drying absorbent materials (cotton). During the early stages of drying moisture was observed leaving the samples in liquid state. This movement was caused by high internal pressures resulting from the rapid heating. Similar effects have been observed recently during freeze drying and will be discussed later. An alternative method of providing a distributed energy source was studied by Hatcher and Sunderland (1972) who measured the influence of gamma radiation on freeze drying rates. For dose rates of 0.645 M rad/hr the increases in drying rates wre not sufficiently large to warrant further investigation.

Another application of microwave heating has been developed for compressed foods at the U.S. Army Natick Research and Development Command (1978). Microwave energy is used to disperse moisture in partially freeze dried foods prior to the compression stage. Previous techniques required that food be freeze dried to 2% moisture, then rehydrated to 15-20% moisture before the compression stage. Previously, if the first drying stage were stopped at 15-20% moisture the water would not disperse throughout the food. Since this dispersion can now be accomplished with the aid of microwave radiation, the initial drying process (carried out by conventional freeze drying) can be stopped at 15%-20% moisture. The overall savings in energy is about 50%.

There is a great deal of information written about instrumentation, field distributions and gas ionization associated with microwave applications. Since these areas are not the primary concern of this review only a few recent references will be mentioned. Bol'shakov *et al.* (1975) presented an investigation of temperature measurements in high electromagnetic fields. Their temperature measurements were

made with an electrically shielded thermocouple. A much more complete study of temperature measurements in microwave fields was reported by Ma (1976). Ringle and David (1975) presented an investigation of the electric field distribution in microwave ovens.

One of the limiting factors of microwave freeze drying is caused by power input restraints necessary to avoid ionization or electrical breakdown of the water vapor. Tetenbaum and Weiss (1979) measured the breakdown electric field in water vapor at 2.45 GHz for a wide range of pressures and two typical freeze drying chamber geometries. These measurements were made at pressures below 133 Pa (1 torr).

Papers More Directly Related to Microwave Freeze Drying Processes

Early significant papers have been written by Harper, Chichester and Roberts (1962) Decareau (1962) and Meryman (1964). More recently Hoover, Markantonats and Parker (1966a,b) presented the results of extensive tests at frequencies of 915 and 632 MHz. They freeze dried frozen chopped beef patties, potato patties, shrimp, peas and coffee extract. They found that the drying times were independent of sample thickness (between 0.25 and 1.0 inch) and were constant for different foods. It should be noted, however, that their samples had a porous or open structure which would not be the case for unground meat of similar overall thickness. The limiting factor in this work was the "glow power" (maximum power before gas ionization). During the experiments the power output was regulated to be close to but slightly less than the power that would cause ionization. These experiments were performed at chamber pressures between 2.7×10^{-3} and 8×10^{-3} Pa (20 and 60 μ). The quality of the products tested was good except for the potato patties that always exhibited regions of overheating. The total drying times were about 1/7 to 1/9 the drying times for conventional freeze drying. The maximum benefits in drying occurred toward the end of the drying cycle when conventional methods are especially slow due to the dried region that surrounds the frozen region. To reduce the moisture content from 10 to 5% by conventional means required 2 h but only 8 min with microwave freeze drying.

Ang, Ford and Pei (1975, 1978) developed a numerical solution for microwave freeze drying rates of beef which included its anistotroic properties. By carfully programming the applied field strength (Ang *et al.* 1978) they could decrease the drying time by 20% compared with drying at constant field strength. It is questionable if this type of fine tuning is practical at this time.

Gould and Kenyon (1970a,b) and Gould, Perry and Kenyon (1972) presented a series of reports on microwave freeze drying. Gould and Kenyon (1970a,b) stated that the major problems with microwave freeze drying were uneven electric fields, meltback with its inherent instabilities and corona breakdown. They presented results of analytical predictions and experimental measurements for the breakdown of air, water vapor and carbon dioxide at 2450 MHz. The most important results are for water vapor since this is the gas that is always present during freeze drying. A later investigation for water vapor has already been discussed (Tetenbaum and Weiss 1979). In this reference the writers presented the results of an analytical (computer) solution and experimental study for freeze drying slowly frozen raw beef samples at 200 Pa (1.5 torr) and 2450 MHz. They used slowly frozen samples because the ice crystal size and the mass transfer diffusivity after drying are higher than for rapidly frozen samples. Since microwave freeze drying rates are limited by mass transfer the rate of freezing has a significant influence on the subsequent drying rate. It should, however, be pointed out that the slow freezing rate may have an adverse effect on the texture of the rehydrated product. Their study is unusual in that they used chamber pressures much higher than other investigators. For their experiment they found a peak absorption at -13.4°C which helped maintain a stable drying situation. Since -13.4°C is lower than the triple point, if overheating occurred, the energy input would decrease as the temperature increased. If similar conditions could be found for other foods, the consistency and stability of microwave freeze drying would be greatly improved. The writers mentioned that salting of meat and sugaring of fruits had important influences on power absorption factors. They stressed the need to develop a sound theoretical base for microwave freeze drying. The process is too complicated to be solved by trial and error techniques for each freeze dryer and each food (and its history). They expressed the need for future work to "refine the theory to allow for temperature transients, the differing mechanism of mass transfer throughout the cycle, and heating of the dried food layers with a goal of optimizing industrial scale microwave freeze dryers and products" (Gould *et al.* 1972).

Most Recent and Ongoing Investigations

Two recent research efforts have been supported by the U.S. Army Natick Laboratories. One of these efforts has been directed by Pro-

fessors Tetenbaum and Weiss of the Physics Department at Worcester Polytechnic Institute. The other more extensive work has been conducted by Professor Y. H. Ma, R. P. Peltre and H. B. Arsem from the Chemical Engineering Department at Worcester Polytechnic Institute. Peltre (1974) performed an analytical and experimental investigation of microwave freeze drying. The investigation was carried out at a frequency of 2450 MHz. From considerations of corona discharge, this frequency has inherent advantages over lower frequencies. He developed the most comprehensive analytical model for microwave freeze drying available at that time. Numerical solutions were obtained for the rate of drying and temperature distributions in beef. He assumed that the properties of the beef were isotropic. This is a good assumption for thin samples or slabs where the heat and mass transfer occur in one direction usually parallel to the meat fiber. For samples with cube or spherical geometry, where drying occurs in more than one direction, this assumption may lead to significant errors. For this case, the papers by Ang *et al.* (1975, 1978) should be used. Peltre (1974) neglected the convective heat transfer between the vapor and the dry region using the results from Dyer and Sunderland (1968) for justifying this assumption. This did not include the case of very rapid drying which occurs with incident microwave energy. It is the writer's opinion that this assumption may not be valid unless the dried region has a nearly uniform temperature. Furthermore, the convective boundary condition used at the free surface (Eq. 4.11, p. 22, Peltre 1974) is not correct. Previous investigations indicate that the water vapor leaves the surface at such a large velocity even without microwave irradiation that convective heat transfer at the surface is negligible. Peltre used a heat transfer coefficient of 1.9×10^4 Cal/s $cm^2°C$ (7.952 $W/m^2°C$) which is a value one might expect for a body heated or cooled by natural convection in air at atmospheric pressure. Heat transfer at the surface takes place almost entirely by thermal radiation.

The numerical model developed by Peltre gave very interesting and valuable results for the transient temperature and concentration distributions during drying. The results gave values of the peak electric field strength that would not cause melting of the ice core. This is one of the two important design restraints which limits the maximum microwave power input. The other restraint is the maximum input that will not cause microwave breakdown of the water vapor. Although Peltre insists that the process is controlled (or limited) by heat transfer (See Abstract, also p. 74), later work indicates that the process is controlled by mass transfer.

Peltre's theoretical investigation provides important new information for microwave freeze drying. He also argues convincingly that Hoover *et al.* (1966a,b) were in error when they concluded that microwave freeze drying rates are independent of sample or bed thickness. Except for the final stages of drying (the final 5% of moisture), the theoretical predictions correlated well with experimental measurements. Peltre recommended chamber pressures as low as .01 Pa (75μ) in order to keep the frozen core at a lower temperature so that the drying time could be shortened by using higher microwave power and to maintain a high mass transfer driving force. Pressures below .01 Pa did not yield improvements in drying times. Maximum drying rates occurred when the sample size was as small as possible as dictated by product requirements and when the maximum power input was used which would not cause corona discharge, overheating in the dried region or melting in the frozen core. The maximum field strength that would not cause melting was 125 V/cm. The maximum value without corona discharge was 225 V/cm. The main accomplishments of his dissertation were published in references (Ma and Peltre 1975a,b).

Peltre, Arsem and Ma (1979) presented a discussion of the economic and technological status of the utilization of microwave freeze drying. At 1975 prices their comparison of microwave and conventional (radiant) freeze drying of beef patties as expressed in cents per pound of frozen products is:

	3 H Microwave Cycle	9 H Radiant Cycle	17 H Radiant Cycle
Capital investment	1.09	2.39	3.23
Utilities	1.25	1.20	1.50
Labor and maintenance	0.74	1.14	1.89
TOTAL COST	3.08	4.73	6.62

The writers expressed that the four main technical problems were corona discharge, uniform heating, impedance matching and efficiency of the applicators. The corona problem can be solved by using continuous wave (CW) microwave generators rather than standing wave generators (SWR). The later cause corona discharge at much lower power outputs than the former generator. Continuous wave generators can then deliver 4 to 10 times as much power to the freeze dryer before corona discharges occur. Consequently the minimum drying time becomes limited by the restraints caused by meltback or

overheating. One cause of nonuniform heating can be prevented by use of a non-resonant multimodes cavity. Furthermore, it is important to maintain a good dielectric load in the applicator at all times. Mechanical stirrers do not adequately improve the field uniformity, however, sweep of the microwave frequency over a given band width offers good results toward this goal. The writers stated that the impedance matching problem is "purely a matter of design and can be overcome." The efficiency of the applicator can approach 100% by decreasing wall losses and reducing leakage. This paper presented a very optimistic view of microwave freeze drying and it seems likely that the cost changes since 1975 would make microwave freeze drying even more desirable.

In one of their most recent publications, Ma and Arsem (1979) discovered and solved another problem involved with microwave freeze drying. During the initial evacuation of the system and before microwave heating is initiated, the ice core temperature becomes very low. At low temperatures, the coupling of the load, the frozen meat, with the electromagnetic field is poor. Consequently, it becomes difficult to initiate the heating of the product. They solved this by using a combination of radiant heating and microwave power. The writers discuss a number of experimental problems they encountered and their solutions. One practical problem resulted from the capacity of the condenser. The condenser normally used with the freeze dryer was not adequate for handling the large rates of water vapor without developing large pressure fluctuations. These pressure fluctuations would feed back into the drying chamber and influence the diffusion through the dried region and, it appears to this writer, the core temperature. Ma and Arsem used McLeod and Alphatron vacuum gauges. McLeod gauges utilize a compression process of a given volume of gas from the vacuum chamber. If the gas is condensible, such as water vapor, it will condense which will lead to erroneous readings and in time will also contaminate the mercury. Some investigators avoid the condensation problem by placing a cold trap or a desiccant in series with the gauge. However, this solution merely replaces one problem with another; namely determining the pressure drop across the cold trap (Dyer *et al.* 1967; Martin *et al.* 1978). Alphatrons are very sensitive to the nature of the gas in the vacuum. Calibration for the gases present is necessary for accurate measurements and in freeze drying the concentration of water vapor and air change during any given experiment.

The experimental data obtained by Ma and Arsem did not correlate very well with the mathematical model previously developed by Ma

and Peltre (1975a,b and Peltre 1974). The reason for the discrepancies turned out to be the entrainment of frozen ice crystals and unfrozen saline solutions in the rapidly flowing water vapor. Since these moisture losses did not require energy for vaporization early drying occurs at a faster rate than previously predicted. Similar effects have been observed by Luikov (1969) under high vacuum conditions and Lyons *et al.* (1972) at atmospheric pressures. Ma and Arsem developed an empirical model to correct for entrainment effects. This model was used successfully for improving the agreement between measured and predicted drying rates. Further work on the entrainment problems should yield better models for mathematical study and also might produce a means for increasing the drying rates and at the same time reduce the energy costs.

Ma and Arsem also made an economic study of the combined radiant/microwave freeze dryer. This study predicted a cost of 11.29¢/lb. of water removed for conventional freeze drying compared with 8.99¢/lb. of water removed for their combined system. The system processed 5 million pounds a year with an estimated 42% return in investment.

Arsem and Ma (1979) presented a review of microwave freeze drying. They reviewed the Ma-Peltre model. This model which was modified and improved by Arsem predicts that the maximum temperature occurs in the dried region and not at the free surface of the product. As shown in Fig. 5 (Arsem and Ma 1979) at 5 h and later there is appreciable heat transfer from the surface of the product which explains why the greatest temperature is in the dried layer. These calculations were made for a surrounding temperature of 20°C. They also presented an economic analysis similar to previous ones.

GENERAL EVALUATION OF PAST WORK

There were a number of excellent early investigations of microwave freeze drying. The early work, in the late 50's and early 60's reported by Harper, Chichester, Decareau and Meryman provided the background experience and data needed for more recent work. Hoover *et al.* (1966a,b) provided considerable practical information but their investigations were performed at 632 and 915 MHz instead of the more desirable higher frequency, 2450MHz. Hoover (1979) expressed the opinion that the lower frequencies used resulted in significant corona discharge problems. The lower frequencies were used because they were required by the sponsoring agency. They made one curious

observation that the drying rate was independent of bed depth. This conclusion was disputed later by Peltre (1974). It is the current writer's opinion that Hoover's data was carefully taken and that the difference in opinion might be explained by the type of foods dried by Hoover. Hoover's samples were open or very porous. For example, he used ground rather than unground meat. Consequently the mass transfer resistances which control ultimate microwave freeze drying rates for "solid" food products were not a major factor for Hoover's work. One of Hoover's largest problems, the corona discharge, was essentially solved by Ma and Arsem (1979). Hoover's work also demonstrates the practicality of developing commercial applications that used microwave heating for the final stages of drying. Hoover's work provided useful experimental and qualitative results.

The research of Ang, Ford and Pei (1975, 1978) was useful from a theoretical perspective. If applications of microwave freeze drying become commercially widespread, their investigations could become useful for developing the most accurately controlled systems.

Gould and Kenyon (1970a,b) and Gould *et al.* (1972) were concerned with problems of uneven electric fields, meltback and corona discharge. They developed a system for using microwave freeze drying at 200 Pa (1.5 torr). This could be contrasted to the work of Hoover and the mroe recent work of Ma *et al.* who used pressures less than .013 Pa (100 μ). The higher pressures are much easier to achieve and although corona discharges are more likely to occur at the higher pressures, other factors such as lower pumping costs and the possibility of higher core absorption factors should be considered. It is likely that different food products will dry more efficiently at different chamber pressures. Prior to freeze drying, the investigators froze their samples slowly in order to have samples with large ice crystals. The larger ice crystals would cause the samples to have higher values of the diffusion coefficient. Since drying rates of solid foods are limited by mass transfer, the prior freezing rate becomes an important factor in the ultimate microwave freeze drying rate.

The work started by Ma and Peltre and now being carried out by Ma, Arsem and Shults is probably the most significant work in mcirowave freeze drying. The accuracy of the pressure measurements in their experimental investigation may be impaired by the use of the alphatron and McLeod pressure gauges. The investigators have solved the corona discharge problem for most practical applications. This has been accomplished through the use of continuous wave rather than standing wave generators. With continuous wave generators meltback will occur before the power becomes large enough to

cause corona discharges. Another significant contribution was their recommendation of varying the mcirowave frqeuency over a given allowable band width in order to improve the uniformity of the microwave field. Their economic analysis clearly shows the usefulness of microwave freeze drying. Other important contributions involve the development of a combined radiant/microwave freeze dryer and the recognition of the ice entrainment situation.

It is important to note that the most significant work in microwave freeze drying was either sponsored by the Army Natick Laboratory or performed by researchers at the Laboratory. Examples include the early work of Harper and co-workers; Decareau; more recently work by Gould and Kenyon; and most recently by investigations by Ma, Peltre, Arsem, Tetenbaum, Weiss and Shults. The writer predicts that the long term military and commercial benefits of this support will be extremely significant.

RECOMMENDATION FOR FUTURE WORK

Introduction

The major problems preventing the commercial use of microwave freeze drying have been solved. The difficulties associated with corona discharge and uniform field intensity have been solved at least in a general manner by Ma and Arsem. Some problems may be encountered when larger commercial systems are constructed. They have also demonstrated that meltback problems can be handled by utilization of analytical results that can be used to preprogram a particular process. The current level of development should be sufficient to attract commercial applications. However, as in most fields, there is always a need for further research and large potential benefits still exist for useful research and development in this area. In a field as complicated as microwave freeze drying, there will always be important problems to solve.

Entrainment

One of the most interesting and potentially useful observations about microwave freeze drying involves entrainment. Frozen liquid particles are entrained in the water vapor leaving the food during drying. Ma and Arsem have reported that during the early stages of drying as much as 60% of the moisture of meat leaves in the solid state due to entrainment. For the entire drying process, entrainment can

account for about 20% of the total moisture removal. Although the frozen substance carries some salt and dissolved protein with it, the quality of the samples they tested does not seem to be adversely affected. At the same time considerable energy savings result because the energy normally required for the phase change is not needed. Larger savings in energy might be obtained if the means for achieving maximum entrainment can be developed. The moisture loss by entrainment is likely to be affected by a large number of factors which could be at least partially controlled. The ice crystal size and permeability of the dried layers of food are influenced by the initial freezing rate. With slow freezing the crystal size and permeability are much larger than when rapid freezing occurs. One would expect entrainment to be affected by both properties. The temperature of the product when the microwave field is first established may have an important influence. It is also possible that the power input could be varied in a manner that would cause high and fluctuating internal pressures that would increase the structural damage of the frozen matter so that it could be carried more easily by the discharging vapor. Varying chamber pressure might cause increases in solid removal especially if some distributed melting would take place. The melted regimes have higher loss factors and would become sites of high pressure. If these sites could be adequately distributed and small enough to prevent product deterioration, large amounts of ice might be forced from the product. Perhaps the easiest method would involve the combination of radiant and microwave heating to increase the loss factor of ice. Another technique would involve the insertion of small metallic probes that would serve as areas of high temperature and thus cause higher pressure regions that would enhance entrainment. Inherent problems of inserting and later removing the probes and overheating must be overcome before this technique could be utilized. Due to the large potential in energy savings, research should be undertaken to take full advantage of moisture removed by entrainment.

Processes and Their Control

Recent work by Ma and Arsem indicates that more careful control of the drying process can be achieved by combining microwave heating with conventional radiant heating. One particular advantage of this system results in the early stages of drying. When food is placed in a vacuum chamber and the pressure is reduced, initial drying causes large decreases in the temperature of the food. During

this stage the microwave unit cannot be turned on because the chamber pressure is not low enough to prevent melting. The loss factors are lower at the lower temperatures so that during the early stages of drying the microwave input is not as efficient as it could be. This situation can be improved by using radiant heating at an earlier stage of the process. Better temperature control throughout the process can be achieved through the combined use of radiant and microwave heating. Further development of the combined process may yield improvements over processes utilizing only microwave energy.

Additional work could be directed in the area of compressed foods. Research should be undertaken to see if microwave energy could be used for the initial stage of drying (to 15-20% moisture) instead of conventional drying, for the dispersion of moisture prior to compression and for the final stage of drying. Efforts could be undertaken to optimize all stages of this process.

Microprocessors ultimately offer the best means for controlling the entire cycle. They can be programmed for various conditions which would be appropriate for differing foods, loading, etc. Since they can continuously monitor different measureable quantities such as pressures, temperatures, humidities and weights, they are ideally suited for controlling food processes where the products vary somewhat for each cycle.

Hybrid cycles involving microwave heating as one stage of the overall drying process could yield important contributions. For example, for foods with small particle size, the initial drying might take place at atmospheric pressure and the final stages undertaken in a vacuum chamber with microwave input. For conventional freeze drying the slowest drying rates occur toward the end of the process. The slow drying rate is caused by the thermal resistance of the dried layer surrounding the frozen core. Since microwave energy input is not limited by the dry layer the rate of drying is not substantially decreased at the final stages. For example, Hoover observed that for his experiments it took two hours in the final stages to dry samples from 10 to 5% moisture with conventional freeze drying. The same sample took only 8 min to dry with microwave freeze drying. Consequently, hybrid cycles using conventional or atmospheric freeze drying followed by microwave drying should be considered. The output of existing freeze drying establishments could be greatly increased by removing the food from the freeze dryers and placing it in a microwave dryer for final drying. One microwave dryer used in this way could handle the final drying of several conventional dryers.

Alternatively, microwave units might be added into existing dryers. One disadvantage of using microwave freeze drying only for the final stages is that the entrainment effect would be greatly diminished.

Gould and Kenyon recommended using pressures around 200 Pa (1.5 torr). More recent investigators use much lower pressures. It is possible, however, that the higher pressures should be used for some foods. The pumping and condenser costs are lower at the higher pressure.

For open structure foods, thick beds may be more economical to process. Thick beds would permit an increased output for each batch dried. The optimization of microwave drying of deep beds could be explored.

Microwave freeze drying is still in a very early stage of development. Consequently, it is difficult to evaluate the many different processes and combinations that are feasible. It is likely that different foods will require different processes. However, one installation shoudl be able to yield the different conditions necessary for widely differing processes. It is also likely that actual processes will not approach the ultimate process due to inherrent restraints of the system and its components coupled with variations between different foods and different batches of the same food.

Design

The design of microwave freeze dryers is possible with existing technology. There is adequate information available to design commercial dryers that should produce good quality freeze dried food at a lower cost than conventional freeze dryers. These installations could be entirely microwave or a combination of microwave and radiant heating. However, since industry has been reluctant to manufacture microwave freeze dryers, detailed design specifications for typical applications might stimulate more activity. Specific designs which have been built and tested for modifying existing freeze dryers would serve as a very useful guide for industry.

The condensers of microwave freeze dryers are subjected to different loading characteristics from conventional dryers. The build up of ice occurs more rapidly and the temperature of the condenser is lower due to operation of lower pressures. Consequently, condensers should be designed for microwave applications.

Some interest has existed for the development of special purpose microwave freeze dryers that would be constructed for one specific product. This equipment would be so specialized that its development

should wait for the industry that has demonstrated the unique need. Thus it would seem important at this time to concentrate research and development efforts for equipment that would serve many applications.

Basic Research

There are a number of areas where basic research could be useful and productive. Since microwave freeze drying of solid foods is limited by mass transfer, there is a need to measure the mass transfer permeabilities. The loss factors are also needed. The effects of the original freezing rate on microwave freeze drying should be investigated. Since the freezing rate influences the ice crystal size, it will also influence the permeability and moisture loss by entrainment.

The Ma-Peltre-Arsem computer model is an excellent analysis of the drying cycle. It could be extended to cover applications where nonisotropic properties of the foods are important and for deep beds of foods made up of particulates. Their model could also be applied to different foods. Convection between the water vapor and the dried food product could be assimilated into their model. The boundary condition at the free surface should be radiation heat transfer. This detailed and accurate solution could then be used as a guide for the development of approximate solutions that would yield adequate accuracy for design purposes and for comparing various processes. Simpler solutions, although not as accurate, would be most beneficial for the design of dryers and the specification of different processes.

The Transfer of Technology

The largest and perhaps the most important problem now facing the commercialization of microwave freeze drying is the transfer of technology to the equipment manufacturers and the food processors. A pilot or demonstration project of sufficient size would accelerate this process. A conference that would bring together various interested parties could prove to be most beneficial. If main research and development personnel were to meet with equipment manufacturers, food processers and large purchasers of freeze dried foods, it is the writer's opinion that much progress would be made toward commercialization of microwave freeze drying.

There also exists a need for less technically sophisticated publications to describe the design and use of microwave freeze dryers. The literature currently available may well intimidate some engineers and discourage their exploration of microwave freeze drying designs and applications.

ACKNOWLEDGMENTS

The writer expresses his gratitude for support from the U.S. Army Natick Research and Development Command. The views and opinions and/or findings contained in this report are those of the author and should not be construed as an official Department of Army position, policy, or decision, unless so designated by other documentation.

REFERENCES

ANG, T. K. 1975. Microwave freeze-drying: a theoretical and experimental investigation, Ph.D. dissertation, Univ. Waterloo (Canada).

ANG, T. K., FORD, J. D. and PEI, D. C. 1978. Optimal modes of operation for microwave freeze drying of food. J. Food Sci., *43*. 648.

ANG, T. K., FORD, J. D. and PEI, D. C. Microwave freeze-drying of food a theoretical investigation. To appear in the Int. J. Heat and Mass Transfer.

ANON. 1978. Microwave/freeze-dried compressed foods. Food Processing, July, p. 44.

ARSEM, H. B. and MA, Y. H. 1979. Microwave freeze drying: A brief review. In *Section IV, Developments in Drying*, (A. S. Mujamdar, ed. Science Press, 8 Brookstone Drive, Princeton, NJ.

BOL'SHAKOV, A. S., BOL'SHAKOV, S. A., KARPEYEV, I. I., MITROFANOV, N. S., ROGOV, I. A. and KHLEBNIKOV, V. I. 1975. Measurement of food product temperature in a super-high temperature (microwave ?) field. (In Russian) Elektronnaya Obrabotka Materialov, *61*(1) *73*.

COPSON, D. A. 1975. *Microwave Heating*, 2nd Ed., Avi Publishing Co., Westport, CT.

DECAREAU, R. V. 1962. Microwave freeze-drying. In *Freeze-Drying of Foodstuffs* (S. Cotson and D. B. Smith, eds.) Columbine Press, Manchester, England.

DYER, D. F., MAYNE, R. W. and SUNDERLAND, J. E. 1967. Total pressure drop across a cold trap in low vacuum applications. Brit. J. Applied Physics, *18*, 297.

DYER, D. F. and SUNDERLAND, J. E. 1968. The role of convection in drying. Chemical Eng. Sci. *23*, 965.

GOLDBLITH, S. A. 1975. Principles and applications of radio-frequency energy to food preservation with particular reference to concentration and dehydration. In *Freeze Drying and Advanced Food Technology*, Chapter 41, (S. A. Goldblith, L. Rey, and W. W. Rothmayr, eds.), Academic Press, New York.

GOULD, J. W. and KENYON, E. M. 1970. Corona breakdown and electric field strength in microwave freeze drying. Paper presented Int. Microwave Power Inst. Conference (IMP), The Hague, Netherlands.

GOULD, J. W. and KENYON, E. M. 1970. Microwave applications to freeze dehydration, gaseous breakdown vs. electric field strength, Technical Report 71-15-FL, Food Lab., U.S. Army Natick Lab., Nov.

GOULD, J. W., PERRY, J. T., JR. and KENYON, E. M. 1972. Microwave

aplications to freeze dehydration-preliminary evaluation of a 2450 MHz system. Technical Report 72-24-FL, p. 11 Food Lab., U.S. Army Natick Lab., Feb.
HARPER, J. C., CHICHESTER, C. O. and ROBERTS, T. E. 1962. J. Agric. Eng. *43*(78), 90.
HATCHER, J. D. and SUNDERLAND, J. E. 1972. The effect of gamma radiation on freeze-drying rates. J. Food Sci. *37*, 336.
HOOVER, M. W. 1979. Personal Communication. Sept.
HOOVER, M. W., MARKANTONATOS, A. and PARKER, W. N. 1966. UHF dielectric heating in experimental acceleration of freeze-drying of foods, Food Technol. *20*(6), 103.
HOOVER, M. W., MARKANTONATOS, A. and PARKER, W. N. 1966. Engineering aspects of using UHF dielectric heating to accelerate the freeze-drying of foods. Food Techn. *20*(6), 107.
KAREL, M. 1974. Fundamentals of dehydration processes. In Advances in Preconcentration and Dehydration of Foods, (A. Spicer ed.) p. 45, J. Wiley, New York.
KING, C. J. 1970. Freeze drying of foodstuffs. CRC Crit. Rev. Food Techn. *1*, Sept.
LUIKOV, A. V. 1969. Heat and mass transfer in freeze drying at high vacuum. Int. Inst. Ref. Commission X, Lausanne, Switzerland.
LYONS, D. W., HATCHER, J. D. and SUNDERLAND, J. E. 1972. Drying of porous medium with internal heat generation. Intl. J. Heat & Mass Transfer, *15*, 897.
MA, Y. H. 1976. Temperature measurements in a microwave field. Final Report, Task 74-432 Dated 24 July 1974, U.S. Army Natick Res. Develop. Center, Jan. 19.
MA, Y. H. and ARSEM, H. P. 1979. Theoretical study of freeze-drying. Final Report for Grant DAAK03-74-G-0002, U.S. Army Natick Res. and Develop. Command, Aug. 21.
MA, Y. H. and PELTRE, P. R. 1975. Freeze dehydration by microwave energy, Part I. Theoretical investigation. AIChE J. *21*, 335.
MA, Y. H. and PELTRE, P. R. 1975. Freeze dehydration by microwave energy, Part 2. Experimental study. AIChE J. *21*, 344.
MARTIN, D. H., LEWIS, S. K. and SUNDERLAND, J. E. 1978. The influence of cold traps in low-vacuum pressure measurements. J. Phys. E: Instrum. *11*, The Inst. Physics. Great Britain.
MERYMAN, H. T. 1964. Induction and dielectric heating for freeze-drying. In *Aspects Theoriques et Industriels de la Lyophilisation*, (L. Rey, ed.) Hermann, Paris.
NYKVIST, W. E. 1977. Microwave meat roasting—A computer analysis for cylindrical roasts, Report Natick TR-77/022, U.S. Army Res. and Develop. Command, Food Eng. Lab., Natick, MA.
NYKVIST, W. E. and DECAREAU, R. V. 1976. Microwave meat roasting. J. Microwave Power, *11*(1) 3.
PELTRE, P. R. F. 1974. Freeze dehydration by microwave energy. Technical Report 75-84-FEL, Food Eng. Lab., U.S. Army Natick Lab., December. Also submitted as Ph.D. dissertation in Chem. Eng. at W. P. I. p. 21
RINGLE, E. C. and DAVID, B. D. 1975. Measuring electric field distribution in a microwave oven, Food Technol., p. 46, Dec.
TETENBAUM, S. J. and WEISS, J. A. 1979. Microwave breakdown of water vapor. IEEE Transactions Plasma Sci. PS-7(2), 109. June.

RETENTION OF FREE FATTY ACIDS DURING SPRAY DRYING OF CHEDDAR CHEESE

C. H. AMUNDSON,[1] K. ISHINO[2] and R. C. LINDSAY
Department of Food Science
University of Wisconsin—Madison
Madison WI 53706

Received for Publication June 22, 1981

ABSTRACT

The effect of processing variables, such as total solids, atomization pressure and inlet drying air temperature, on the retention of free fatty acids (FFA) in Cheddar cheese during spray drying was investigated. A cheese homogenate was prepared with minimum heat treatment and spray dried at a feed temperature of approximately 43°C. The retention of FFA increased with molecular weight under all drying conditions. In the absence of emulsifying salts, a lower total solids content in the homogenate fed to the dryer increased the retention of FFA. For example, the maximum retention of butyric acid at 30% T.S. and at 40% T.S. was about 60% and 35%, respectively. In addition, higher atomization pressures and higher inlet drying air temperatures decreased the retention of FFA. Emulsifying salts were effective, especially at 40% T.S., in increasing the retention of FFA. These results could be predicted from the selective diffusion theory of the retention of volatile compounds.

INTRODUCTION

In the food industry, dehydration is widely used to extend shelf-life and to reduce bulk. The most commonly used method of dehydration is spray drying. However, loss of volatile flavor compounds during dehydration has long been recognized as a problem. This is especially true of products such as dried cheese whose flavor depends upon a delicate balance of numerous flavor compounds, many of which are volatile. Earlier researchers have studied this problem (Rogers 1962; Bullock *et al.* 1963; Bradley and Stine 1963, 1964, 1968; Metwally

[1]Address Correspondence to C. H. Amundson
[2]Present address: Koiwai Dairy Products, Co., Ltd., 4-1, Marunouchi 2 Chome, Chiyoda-Ku, Tokyo, Japan

Journal of Food Process Engineering 4 (1980) 213-225.

1968), but most of this work has been qualitative rather than quantitative.

On the other hand, the retention of volatile compounds during spray drying was investigated quantitatively (Boudreau *et al.* 1966; Reineccius and Coulter 1969; Rulkens and Thijssen 1972; Reineccius *et al.* 1978), and theoretical models which attempt to explain flavor retention have been developed (Bomben *et al.* 1973; King and Massaldi 1974; Kerkhof and Thijssen 1977). However, flavor retention is extremely complex, and additional studies are needed.

In this study, the retention of FFA during the spray drying of Cheddar cheese has been measured in relation to processing variables such as total solids, atomization pressure and inlet drying air temperature. Volatile FFA, especially butyric acid, have been identified as important flavor compounds in Cheddar cheese. A new gas chromatographic (GC) method for the quantitative analysis of low levels of FFA in butter and cream developed by Woo and Lindsay (1980) and adapted to cheese (Woo and Lindsay 1981) was used in this study. This method is an improvement over previous ones because the analytical error due to the fat hydrolysis on the column for isolation of FFA has been eliminated and a stable GC system for analysis of FFA has been developed.

MATERIALS AND METHODS

Cheddar Cheese Homogenate

Nine kg blocks of Cheddar cheese from 2 to 15 months old were obtained from the University of Wisconsin dairy plant. In each trial, 18 to 45 kg of cheese was used. Refrigerated cheese was cut into small slabs and ground in a sausage grinder (Style 201, Sanitary Co.). The ground cheese was slurried to a desired concentration of total solids by adding water at 37°C and mixing. Emulsifying salts which consisted of equal amounts of sodium citrate and disodium phosphate were used in two trials to determine their effect on FFA retention. The emulsifying salts were weighed out in an amount equal to 2% of the weight of the ground cheese. These salts were dissolved in water and added to the cheese slurry which was then warmed to 41°C and homogenized in a two-stage homogenizer (Manton-Gaulin, Model 400), with 35 kg/cm^2 on the second stage, and a total pressure of 140 kg/cm^2 on the first-stage.

Spray Drying

The cheese homogenate was spray dried in the University of Wisconsin experimental dryer (Amundson 1967). The homogenate at 43°C was atomized through a Whirljet or SX type pressure nozzle (Spraying Systems Co.). Inlet air temperature was controlled by adjusting a gas fired burner. The outlet air temperature was maintained at 90 ± 3°C. The processing variables evaluated were total solids in the homogenate (30 and 40%), atomization pressure (49.2, 105.5 and 211.0 kg/cm^2) and inlet air temperature (158 and 193°C). Based on preliminary trials, the following standard conditions were used as control: Total solids 30%; feed pressure 105.5 kg/cm^2; feed temperature 43°C; inlet air temperature 193°C; outlet air temperature 91°C; and no emulsifying salts. Only one variable was changed at a time. For the spray drying of cheese homogenates without emulsifying salts, young cheese of 2 to 3 months old was used.

Sample Analysis

Samples for analyses were taken from the cheese, the homogenate and the powder. All powder samples were collected from the primary outlet of the dryer. All samples were stored in a freezer until analyzed.

The moisture contents of the cheese and the homogenate were analyzed by an Infra-red Moisture Balance (Cenco) and of the powders by the Toluene distillation method (Joslyn 1970). Total fat in the cheese was analyzed by the modified Babcock method (Marth 1979), total fat in the powder by the Roese-Gottlieb method (Marth 1979), and free fat in the powder by the method of Thomas *et al.* (1957). All analyses were made in duplicate.

Free fatty acids with even carbon-numbers in the cheese, the homogenate and the powder were analyzed by a modification of the method of Woo and Lindsay (1980, 1981). The modification was made in the preparation of the cap material which is intended to uniformly distribute the sample in an acidic system and allow selective elution of fats and FFA from other components. Cheese paste, which was to be incorporated in the cap material, was prepared as follows: For cheese analysis, 20 g of cheese was mixed with 15 g of distilled water and homogenized in a Waring Blendor for 4 min, and an 8.75 g sample was weighed for subsequent use. For the 30 and 40% cheese homogenate analyses, a frozen sample was thawed in a warm water bath and mixed thoroughly. For the 30% T.S. samples, 8.2 g of homogenate was weighed and used as cheese paste without dilution. For the 40% T.S. samples, 7.5 g of homogenate was mixed with 1.25 g

of distilled water. For the powder analyses, 3.0 g of powder was reconstituted into a cheese paste by adding 5.95 g of distilled water. Each cheese paste was acidified with 0.7 ml of 5.5 N H_2SO_4, and mixed thoroughly with 7 g of silicic acid, 30 g of pulverized anhydrous sodium sulfate, 6 g of celite and 1 ml of internal standard solution of heptanic acid. The mixture served as the cap material for each sample.

The validity of this modification was confirmed by Woo and Lindsay (1981). The FFA were isolated by a modified silicic acid-potassium hydroxide arrestant column and were separated with a 1.8 m long by 2 mm inner diameter glass column packed with 10% neopentyl glycol adipate on 80 to 100 mesh Chromosorb W. A Varian-Aerograph Model 1740-10 gas chromatograph equipped with a flame ionization detector and a Varian Model A-25 recorder were employed. The isolation and concentration procedures of FFA, the GC conditions and the calculation method were as described by Woo and Lindsay (1980). Correction factors for fat hydrolysis developed by these authors were applied to prevent overestimation of FFA. The percent retention of FFA in cheese homogenate and powder was expressed as percent recovery by comparing the amount of each FFA in the cheese with the amount remaining in the homogenate and in the powder on a dry weight basis. Each sample was analyzed in duplicate.

The organoleptic quality of cheese and powder was evaluated by individuals experienced in dairy products judging.

RESULTS AND DISCUSSION

Retention of FFA in Cheese Homogenate

Data for individual FFA in typical samples used in the study are shown in Table 1 to indicate the amounts of FFA present. Table 2 shows the retention of FFA during the preparation of cheese homogenates. In 30% T.S. homogenate without emulsifying salts, roughly 6 to 16% of butyric acid and less than 10% of caproic and caprylic acids were lost. Virtually no loss was observed in capric and longer chain FFA. A similar retention of FFA was observed in 40% T.S. homogenate. The addition of emulsifying salts appeared to increase the retention of short chain FFA.

Retention of FFA in Cheese Powder

Effect of Atomization Pressure and Total Solids on the Retention of FFA. Table 3 shows the retention of FFA under

Table 1. Concentrations of FFA in typical Cheddar cheese, homogenate, and cheese powder samples

Fatty Acid	Concentration		
	Cheese	Homogenate	Powder*
	(ppm, dry wt. basis)		
$C_{4:0}$	37.6	32.4	12.4
$C_{6:0}$	20.2	18.9	8.3
$C_{8:0}$	17.7	16.6	11.5
$C_{10:0}$	35.4	35.0	32.2
$C_{12:0}$	64.7	61.1	65.4
$C_{14:0}$	194.8	195.3	195.2
$C_{16:0}$	728.9	718.7	870.4
C_{18}congeners	820.3	870.4	814.5

*Drying conditions: inlet air 190-195°C, pressure 105.5 kg/cm^2, 30% T.S., no emulsifying salt. FFA of powder average of duplicate analyses; standard deviation $<\pm 5\%$ for all determinations

Table 2. Retention of free fatty acids during the preparation of cheese homogenate

	Conditions			
	No Emulsifying Salts		Emulsifying Salts Added*	
	30% T.S.**	40% T.S.	30% T.S.	40% T.S.
FFA	Retention (%)			
$C_{4:0}$	89 ± 5	84	95	92
$C_{6:0}$	97 ± 4	86	100	111
$C_{8:0}$	100 ± 9	89	101	95
$C_{10:0}$	100 ± 5	104	97	101
$C_{12:0}$	102 ± 5	94	103	96
$C_{14:0}$	102 ± 2***	93	98	89
$C_{16:0}$	98 ± 8	97	87	99
C_{18}congeners	102 ± 5	95	102	106
pH of homogenate	4.9 - 5.1	5.0	5.6	5.7
No. of trials	7	1	1	1

*1:1 mixture of sodium citrate and disodium phosphate. 2% emulsifying salts was used based on the weight of Cheddar cheese
**Mean ± standard deviation
***Six trials

standard conditions and the effect of increasing the atomization pressure from 105.5 kg/cm^2 to 211.0 kg/cm^2, as well as the effect of increasing total solids content to 40%. The properties of the resultant powders are shown in Table 4.

The retention of butyric, caproic and caprylic acids were ca 33%, 40% and 64%, respectively, under standard conditions. More than 90% of lauric and longer chain acids were retained in the powder. In

Table 3. Effect of atomization pressure and total solids on the retention of free fatty acids during the spray drying of Cheddar cheese at an inlet air temperature of 190-195°C

Drying Conditions	I*	II	III
Pressure (kg/cm²)	105.5	211.0	105.5
T.S. (%)**	30.3	30.1	39.9
FFA		Retention (%)**	
$C_{4:0}$	33 ± <1	24 ± 2	24 ± 5
$C_{6:0}$	40 ± 1	37 ± 2	43 ± 2
$C_{8:0}$	64 ± 1	47***	51 ± 2
$C_{10:0}$	91***	70 ± <1	84 ± <1
$C_{12:0}$	99 ± 2	72 ± <1	86 ± 5
$C_{14:0}$	98 ± 3	71 ± 3	89 ± 7
$C_{16:0}$	96 ± 5	82 ± 2	92 ± <1
C_{18}congeners	100 ± 1	87 ± 2	95 ± 7
No. Trials	2	2	2

*Standard drying conditions
**Average of two trials, except as indicated
***Single determination

Table 4. Properties of spray-dried cheese powders obtained at an inlet air temperature of 190-195°C*

	Drying Conditions		Moisture Content (%)	Fat Content (%, Dry Basis)	Free Fat (%)	Flavor and Texture
	Pressure (kg/cm²)	T.S. (%)				
I.	105.5	30.3	3.3**	50.6	87	Clean, bland
II.	211.0	30.1	2.0**	50.6	86	Strong toasted cheese flavor.
III.	105.5	39.9	3.9**	50.2	86	Toasted cheese flavor, coarse or grainy

*Single determinations, except as indicated
**Average of two trials

general, the retention percentages increased with carbon chain length.

An increase in the atomization pressure to 211.0 kg/cm² decreased the retention of all FFA. The retention of butyric acid decreased by 8% to ca 24%. Especially significant was the decreased retention of the long chain FFA from myristic to linolenic acids, which is undoubtedly due to the greater drying efficiency obtained because of decreased drop size which is evidenced by the reduced moisture content.

Increasing the total solids to 40% at 105.5 kg/cm^2 atomizing pressure also decreased the retention of FFA compared with that under standard conditions. These detrimental effects of increasing the total solids content may be attributed to the high viscosity of the homogenate. Concerning the effect of the viscosity on the retention of volatile compounds, Rulkens and Thijssen (1972) reported that highly viscous solutions of malto-dextrin retained less volatile compounds than low viscosity solutions when spray dried, other conditions being the same. The authors theorized that a greater amount of volatile compounds would evaporate from the atomized hollow cone which would persist for a longer time due to the high viscosity and that its detrimental effect would prevail over the favorable effect of larger droplet diameters and a more rapid dry skin formation. Later, Kerkhof and Thijssen (1977) stated that, at high initial dissolved solids concentration, the major loss was due to the expansion of drying droplets and crater formation since internal circulation streams would be suppressed in highly viscous droplets and the temperature rise would be rapid.

From these results, it is confirmed that the atomization of a cheese homogenate at a high pressure is detrimental to the retention of FFA, presumably due to the formation of small droplets. In addition, the greater retention of FFA at 30% T.S. versus 40% T.S. suggests that the viscosity of the homogenate will influence the retention of volatile flavor compounds.

Effect of Atomization Pressure and Emulsifying Salts at Low Inlet Air Temperature and 30% T.S. It has been reported that low inlet air temperatures generally improve the retention of volatile compounds during spray drying (Reineccius and Coulter 1969; Rulkens and Thijssen 1972). To determine the effect of this on FFA retention in spray dried cheese, the inlet air temperature was reduced from 190-195°C to 157-158°C. In addition, since high atomization pressure was shown to reduce FFA retention, the effect of lowering the pressure still further from 105.5 to 49.2 kg/cm^2 was evaluated both with and without added emulsifying salts (Tables 5 and 6). When the inlet air temperature was reduced, it can be seen that the retention of butyric and caproic acids increased to ca 47% and 52%, respectively. However, the retention of caprylic, capric and lauric acids decreased slightly, compared with retention under standard conditions. When the atomization pressure was reduced to 49.2 kg/cm^2, a further increase in the retention of short chain FFA was observed. The retention of butyric, caproic and caprylic acids

Table 5. Effect of atomization pressure and emulsifying salts on the retention of free fatty acids during the spray drying of Cheddar cheese at 30% total solids and an inlet air temperature of 157-158°C

Drying Conditions	IV	V	VI
Pressure (kg/cm²)	105.5	49.2	49.2
Emulsifying Salts*	—	—	+
FFA		Retention (%)	
$C_{4:0}$	47	60 ± 3	68
$C_{6:0}$	52	63 ± 5	85
$C_{8:0}$	53	78**	88
$C_{10:0}$	79	88 ± 3	88
$C_{12:0}$	87	92 ± 1	100
$C_{14:0}$	95	96 ± 7	102
$C_{16:0}$	87	94 ± 4	104
C_{18}congeners	95	97 ± 2	104
No. of trials	1	2	1

*1:1 mixture of sodium citrate and disodium phosphate
**Single determination

Table 6. Properties of spray-dried cheese powders obtained at 30% total solids and an inlet air temperature of 157-158°C*

	Drying Conditions		Moisture Content (%)	Fat Content (%, Dry Basis)	Free Fat (%)	Flavor and Texture
	Pressure (kg/cm²)	Emulsifying Salts				
IV.	105.5	—	2.4**	50.3	87	Clean, very mild, smooth
V.	49.2	—	4.1**	50.2	82	Clean, mild Cheddar flavor
VI.	49.2	+	4.1**	52.1	81	Clean, fair Cheddar flavor, smooth

*Single determination, except as indicated
**Average of two trials

increased to ca 60%, 63%, and 78%, respectively. The flavor of the resulting powder also showed an improvement and a diminished toasted cheese flavor.

These results generally agree with the rules for greater retention, suggested by Kerkhof and Schoeber (1974). Therefore, the effect of each processing variable can be apparently explained by their interpretation, even though a cheese homogenate is much more complex than a simple aqueous model system.

The increased retention of FFA by lowering the atomizing pressure to 49.2 kg/cm^2 is conceivably due to the formation of larger droplets. Although the constant rate period of drying is prolonged because of the decreased surface area per unit volume, a higher concentration of FFA remains in the droplet at the time of the formation of a dry skin. Subsequently, greater amounts of FFA are retained in the dry particle with a minimum loss caused by the expansion of the droplet and the crater formation, owing to low inlet air temperature.

The effect of emulsifying salts at low inlet air temperature and atomization pressure appears to result in greater retention of the short chain FFA. The important action of emulsifying salts is the solubilization of the cheese proteins. Because soluble proteins stabilize fat globules, the migration of fat to the surface of a drying droplet may be reduced, and the vaporization of FFA from the surface decreased. in addition, the hydration of sodium paracaseinate may change the relative volatilities of FFA. Reineccius and Coulter (1969) reported that the presence of sodium caseinate in a water-diacetyl solution greatly reduced the vapor pressure of the diacetyl. Although no data are available on the effect of sodium or calcium paracaseinate on the relative volatilities of FFA, sodium paracaseinate may reduce the relative volatilities of FFA. This would decrease the loss of FFA during the droplet formation period. Furthermore, the hydration may influence the drying characteristics of a liquid droplet.

From these results, the favorable effect of low atomization pressure and a low inlet air temperature was confirmed. Even in a fat-containing system like cheese, the retention of FFA from butyric to lauric acids apparently follows the prediction of the selective diffusion theory (Thijssen and Rulkens 1968). In addition, the flavor of the powder was apparently related to the retention of FFA. This implies that more volatile flavor compounds in cheese, most of which are fat-soluble, may be retained in accordance with the retention of FFA.

Effect of Atomization Pressure and Emulsifying Salts at Low Inlet Air Temperature and 40% T.S. In general, increasing the total solids from 30% to 40% T.S. decreased the retention of FFA under standard operating conditions. However, we had not previously determined the effect of emulsifying salts and reduced atomization pressure at a reduced drying inlet air temperature of 157–158°C. This information is shown in Tables 7 and 8. When a 40% T.S. homogenate was spray dried at a temperature of 157–158°C and a pressure of 105.5 kg/cm^2, the retention of butyric and caproic acids decreased to 27% and 39%, respectively, when compared to a 30% T.S. homogenate dried

Table 7. Effect of atomization pressure and emulsifying salts on the retention of free fatty acids during the spray drying of Cheddar cheese at 40% total solids and an inlet air temperature of 157-158°C

Drying Conditions	VII	VIII	IX
Pressure (kg/cm²)	105.5	49.2	49.2
Emulsifying Salts*	—	—	+
FFA		Retention (%)	
$C_{4:0}$	27	35 ± <1	61
$C_{6:0}$	39	54 ± 2	86
$C_{8:0}$	53	67**	90
$C_{10:0}$	86	83 ± <1	89
$C_{12:0}$	81	85 ± 7	96
$C_{14:0}$	94	93 ± 6	92
$C_{16:0}$	95	100 ± 2	108
C_{18}congeners	97	97 ± 8	102
No. of trials	1	2	1

*1:1 mixture of sodium citrate and disodium phosphate
**Single determination

Table 8. Properties of spray dried cheese powders obtained at 40% total solids and an inlet air temperature of 157-158°C*

	Drying Conditions		Moisture Content (%)	Fat Content (%, Dry Basis)	Free Fat (%)	Flavor and Texture
	Pressure (kg/cm²)	Emulsifying Salts				
VII.	105.5	—	1.8**	50.3	87	Weak toasted cheese flavor, slightly grainy
VIII.	49.2	—	5.5**	48.8	97	Weak toasted cheese flavor, very grainy
IX.	49.2	+	3.6**	53.3	52	Weak toasted cheese flavor, Cheddar flavor, smooth

*Single determination, except as indicated
**Average of two trials

under the same conditions where the retention was 47% and 52%, respectively. Virtually no change was observed in the retention of the other FFA. Lowering the pressure from 105.5 to 49.2 at 40% T.S. increased the retention of butyric and caproic acids to 35% and 54%, respectively. However, the moisture content increased to 5.5% as a result of increased drop size and decreased drying efficiency, which alone could account for the increased FFA retention.

Under the same pressure and air temperature conditions, the retention of butyric acid was ca 25% greater at 30% T.S. (60% retention) than at 40% T.S. (35% retention).

From these results, it is clear that the spray drying of 40% T.S. homogenate had adverse effects on the retention of FFA. However, the effect of added emulsifying salts at 40% T.S. was notable. About 61% of butyric acid and more than 85% of the other acids were retained. In addition, the flavor of the powder improved and the moisture content and free fat (Table 8) decreased markedly compared with the powder dried without emulsifying salts. The 52% free fat in the powder obtained from 40% T.S. homogenate was significantly lower than 81% from 30% T.S. homogenate. Although the same amount of emulsifying salts were used in each trial, (2% of the weight of the cheese) the lower free fat at 40% T.S. may result from the higher concentration of emulsifying salts in the aqueous phase of the homogenate. The higher concentration of emulsifying salts may solubilize a larger amount of calcium paracaseinate and enhance fat golbule stabilization. This could also account for the increased retention of FFA. Thus, decreased surface fat and decreased relative volatilities increased FFA retention. Further, this effect on retention would be more pronounced at 40% T.S. than at 30% T.S.

These results indicate increased protein solubility and the resulting decrease in viscosity may be an important factor in the retention of volatile compounds during spray drying. Total solids content may not be a good indicator because the viscosity of a cheese homogenate changes depending upon the age or type of cheese.

The use of emulsifying salts is effective especially at 40% T.S. Although there may be a need for additional research to determine the effect of emulsifying salts versus homgoenization, it appears that the reduction of free fat in the powder is important in the retention of volatile flavor compounds as suggested by Reineccius *et al.* (1978).

CONCLUSION

The retention of FFA in the spray dried cheddar cheese powder was influenced by processing variables such as total solids, atomization pressure, inlet air temperature and added emulsifying salts.

Best retention of FFA was attained when a 30% T.S. homogenate was spray dried at a low atomization pressure and a low inlet air temperature in the preence of emulsifying salts. Under these conditions, ca 68% of butyric acid and more than 85% of the other FFA were

retained in the powder. Increasing atomization pressure or inlet air temperature invariably decreased the retention. A highly viscous homogenate of 40% T.S. decreased the retention significantly.

The effect of these processing variables generally agreed with the prediction of the selective diffusion theory.

ACKNOWLEDGMENTS

This work was supported in part by the College of Agricultural and Life Sciences, the Food Engineering Pilot Plant Laboratory and the Dairy Plant, University of Wisconson—Madison. The authors also wish to thank H. Gireke and A. Woo for their assistance.

REFERENCES

AMUNDSON, C. H. 1967. Spray drying of dairy and food products. Ashrae J. *9*, 70-73.

BOMBEN, J. L., BRUIN, S., THIJSSEN, H. A. C. and MERSON, R. L. 1973. Aroma recovery and retention in concentration and drying of foods. Adv. in Food Res. *20*, 1.

BOUDREAU, A., RICHARDSON, T. and AMUNDSON, C. H. 1966. Spray-dried butter and loss of volatile fatty acids during spray drying. Food Technol. *20*, 668.

BRADLEY, R. L., JR. and STINE, C. M. 1963. Spray drying of natural cheese. Mfd. Milk Prod. J. *54*, 8.

BRADLEY, R. L., JR. and STINE, C. M. 1964. Foam spray drying of natural cheese. Mfd. Milk Prod. J. *55*, 6.

BRADLEY, R. L., JR. and STINE, C. M. 1968. A gas chromatographic study of the volatile flavors in natural and spray dried Cheddar cheese. J. Gas Chromatog. *6*, 344.

BULLOCK, D. H., HAMILTON, M. D. and IRVINE, D. M. 1963. Manufacture of spray-dried Cheddar cheese. Food in Canada. *23*, 26.

JOSLYN, M. A. 1970. *Methods in Food Analysis: Physical, Chemical and Instrumental Methods of Analysis*, Academic Press, New York.

KERKHOF, P. J. A. M. and SCHOEBER, W. J. A. H. 1974. *Advances in Preconcentration and Dehydration of Foods*, AVI Publishing Co., Westport, CT.

KERKHOF, P. J. A. M. and THIJSSEN, H. A. C. 1977. The effect of process conditions on aroma retention in drying liquid foods. AIChE symposium Series. *163,* 33.

KING, C. J. and MASSALDI, H. A. 1974. Aroma preservation during evaporation and drying of liquid foods: consideration of mechanism and effects of more than one phase being present. Proc. IV. Int. Congress Food Sci. and Technol. *4*, 183.

MARTH, E. H., editor. 1979. Standard methods for the examination of dairy products. 14th ed. American Public Health Association. Washington, D.C.
METWALLY, M. M. 1968. A gas chromatographic method for the analytical determination of carbonyl compounds and a study of the effect of spray drying on the flavor of cheese. Ph.D. thesis. University of Wisconsin. 293 pp.
REINECCIUS, G. A. and COULTER, S. T. 1969. Flavor retention during drying. J. Dairy Sci. *52*, 1219.
REINECCIUS, G. A., ANDERSON, H. C. and FELSKA, B. J. 1978. Influence of butter fat content on methyl-ketone retention during spray drying as determined by high pressure liquid chromatography of 2,4-dinitrophenyl-hydrazones. J. Food Sci. *43*, 1495.
ROGERS, R. H. 1962. Process of manufacturing dehydrated powdered cheese. U.S. Pat. 3,056. Oct. 2.
RULKENS, W. H. and THIJSSEN, H. A. C. 1972. The retention of organic volatiles in spray-drying aqueous carbohydrate solutions. J. Food Technol. *7*, 95.
THIJSSEN, H. A. C. and RULKENS, W. H. 1968. Retention of aroma in drying food liquids. De Ingenieur. *85*, 45.
THOMAS, R. H., HOLGREN, C. J., LOKAY, L. and BLOCK, F. 1957. A rapid method for determining free fat in dry milks. J. Dairy Sci. *40*, 605.
WOO, A. H. and LINDSAY, R. C. 1980. Method for the routine quantitative gas chromatographic analysis of major free fatty acids in butter and cream. J. Dairy Sci. *63*, 1058.
WOO, A. H. and LINDSAY, R. C. 1981. Rapid method for quantitative analysis of individual free fatty acids in Cheddar cheese. J. Dairy Sci. Manuscript submitted.

RESPONSE SURFACE ANALYSIS OF EGG WHITE GELLING PROPERTIES IN A MEAT LOAF ANALOG

Y. C. JAO, J. W. LARKIN,[1] A. H. CHEN,[2] W. E. GOLDSTEIN
Department of Biochemical Engineering Research and Pilot Services
Biotechnology Group
Miles Laboratories, Inc.
P.O. Box 932
Elkhart, Indiana 46515

Received for Publication December 2, 1980
Accepted for Publication April 6, 1981

ABSTRACT

The effects of pH (5.0 to 7.0), salt content (0 to 3%), cooking time (15 to 75 min at 100°C), soy isolate and egg white level (both from 1 to 5%) on the gel strength of a model meat loaf analog system are investigated. An Instron Universal tester is used for evaluating the analog's strength of various compositions. The study indicates an insignificant influence of pH and soy isolate content on the analog's strength. Effects of egg white content, salt content, and cooking time are expressed in terms of a second order polynomial, where linear effects and interactions are shown to be significant. Egg white content and cooking time are exponentially related to the hardness, whereas, salt content is linearly proportional to the logarithm of hardness. Response surface analysis reveals that egg white usage can be greatly reduced if salt content and cooking time are manipulated. This study provides a model that can be used to optimize a process for producing meat loaf analogs.

INTRODUCTION

Egg white is commonly used in various meat analog systems to ensure proper binding and texture characteristics of the product. However, its addition potentially increases manufacturing cost,

[1]Current Address: Michigan State University, Department of Food Science and Human Nutrition, East Lansing, Michigan 48824
[2]Current Address: W. L. C. Research Center, Anderson Clayton Foods, Richardson, Texas 75080

Journal of Food Process Engineering 4 (1980) 227-239.

thereby adversely affecting product cost. It is necessary to understand the gelling properties of egg white in such a food system in order to allow manipulation of component levels. This manipulation could therefore be used to optimize gelling properties with least amount of egg white consumption.

Shimada and Matsushita (1980) studied on thermal coagulating of egg albumin and reported that the coagulation was pH and protein concentration dependent. They suggested that the coagulation mechanism involves formation of SS bonds and exposure of hydrophobic groups followed by inter-molecular SH-SS bonds exchange to form protein network structure. Furukawa *et al.* (1980) also suggested that the network formation of a soybean protein paste system is due to cross linking of disulfide, hydrogen and hydrophobic bondings. It is reported (Baldwin *et al.* 1967) that the functional (gelling, binding, textural, etc.) properties of egg white are affected by such factors as concentration, pH, cooking temperature, cooking time, ionic strength, solids content and the addition of other gelling compounds. Catsimpoolas and Meyer (1970) reported the possible weakening of protein gelling formation in solution with the presence of high ionic strength. MacDonnell *et al.* (1955) investigated a food formulation containing egg white with the emphasis on its foaming properties instead of binding properties. Baldwin (1977) and Seideman *et al.* (1963) provided literature reviews of egg white functionality in various systems; however, these reviews are limited primarily to solution systems containing egg white.

This study emphasizes measurement and analysis of functional characteristics of meat loaf analogs in terms of compositional variations and effects of pH and cooking time. The experimental design involves pH, salt content, cooking time, egg white content, and soy isolate content. A specially designed apparatus was used for measuring gel functional properties and results are expressed in terms of a response surface model to discuss interactions among variables on gel hardness and to present various suggested influences on a meat analog model system.

MATERIALS AND METHODS

Meat Analog Formulation and Preparation

The model meat loaf analog formulation used in this study is shown in Table 1. This model system was recommended by our textured vegetable proteins research scientist (Leiss 1978). The total level of

Table 1. Composition of model system

Item	Percentage of Total Weight (%)
Vegetable oil	14.0
Water	52.0
Extruded soy granules	21.5
Sum of salt, egg white, soy isolate, and inert material	12.5

The total content of salt, egg white, Supro 620 and corn protein concentrate is equal to 12.5% by weight at all cases

salt, egg white, soy isolate and inert material was restricted to a constant level of 12.5%. When one of the three variables was changed, inert material was added or removed to maintain the level of 12.5%. The vegetable oil was a retail grade salad oil purchased from a local market. The soy granules (BF3702) were supplied by Worthington Foods, Miles Laboratories, Inc. The soy isolate used was Supro 620 from Ralston Purina Co., this material was considered to be a good commercially available gelling isolate. The egg white was commercial grade dried egg white obtained from the Marschall Dairy Ingredients, Division of Miles Laboratories. The inert material used was a corn protein concentrate derived from pilot plant preparations as described by Phillips (1977). The corn protein is quite insoluble and it binds a constant amount of water over the temperature range of 25 to 121 °C (Phillips and Sternberg 1979). This material was deemed to have no gelling properties based on laboratory tests (Leiss 1978), and therefore, was a suitable inert substance.

The mixing process started with blending pH-adjusted water and granules in a Hobart mixer (model C-100) with regular beater at 120 rpm for two minutes. This was further mixed with salt, egg white, soy isolate, and inert filler for one minute followed by addition of oil and mixing containued for another minute. The mixture was then packed with spatula and sealed into a #401 can, with a head space not to exceed 1 cm, followed by cooking at 100°C in an autoclave. During the cooking process, the temperature of the center of the product was monitored with an Ecklund C-1 type thermocouple designed especially for the #401 can (National Canners Association 1968). The can was then stored in a refrigerator at 4.0°C after cooking.

Experimental Data

A central rotatable composite design was employed for this study (a 2^5 factorial with 1/2 replication, Cochran *et al.* 1957). The range of

Table 2. Experimental Design[1]

pH	NaCl (%)	Cooking Time[2] (Min)	EW[3] (%)	Supro 620[4] (%)
5.5	0.75	30	2.0	2.0
6.5	0.75	30	2.0	4.0
5.5	2.25	30	2.0	2.0
6.5	2.25	30	2.0	4.0
5.5	0.75	60	2.0	2.0
6.5	0.75	60	2.0	4.0
5.5	2.25	60	2.0	4.0
6.5	2.25	60	2.0	2.0
5.5	0.75	30	4.0	2.0
6.5	0.75	30	4.0	4.0
5.5	2.25	30	4.0	4.0
6.5	2.25	30	4.0	2.0
5.5	0.75	60	4.0	4.0
6.5	0.75	60	4.0	2.0
5.5	2.25	60	4.0	2.0
6.5	2.25	60	4.0	4.0
5.0	1.50	45	3.0	3.0
7.0	1.50	45	3.0	3.0
6.0	0.00	45	3.0	3.0
6.0	3.00	45	3.0	3.0
6.0	1.50	15	3.0	3.0
6.0	1.50	75	3.0	3.0
6.0	1.50	45	1.0	3.0
6.0	1.50	45	5.0	3.0
6.0	1.50	45	3.0	1.0
6.0	1.50	45	3.0	5.0
6.0	1.50	45	3.0	3.0
6.0	1.50	45	3.0	3.0
6.0	1.50	45	3.0	3.0
6.0	1.50	45	3.0	3.0
6.0	1.50	45	3.0	3.0

[1]Experiment run was in a random order
[2]Cooking temperature = 100°C retort in #401 can
[3]EW = Egg white concentration by weight
[4]Supro 620 is a commercial soy isolate manufactured by the Ralston Purina Co.; % is concentration by weight

variables were: (1) pH from 5.0 to 7.0, (2) cooking time from 15 to 75 min., at 100°C, (3) salt content from 0. to 3.%, (4) egg white content from 1 to 5%; and (5) soy isolate from 1 to 5%. The 32 experiments depicted in Table 2 were randomized by using a random numbers table. The pH of the system was adjusted without changing the moisture level of the system. The acid used for pH adjustment was

reagent grade concentrated phosphoric acid, while the alkali used was a production grade 50% sodium hydroxide. Acid or alkali was added to an estimated amount of water needed for mixing of the bulk ingredients. Using 500 g batch, it was never necessary to add more than five milliliter of additional acid or alkli to readjust the pH to the desired value.

Analysis of Meat Analog Body Strength

The can was allowed to warm to room temperature for two hours prior to textural analysis. The meat loaf can be pushed out from the can once both ends were opened. The product was then sliced to a thickness of 1.90 cm for textural evaluation. The common technique used for textural evaluation of the slice involves bending the slice between the thumbs and index fingers of both hands until it cracks. A more quantitative technique applied in this study was to use the apparatus depicted in Fig. 1. This apparatus was designed and constructed especially to simulate the aforementioned fingers bending action and to be adaptable to the Instron Universal Testing Machine.

The testing unit consists of two parts, the upper portion being a smooth cylindrical bar with a diameter of 2.5 cm and a length of 7.75 cm, attached to the Instron's crosshead for uniaxial compression movement. The lower portion of the apparatus is a sample supporter with two supporting bridges where the sample slice rests on a flat surface. The distance between the poles of the supporter is adjustable. In this study, a distance of 7 cm separation provided consistent testing results. Figure 2 depicts the gel strength testing system in action.

During each test, the Instron crosshead speed and chart speed were set at 2 and 20 cm/min, respectively. This ten-fold difference between speeds was sufficient to minimize possible error due to recorder pen movement. The area covered by the combined response of force and distance is determined. Four textural parameters, namely, hardness, toughness, apparent elasticity, and strength are interpreted from the representative curve exhibited in Fig. 3. In review, hardness (expressed in Kg, a direct reading from the Instron Tester) is the maximum resistance force before cracking. Toughness (expressed in Kg-cm, a direct integrated value from the Instron recording system) is the total work resulting from integration of resistant force and distance traveled to break the sample. It represents the total area under the curve (see Fig. 3). Apparent elasticity (cm) is the maximum

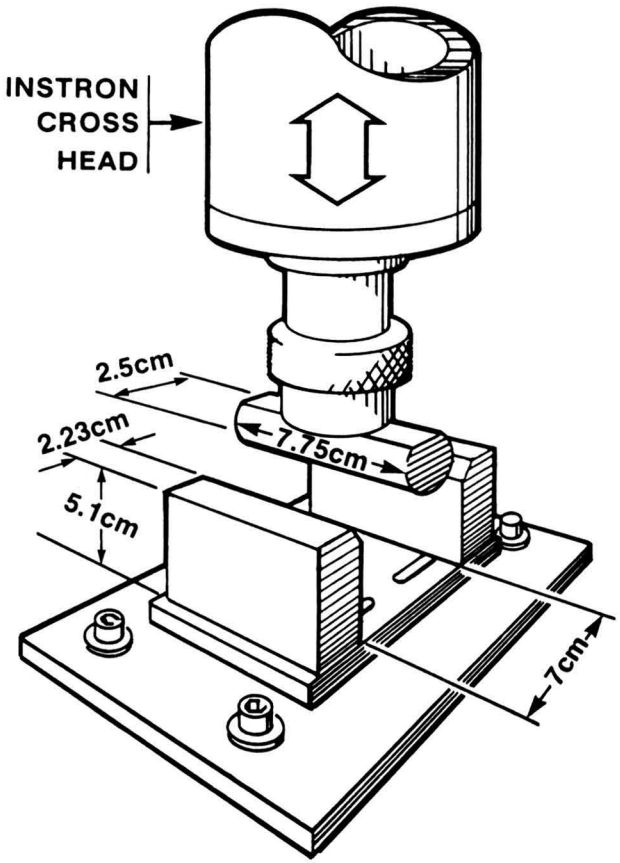

FIG. 1 EXHIBIT OF GEL TESTING SYSTEM WITH THE INSTRON CROSS HEAD

deformation exhibited before sample fracture. Strength (cm) is the total deformation required to break the sample into two pieces.

The amount of error involved in these measurements was evaluated by using a large batch of the analog containing 4% egg white. The coefficient of variance for these four parameters ranged from 2 to 7% for the bottom slice and 4 to 9% for the middle slice. When textural parameters were measured on analogs with five different egg white levels, results indicated that incrase in egg white quantity would result in a proportional increase in gel binding property (Fig. 4). Similar result was also reported by Shimada and Matsushita (1980). The correlation coefficients (R) for the hardness-egg white relationship for both the bottom and middle slices were 1.0 and .99, respectively. The correlation coefficients for toughness, apparent elasticity, and strength using the middle slice as a testing material were 0.98,

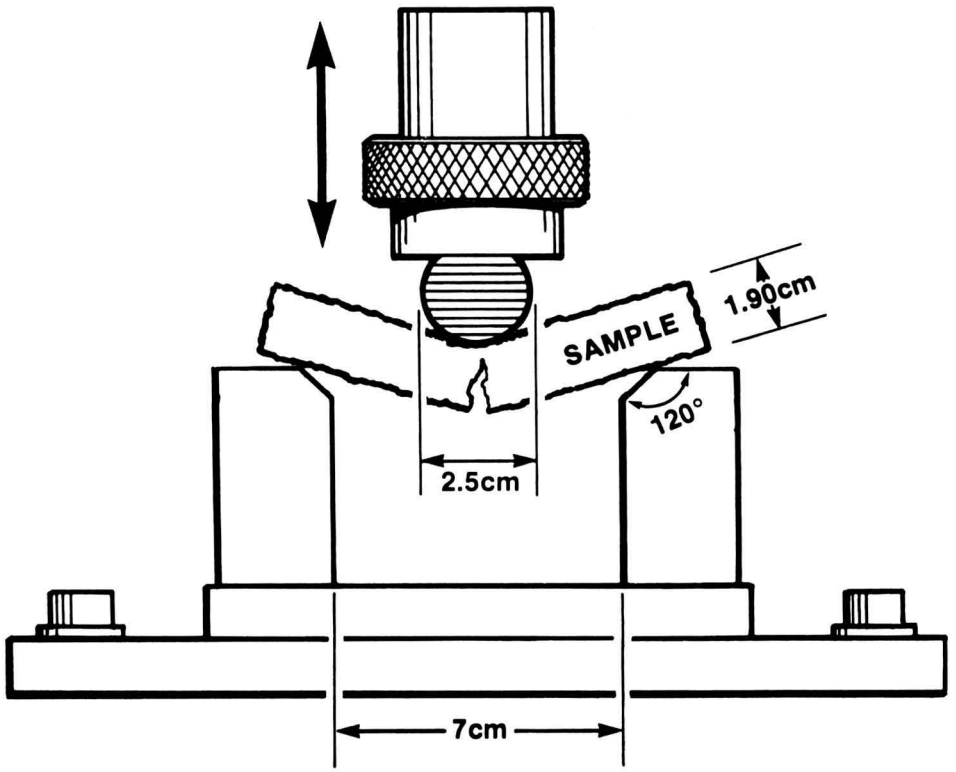

FIG. 2. EXHIBIT OF GEL TESTING SYSTEM IN ACTION

0.90, and 0.92 respectively, the hardness was therefore selected as a criterion for egg white gel property evaluation for the system.

Figure 5 reveals data of product center temperature profile versus cooking time. It depicts that the center temperature reached 94°C in 75 min in our 100°C retorting system. The center slice of the product was selected for gel strength determination for all samples. The hardness of samples with various egg white content, cooking time and salt content were investigated accordingly. It was assumed that the variation in time/temperature exposure is directly related to the gel strengths of the model system (Furakawa *et al.* 1980).

RESULTS AND DISCUSSION

A second order polynomial equation was used to fit the experimental data. Analysis of variance indicated that some variables were insignificant to the regression model; therefore, a step-wise regression

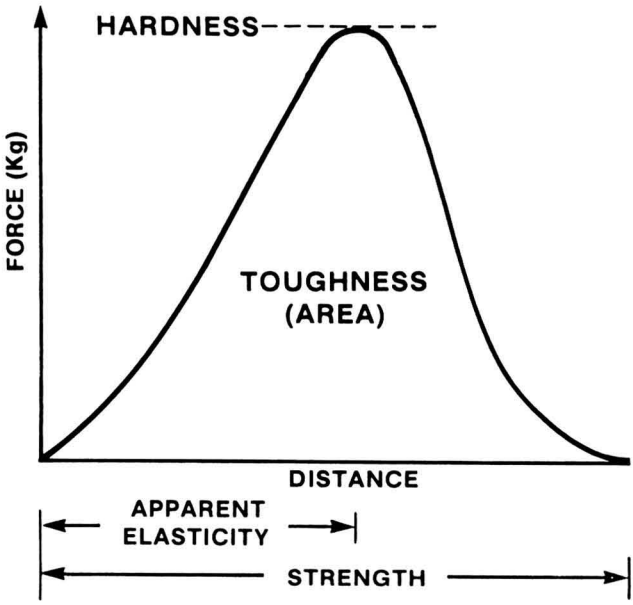

FIG. 3. TYPICAL FORCE DISPLACEMENT CURVE OF THE GEL STRENGTH TEST

Hardness:	Maximum Resistance
Toughness:	Applied Work (Area under the Curve)
Apparent Elasticity:	Deformation before Fracture
Strength:	Total Deformation

was applied to further eliminate these variables. The results indicated that hardness was not affected by changing in pH, soy isolate, and their interaction. The effect of Supro 620 on gel hardness was not pronounced in this study when compared with Furukawa *et al.*'s (1980) finding. It is likely due to its low concentration level applied in these experiment runs. The pH range of 5.0 to 7.0 also seemed not wide enough to affect the hardness of the analog model system.

The diagram of hardness plotted against each independent variable reveals that egg white content and cooking time exhibit exponential response while the salt content appeared to be linear with the logarithm of hardness. A transformation on the variables was therefore conducted to obtain a polynomial model consisting of the natural logarithm of hardness, cooking time and egg white content. Regression analysis was then conducted with a complete second order polynomial, and a partial second order polynomial where the squared effects were depleted. The analysis of variance showed that the

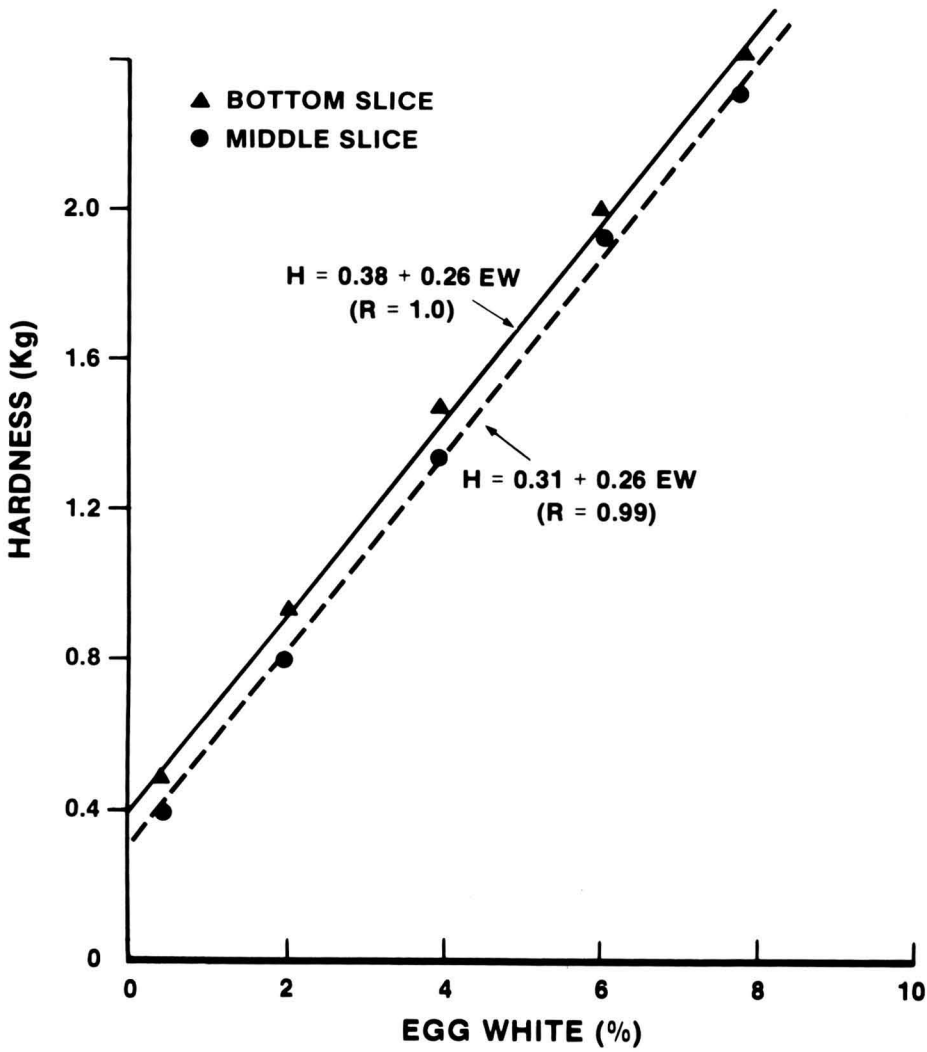

FIG. 4. GRAPH OF GEL HARDNESS AS A FUNCTION OF EGG WHITE CONTENT IN THE MODEL SYSTEM

H: Hardness in Kilogram
EW: Egg White in Percent Weight

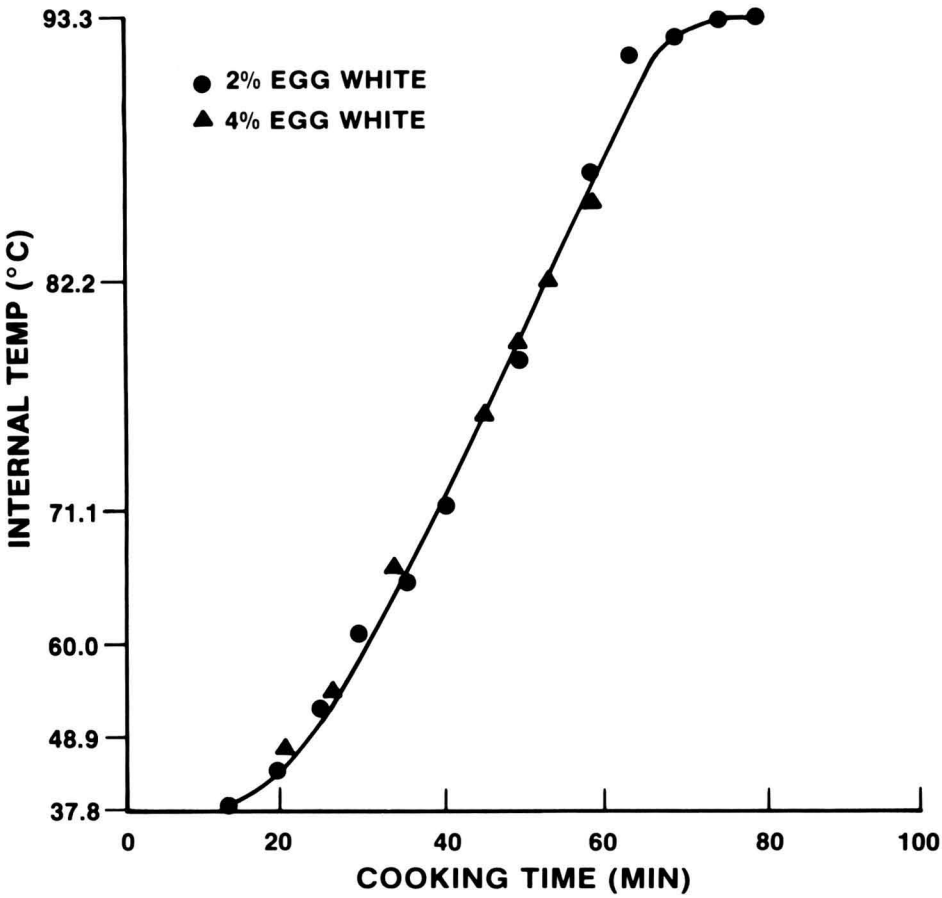

FIG. 5. RELATIONSHIP OF COOKING TIME (AT 100°C) AND TEMPERATURE PROFILE AT THE CENTER OF A MEAT ANALOG MODEL SYSTEM (EGG WHITE EXPRESSED IN % WEIGHT BASIS) IN A #401 CAN

squared effects did not significantly increase the precision of the model in comparison to the linear and the interactions effects. The F-test between the two models showed no significant difference (F = 1.06). Therefore, the model, which contains no squared effects, as well as its transform is shown below with a correlation coefficient of 0.95.

$$\ln H = -4.46 - 0.911 S + 0.955 \ln CT + 2.93 \ln EW - 0.254 S \ln EW + 0.281 S \ln CT - 0.537 (\ln CT)(\ln EW)$$

$$\text{or } H = \exp(-4.46 - 0.911 S - 0.537 \ln CT \times \ln EW) \times EW^{2.93 - 0.254 S} \times CT^{0.955 + 0.281 S}$$

Where

H = Hardness (Kg)
S = Salt Content (1 to 5%)
CT = Cooking Time (15 to 75 min. at 100°C)
EW = Egg White Content (0 to 3%)

The effects of these parameters on the gel strength can be visualized in a three dimensional diagram as shown in Fig. 6 derived from the model. It reveals that at a low salt content, the cooking time needed for a specific gel hardness (in this case, 1 Kg) decreases sharply by the addition of egg white. As the salt content is increased, the effect of egg white on the cooking time becomes marginal. The graph also reveals that variations in salt content affects the gel strength differently. For example, an increase in salt content at low level of egg white reduces the cooking time for the specific gel hardness. However, at a higher egg white level, increasing the salt content necessitates an increased cooking time to reach a specified gel hardness. The model indicates that cooking time and egg white content can have less effect on gel

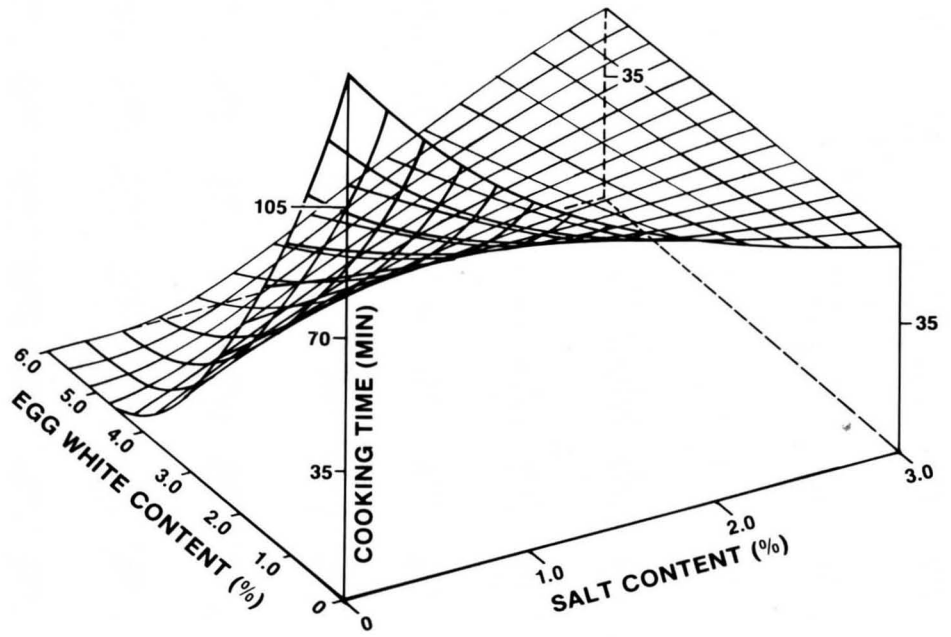

FIG. 6. RESPONSE SURFACE OF HARDNESS (AT 1.00 KG) FOR DIFFERENT LEVELS OF SALT, COOKING TIME, AND EGG WHITE CONTENT IN THE MODEL SYSTEM

hardness, depending on the concentration of salt. Since the cooking time in the exponential term is less than one (for low salt and any concentration of egg white), any increase in cooking time decreases the rate at which gel hardness increases. This effect is even more prevalent when the egg white content is increased, implying the existence of a maximum cooking time. Similar finding was also reported by Furukawa *et al.* (1980) on their 20% soybean protein paste system. From the information discussed previously, the maximum will probably be reached when the cooking time is in excess of about 80 min (Fig. 5). It seems apparent that when the cooking process continues, the majority of the egg white present will be gelled to its maximum hardness once the meat loaf analog center reaches temperature above 90°C.

An important criterion for manipulating the level of each variable is closely related to its cost effect involved in processing. For cost minimization of this meat analog system, a linear programming method could be used to find the point on the surface where the least cost for production occurs.

CONCLUSION

From the results of this study, we conclude that:

1. Our work presents a textural technique to determine the gel hardness of a meat analog system.
2. pH and concentration of Supro 620 had no significant effect on gel hardness within the narrow ranges of this study; $5.5 \leqslant \text{pH} \leqslant 7.0$ and $1\% \leqslant \text{Supro } 620 \leqslant 5\%$.
3. Response surface methodology reveals egg white usage can be greatly reduced if cooking time and salt content are manipulated.
4. Results from this study provide a model that can be used to optimize a process for producing meat analogs.

ACKNOWLEDGMENT

Special thanks to Dana Cooper for the construction of the meat analog strength testing device.

REFERENCES

BALDWIN, E., MATLER, C., UPCHURCH, R. and BREIDENSTEIN, D. 1967. Effects of the Microwaves on Egg Whites. I. Characteristics of Coagulation. J. Food Sci. *32*, 305.

BALDWIN, R. 1977. Functional Properties of Eggs. In *Egg Science and Technology*. p. 248. AVI Publishing Co., Westport, CT.

CATSIMPOOLAS, N. and MEYER, E. W. 1970. Gelation Phenomena of Soybean Globulins. I. Protein-Protein Interactions. Cereal Chem. *47*(5), 559.

COCHRAN, W. G. and COX, G. M. 1957. *Experimental Design,* 2nd Ed., John Wiley & Sons.

FURUKAWA, T., OHTA, S. and YAMAMOTO, A. 1980. Texture-structure Relationships in Heat-Induced Soy Protein Gels. J. Texture Stud. *10*(4), 333.

LEISS, R. S. Model System for Egg White Solids Replacer Studies. June 28, 1978. Inter-office communication RSL-52-78.

MacDONNELL, L. R., REENEY, R. E., HANSON, H. L., CAMPBELL, A. and SUGIHARA, T. F. 1955. The Functional Properties of the Egg White Proteins. Food Technol. *49*.

NATIONAL CANNERS ASSOCIATION. 1968. Laboratory Manual for Food Canners and Processors, Ch. 8, Vol. 1, 3rd Ed., AVI Publishing Co., Westport, CT.

PHILLIPS, R. D. 1977. Process for producing bland protein enriched products from grain gluten. U.S. Patent 4,024,120.

PHILLIPS, R. D. and STERNBERG, M. 1979. Corn Protein Concentrate: Functional and Nutritional Properties. J. Food Sci. *44*, 1152.

SEIDEMAN, W. E., COTTERILL, O. J. and FUNK, E. M. 1963. Factors Affecting Heat Coagulation of Egg White. Poultry Sci. *42*, 406.

SHIMADA, K. and MATSUSHITA, S. 1980. Thermal Coagulation of Egg Albumin. J. Agric. Food Chem. *28*(2), 409.

BOOK REVIEW

Principles of Food Packaging, Second Edition, Stanley Sacharow and Roger C. Griffin, Jr., AVI Publishing Co., Westport, Connecticut. 1980.

A delightful and entertaining potpourri of the wonderful world of food packaging has been delivered by the dynamic duo of packaging literature, Sacharow and Griffin. For sheer joy of reading and chewing on the lore of packaging from Adam through Buck Rogers, Sacharow and Griffin are unequalled. One can browse this volume for hours and learn that Uddo and Taormina Corp. are packaging grated cheese in PVC or that grapes and olives were cultivated in Transcaucasia in 6000 B.C.

The information has been collected in about as systematic a fashion as humans can attempt to organize the complex maze of food packaging: elementary packaging materials; basic food technology; food products and their packaging; and each chapter begins with a tantalizing digest of the history of the category and its packaging. Each chapter on a specific food group and its packaging describes the food, its requirements, its processing methods, the packaging materials and methods used, and often an updating since the book's first edition. A brief list of references closes each chapter. And, as in virtually every book with Sacharow authorship, the inevitable chapter on regulation and religious laws governing packaging appears.

Profusely illustrated and containing numerous tabulations of material properties, the book requires only 477 pages to comprehend all of two major disciplines, food technology and food packaging. And therein lies a basic flaw: despite actually covering and explaining the massive knowledge of the two disciplines, the book is neither a definitive reference nor an orderly textbook. Rather, it is a compendium, peppered with bits and chunks of interesting and useful information in reasonably appropriate order. As has been their trademark, Sacharow and Griffin write economically and update with even fewer amendments. The sight of crewcut technicians in photographs brings back memories that pre-date "American Graffiti."

Thus, the book can serve as a backgrounder for entering food packaging students who are receiving lectures from a knowledgable professor in a course—or it can serve as the sole text for food science or technology students taking their mandatory packaging course. As a fun way to learn a little bit about a lot of things for formal and informal students, "Principles of Food Packaging" is a treat.

As a volume that is opened, perused for five to ten minutes and then shelved until another day, the book is ideal. It is too technical for the popular shelf and too sketchy and replete with trivia to warrant serious consideration as a true reference textbook.

Few of the deficiencies of the first edition have been corrected, and more convolutions have been inserted. As usual, the book is teeming with inconsistencies and emphasis on the wrong subjects. A long dissertation on manufacturing smoked salmon is utterly fascinating, but is this in proportion in a volume that barely touches on vacuum packaging of fresh red meat and does not mention its pioneer, Cryovac Div., W. R. Grace? The unevenness of showing Perga, ZuPak and TetraRex for milk packaging when PurePak and TetraBrik are the dominant factors is difficult to fathom. Perhaps the greatest paradox, however, is a full-page photograph of a bust of Napoleon, the mentor, to represent Nicolas Appert, the inventor of canning.

For whatever reason, almost all data have been converted to the metric system which is perhaps quite acceptable for European readers. How many American students can make the conversion from metric to points of paperboard, mils of polyethylene, gage of polyester, or inches of aluminum foil—the standard American usage?

On the other hand, many tables published here intact from the earlier edition employ conventional English systems, thus compelling the serious student to compute the conversions to follow the text. Perhaps the most interesting use of metrics is in per capita consumption of juice expressed in kilograms—possibly the only place in the world where liquid volume is expressed in this manner.

Errors and out-of-date information pop up throughout the book: American Viscose has not made cellophane in many, many years; Nescafe is hardly the only American producer of instant decaffeinated coffee; three piece tin cans for soft drinks are almost an anachronism; a five-cent bag of potato chips is an historic relic; U.S. value of produce was $9.5 billion and not $9.5 million, etc. etc. Misspellings of company names and trademarks are not uncommon.

The second edition of "Principles of Food Packaging" should have some tough editing to correct the obvious flaws and to even out the distortions. What is an interesting book to savor could, with relatively little work, become a classic. Students, teachers and practitioners need a definitive and comprehensive book on food packaging. Sacharow and Griffin have surrounded the problem without fully attacking it.

Nevertheless, like peanuts, once you have nibbled, it is hard to stop leafing it.

AARON L. BRODY

LITERATURE ABSTRACTS

ABSTRACTS FROM JOURNAL OF FOOD SCIENCE

OBJECTIVE AND SUBJECT TEXTURE EVALUATION OF IRRADIATION STERILIZED MEAT PRODUCTS. R. A. Segars, A. V. Cardello & J. S. Cohen. J. Food Sci. *46*, 999-1003 (1981).

Instrumental measures of textural properties and texture panel evaluations were obtained on several meat products irradiated using various dose-temperature conditions. Both the panel results and the instrumental data revealed several irradiation treatments that produced a tougher meat than the nonirradiated controls. Further studies indicated this toughening was due to a freezing-irradiation interaction.

EFFECTS OF MICROBIOLOGICAL DECONTAMINATION ON THE STORAGE STABILITY OF FRESH FISH. P. H. Kosak & R. T. Toledo. J. Food Sci. *46*, 1012-1014.

The effect of microbiological decontamination on the storage stability of fresh fish was investigated, using chlorine pretreatment in combination with various packaging techniques as a means of delaying microbial growth. A 3½ min dip in a 1000 μg/ml free chlorine solution, in combination with either a vacuum pack or polyethylene bag with 10% v/w tap water, yielded a 12-day extension of fresh fish quality. Hypoxanthine accumulation was considerably delayed and TBA numbers were significantly lowered.

TWO SIMPLE METHODS FOR PREDICTION FOOD FREEZING TIMES WITH TIME-VARIABLE BOUNDARY CONDITIONS. M. P. F. Loeffen, R. L. Earle & A. C. Cleland. J. Food Sci. *46*, 1032-1034.

Two simple methods for predicting the freezing times of rectangular bricks, slabs, cylinders, and spheres in situations where boundary conditions change with time are proposed. These methods are based on numerical integration of a simple differential equation derived from a previously proposed modification to Plank's equation. The methods were tested against a three time-level finite difference scheme for varying cooling medium temperatures and surface heat transfer coefficients. Agreement was generally good (difference $<10\%$) between the two methods and the corresponding finite difference solution.

WATER SORPTION ISOTHERMS OF SUCROSE AND GLUCOSE BY INVERSE GAS CHROMATOGRAPHY. D. S. Smith, C. H. Mannheim & S. G. Gilbert. J. Food Sci. *46*, 1051-1053.

A novel gas chromatographic procedure was used to obtain the water sorption isotherms of sucrose and glucose. The method allows calculation of partial pressure of

water and water uptake directly from a chromatogram. The isotherms developed are in a water activity range well below that of conventionally developed isotherms.

EXTRACTION WITH ETHANOL AS AN ENERGY-SAVING ALTERNATIVE TO CONVENTIONAL DRYING OF CORN STARCH. J. M. Krochta, K. T. Look, J. S. Hudson & A. E. Pavlath. J. Food Sci. *46*, 1054-1058 + 1063.

Drying of starch derived from corn wet-milling is an energy intensive operation in an energy intensive industry. An alternative to conventional drying involves extraction of water from the starch with an ethanol solution and reconcentration of the ethanol by distillation. Equilibrium data for starch with various concentrations of ethanol in water were obtained. These data were used to calculate the effect of multistage countercurrent extraction of mechanically dewatered starch using a mathematical model of the process. The energy required for drying the extracted starch and recovering the alcohol is predicted to be considerably less than that required for conventional drying. Energy savings up to 40% and more are possible.

EFFECT OF THERMAL PROCESSING ON ENDOGENOUS AND ADDED IRON IN CANNED SPINACH. K. Lee & F. M. Clydesdale. J. Food Sci. *46*, 1064-1068 + 1073.

The effect of thermal processing on endogenous and added iron in canned spinach puree was investigated. Eight different sources of iron were evaluated for their distribution of iron forms, of "iron profile" after four treatments. The treatments included: control, unprocessed, processed, and processed with ascorbate. Iron endogenous to raw spinach was 93% in the insoluble form whereas iron added to spinach varied widely in degree of insolubility. For certain iron sources, processing increased the proportion of insoluble as well as ferrous iron over what was present in unprocessed spinach. Processing with ascorbate also increased ferrous iron in some cases. One iron source, ferric EDTA, was exceptional as it was affected minimally in all four treatments. The effects of foods and processes on iron chemistry may help explain the large variations in iron absorption observed from various foods and diets.

EFFECT OF COOKING TEMPERATURE AND TIME ON THE SHEAR PROPERTIES OF MEAT. P. E. Bouton, P. V. Harris & D. Ratcliff. J. Food Sci. *46*, 1082-1087.

The effect of cooking temperature in the range 40-95°C on Warner-Bratzler shear force-deformation curves, obtained for stretched and cold-shortened meat samples from young and old bovine animals, has been investigated. The results were interpreted as indicating that the relative contributions of the connective tissue and myofibrillar structures to the peak shear force values were markedly altered as cooking temperature was increased. The changes of the myofibrillar structure were reflected by the changes in initial yield force values. In general, the initial yield force increased about three- to fourfold between 40°C and 60°C for both stretched and cold-shortened meat but between 60°C and 80°C the increase was about twice for the former and about fivefold

for the latter. The connective tissue contribution decreased as cooking temperature was raised above 50°C for meat for young animals and above 60°C for very old animals—the contribution at temperatures above 70°C being very small for the former but still relatively large for the latter.

PROTEIN STABILITY OF FROZEN MILK AS INFLUENCED BY STORAGE TEMPERATURE AND ULTRAFILTRATION. M. S. Koschak, O. Fennema, C. H. Amundson & J. Y. Lee. J. Food Sci. *46*, 1211-1217.

Milk and milk concentrates containing 12-35% total solids were stored at 0, -2, -4, -6, -8, -12, and -20°C and protein stability of the thawed products was evaluated periodically. Samples stored at -4 to -12°C exhibited poorer protein stability than samples stored at higher or lower temperatures. Ultrafiltered (UF) skimmilk with permeate: retentate ratios of 10:90, 20:80, and 30:70 were stored at -8°C and they remained stable at least three times longer than frozen control samples of UF skimmilk stored at the same temperature. When the extent of UF was increased to 40:60, protein stability in the frozen retentate declined somewhat as compared to that of less concentrated retentates.

APPARENT ACTIVATION ENERGY OF VISCOUS FLOW IN PECTIN JELLIES. R. H. Walter & R. M. Sherman. J. Food Sci. *46*, 1223-1225.

A change of state in a cooling jelly sol is preceded by a narrow temperature interval of viscous flow that may be measured, in order to compute the activation energy of such flow. The contribution of decreasing temperatures to the viscosity-increase was 10^6 times greater than that of time. The apparent activation energy of viscous flow in citrus and apple jelly was found to be of the same order of magnitude, 10^4 cal/mole. Of the pectins studied, those that were commercially designated as slow-setting tended to have a higher activation energy than those that were rapid-setting. The flow pattern of some jellies, notably from pure citrus and rapid-set pectins, was characterized by a different activation energy at high and low temperatures.

A SIMPLE CENTRIFUGAL METHOD FOR MEASURING EXPRESSIBLE MOISTURE, A WATER-BINDING PROPERTY OF MUSCLE FOODS. C. A. Jaurequi, J. M. Regenstein & R. C. Baker. J. Food Sci. *46*, 1271 + 1273.

With the development of more refined methods of measuring water-binding properties of meats, the term "water-holding capacity" needs to be replaced with more specific and carefully defined terms such as expressible moisture, water-binding potential, and free drip. An improved method of measuring expressible moisture is described which is simple and reproducible. It basically measures the amount of liquid squeezed out of a protein system with centrifugal force, by measuring the weight gain of a filter paper surrounding the sample. This method seems to be highly sensitive to factors that affect the water-binding properties of muscle foods.

WATER CONSERVATION IN CLOSED ROTARY COOKERS BY EVAPORATED COOLING. E. S. Yawger, H. W. Adams & P. K. Hardt. J. Food Sci. *46*, 1286-1287.

Better cooling and water savings of up to 40% may be realized by installing a blower in closed rotary coolers. The air blown through the cooler headspace aids cooling by causing water to evaporate from the cans' surface. In four tests at a tomato plant in California, water flow rates with the blower off ranged from 25-29 gpm and with the blower on ranged from 12.5-18 gpm. The blower decreased the maximum temperature in the shell from 2-6°F and decreased the final average can temperature from 3.5-7°F.

EFFECT OF COOKING RATES IN ELECTRIC OR MICROWAVE OVEN ON COOKING LOSSES AND RETENTION OF THIAMIN IN BROILERS. K. N. Hall & C. S. Lin. J. Food Sci. *46*, 1292-1293.

A study was conducted to determine the effect of two microwave oven and two electric oven cooking rates on retention of thiamin and cooking losses with broiler chickens. Thiamin was determined by a microbiological turbidimetric assay of raw and cooked meats. Broilers cooked in the microwave oven retained more thiamin than broilers cooked in the electric oven. There was no difference in thiamin retention between broilers cooked in the microwave oven at 800 and 1600 watts. Broilers cooked in the electric oven at 204°C retained more thiamin than broilers cooked at 121°C. Broilers cooked in a 1600 wat microwave oven had the greatest weight loss. No difference in weight loss occurred between broilers cooked in an 800 watt, 121°C or 204°C oven.

SENSORY TEXTURAL PROPERTIES OF STABILIZED ICE CREAM. L. J. Moore & C. F. Shoemaker. J. Food Sci. *46*, 399-402 + 409.

Vanilla ice cream samples containing five different levels of sodium carboxymethylcellulose (CMC) were evaluated for textural differences using time-intensity and graphic rating (line-marking) methods. The time-intensity method showed significant correlations between CMC concentration and the sensory textural properties of iciness, viscosity, and melting time. The graphic rating tests showed significant correlations between CMC concentration and the sensory textural properties of coldness, iciness, viscosity, and firmness. Comparison of time-intensity and graphic rating tests for the same textural properties showed significant correlations for iciness and viscosity. This investigation showed time intensity and graphic rating to be complementary methods for the sensory evaluation of the textural properties of a stabilized vanilla ice cream.

EFFECT OF WATER ACTIVITY ON THE SENSORY CRISPNESS AND MECHANICAL DEFORMATION OF SNACK FOOD PRODUCTS. E. E. Katz & T. P. Labuza. J. Food Sci. *46*, 403-409.

Potato chips, popcorn, puffed corn curls, and saltines were equilibrated to various water activities (a_w) over saturated salt solutions. Sensory panels determined the crispness and textural hedonic quality of the humidified products by the magnitude estimation technique coupled to a verbal concept scale. Critical water activities (a_c), where the

products became organoleptically unacceptable, generally fell in the 0.35-0.50 a_w range. Instron analyses showed that the force-deformation curve changed distinctly near the a_c for saltines and puffed corn curls, while the curve changed more gradually with increasing a_w for popcorn. Potato chips did not produce a consistently shaped force-deformation curve. The cohesiveness value of popcorn was found to be a good indicator of its sensory crispness.

EFFECTS OF MICROWAVE, STEAM AND WATER BLANCHING ON FREEZE-DRIED SPINACH. N. M. Quenzer & E. E. Burns. J. Food Sci. *46*, 410-413 +418.

Microwave energy was demonstrated to be a convenient and effective method of blanching. Compared to steam or water, microwave blanching was superior in retention of ascorbic acid. The texture of rehydrated, microwave blanched spinach was firm, chewy and highly acceptable. Water blanching ruptured the cells and destroyed fine cellular structure as compared to steam blanching which caused less cellular disruption and greater retention of tissue structure. Microwave blanching resulted in coagulated protoplasmic material surrounding the cell walls. Cell and tissue structure remained intact which results in high rehydration ratios and acceptable textural characteristics. Microwave blanching yielded a superior freeze-dried product as compared to water and steam blanching.

A COOLING SYSTEM WITH WATER RECYCLE FOR BLANCHED VEGETABLES. J. B. Swartz & P. A. Carroad. J. Food Sci. *46*, 440-444.

A water conserving cooling system with water recycle for blanched vegetables was designed to complement a previously developed water recycling blancher. The two stage cooler consisted of an evaporative cooling section with forced air and water sprays and a flume cooler with water, which was both refrigerated and recycled. A pilot scale blanching and cooling system was constructed, and broccoli spears were processed. The cooling system was effective at lowering the product temperature rapidly while maintaining the quality of the product at a high level as determined by ascorbic acid concentration, percentage of total solids, percentage of retained chlorophyll, and microbial counts.

BIMODAL HEAT STABILITY CURVES OF FUNGAL PECTOLYTIC ENZYMES AND THEIR IMPLICATION FOR SOFTENING OF CANNED APRICOTS. L. L. Strand, J. M. Ogawa, E. Bose & J. W. Rumsey. J. Food Sci. *46*, 498-500 + 505.

Pectolytic activity can be isolated from canned apricots showing severe softening induced by a single fungal lesion. The pectolytic activities of fungi important in causing progressive softening have bimodal heat stability curves with minimal stabilities at 70-80°C. The activities produced by fungi that do not cause appreciable softening do not show bimodal stability curves. A 6-min treatment at 75°C before canning eliminated detectable enzyme activity and significantly reduced subsequent softening in No. 303 cans of apricots to which single fruit halves with 5 mm fungal

lesions had been added. These results suggest that a pretreatment at about 75°C could help alleviate this problem in canned apricots.

THERMAL DEGRADATION KINETICS OF PYRIDOXINE HYDROCHLORIDE IN DEHYDRATED MODEL FOOD SYSTEMS. S. R. Evans, J. F. Gregory III & J. R. Kirk. J. Food Sci. *46*, 555-558 + 563.

The thermal degradation kinetics of pyridoxine hydrochloride were examined using a dehydrated model food system designed to simulate a ready-to-eat breakfast cereal. This study was carried out to provide information useful in estimating the thermal losses of pyridoxine hydrochloride in the processing of breakfast cereals and other low moisture dehydrated food systems. Portions of the model system which were fortified with pyridoxine hydrochloride were toasted in a conduction oven at 155°, 170°, 185°, and 200°C for a minimum of six heating times at each temperature. Pyridoxine (PN) content was determined in the heat treated model systems by high performance liquid chromatography (HPLC). For each heat treatment, the loss of pyridoxine could be described by a first order kinetics model. The first order rate constants for 155°, 170°, 185°, and 200°C were 1.74×10^{-2} min^{-1}, 5.22×10^{-2} min^{-1}, 16.88×10^{-2} min^{-1}, and 48.95×10^{-2} min^{-1}, respectively. The calculated Arrhenius activation energy was 29.8 Kcal/mol. In compariing the HPLC method to the standard microbiological assay, the HPLC assay gave lower PN values for the toasted model system. To explain this discrepancy, HPLC fractions were collected and analyzed by the microbiological assay. No significant vitamin B_6 activity was found in any fraction other than that containing the PN peak. It is possible that the milder extraction procedure used in the HPLC assay is less capable of recovering forms of PN which may become bound during the toasting process. These potentially bound forms may or may not be biologically available.

AUTHOR INDEX

SUBJECT INDEX

GUIDE FOR AUTHORS

Typewritten manuscripts in triplicate should be submitted to the editorial office. The typing should be double-spaced throughout with one-inch margins on all sides.

Page one should contain: the title, which should be concise and informative; the complete name(s) of the author(s); affiliation of the author(s); a running title of 40 characters or less; and the name and mail address to whom correspondence should be sent.

Page two should contain an abstract of not more than 150 words. This abstract should be intelligible by itself.

The main text should begin on page three and will ordinarily have the following arrangement:

Introduction: This should be brief and state the reason for the work in relation to the field. It should indicate what new contribution is made by the work described.

Materials and Methods: Enough information should be provided to allow other investigators to repeat the work. Avoid repeating the details of procedures which have already been published elsewhere.

Results: The results should be presented as concisely as possible. Do not use tables *and* figures for presentation of the same data.

Discussion: The discussion section should be used for the interpretation of results. The results should not be repeated.

In some cases it might be desirable to combine results and discussion sections.

References: References should be given in the text by the surname of the authors and the year. *Et al.* should be used in the text when there are more than two authors. All authors should be given in the Reference section. In the Reference section the references should be listed alphabetically. See below for style to be used.

DEWALD, B., DULANEY, J. T. and TOUSTER, O. 1974. Solubilization and polyacrylamide gel electrophoresis of membrane enzymes with detergents. In *Methods in Enzymology*, Vol. xxxii, (S. Fleischer and L. Packer, eds.) pp. 82—91, Academic Press, New York.

HASSON, E. P. and LATIES, G. G. 1976. Separation and characterization of potato lipid acylhydrolases. Plant Physiol. *57*, 142—147.

ZABORSKY, O. 1973. *Immobilized Enzymes*, pp. 28—46, CRC Press, Cleveland, Ohio.

Journal abbreviations should follow those used in *Chemical Abstracts*. Responsibility for the accuracy of citations rests entirely with the author(s). References to papers in press should indicate the name of the journal and should only be used for papers that have been accepted for publication. Submitted papers should be referred to by such terms as "unpublished observations" or "private communication." However, these last should be used only when absolutely necessary.

Tables should be numbered consecutively with Arabic numerals. The title of the table should appear as below:

Table 1. Activity of potato acyl-hydrolases on neutral lipids, galactolipids, and phospholipids

Description of experimental work or explanation of symbols should go below the table proper.

Figures should be listed in order in the text using Arabic numbers. Figure legends should be typed on a separate page. Figures and tables should be intelligible without reference to the text. Authors should indicate where the tables and figures should be placed in the text. Photographs must be supplied as glossy black and white prints. Line diagrams should be drawn with black waterproof ink on white paper or board. The lettering should be of such a size that it is easily legible after reduction. Each diagram and photograph should be clearly labeled on the reverse side with the name(s) of author(s), and title of paper. When not obvious, each photograph and diagram should be labeled on the back to show the top of the photograph or diagram.

Acknowledgments: Acknowledgments should be listed on a separate page.

Short notes will be published where the information is deemed sufficiently important to warrant rapid publication. The format for short papers may be similar to that for regular papers but more concisely written. Short notes may be of a less general nature and written principally for specialists in the particular area with which the manuscript is dealing. Manuscripts which do not meet the requirement of importance and necessity for rapid publication will, after notification of the author(s), be treated as regular papers. Regular papers may be very short.

Standard nomenclature as used in the engineering literature should be followed. Avoid laboratory jargon. If abbreviations or trade names are used, define the material or compound the first time that it is mentioned.

EDITORIAL OFFICE: Prof. D. R. Heldman, Editor, Journal of Food Process Engineering, Michigan State University, Department of Food Science and Human Nutrition, East Lansing, Michigan 48824 USA.

CONTENTS