Journal of
FOOD PROCESS
ENGINEERING

Edited by
D. R. HELDMAN

JOURNAL OF FOOD PROCESSING ENGINEERING

JOURNAL OF FOOD PROCESS ENGINEERING

Journal of
FOOD PROCESS
ENGINEERING

Printed in the United States of America

CONTENTS

ENERGY REQUIREMENTS
OF BEET COLORANT PRODUCTION

J. E. BLOCK

Campbell Soup Company
Campbell Place
Camden, New Jersey 08103

C. H. AMUNDSON and J. H. VON ELBE

Department of Food Science
University of Wisconsin-Madison
Madison, Wisconsin 53706

ABSTRACT

Energy requirements were monitored during the production of a beet colorant on a pilot plant scale. Colorant production involved centrifugation, concentration by fermentation, vaccum concentration, and spray drying. The economic feasibility of adding the fermentation operation to the present extraction and concentration operations was studied. Data were obtained on the production rate, pigment recovery, energy consumption (electrical, steam, gas), and pigment concentration at each unit operation. Calculations were based on a ton of raw beets processed. Energy costs were $15.57 per ton. The final spray dried colorant contained between 3 and 5% pigment depending on raw product quality. Byproducts of yeast and alcohol helped to offset 16% of the energy and raw product costs.

INTRODUCTION

In recent years, because of the prohibition or restriction of synthetic dyes such as FD and C Red No. 2, 3, 4 and 40, there has been an increased interest in natural food colorants. Table beets, which contain betalaine pigments, have been considered one possible source. Beet juice extracts have been used to color a variety of foodstuffs including sausage-type meats, dry powdered mixtures, and dairy products (von Elbe *et al.* 1974a; von Elbe 1977a). Compatibility of betalaines with food stuffs depends on the product pH, storage temperature and time, water activity, and the presence of oxygen and light (von Elbe 1977b).

The structure of the chromphore in betalaines is a protonated 1, 2, 4, 7, 7, pentasubstituted 1, 7 diazaheptamethin system. This system accounts for the yellow pigments which have maximum absorptivities near 476 nm. If the conjugation of this system is extended by an aromatic group, the maximum absorptivity shifts to near 538 nm. This accounts for the red pigments.

Betanine accounts for 75 to 95% of the red pigments in sugar beets; vulgazanthine I accounts for nearly 95% of the yellow pigments in beets (Mabry 1970). The concentration of betalaines and the red/yellow pigment ratio is dependent upon beet variety, harvest time, growing conditions, and beet size (von Elbe 1977b). The red pigment concentration peaks and then declines with age whereas the yellow pigment concentration increases until the beet is processed.

The betalaines are usually quantified by spectrophometry. Nilsson (1970) provided a formula to compute the red and yellow pigments in beets and reported them as betanine and vulgazanthine I, respectively. The formula is based on betanine having a maximum absorptivity ($A_1^{1\%}cm$) of 1120 and vulgazanthine I having a maximum absorptivity of 750.

Presently, commercially available beet pigment is in the form of concentrated beet juice and spray dried powder made from concentrated beet juice. The initial beet juice is an aqueous extract from a counter-current diffuser apparatus or the liquid product of a physical pressing operation. This juice is pasteurized and then vacuum concentrated to 60-65% total solids. It can then be used as is or spray dried.

The major disadvantage of the available concentrates is that they contain only 0.2 to 1.0% pigment expressed as betanine on a dry weight basis (Riboh 1977). The remainder of the concentrates is composed of about 80% fermentable carbohydrates, 10% ash, and 10% protein (von Elbe 1977b). They also contain the compounds responsible for the typical beet odors and flavors. It should be noted that at present, beet juice can not legally be purified to realize a higher concentration of pigment because of the restrictions of the 1960 Color Additive Amendment which only permits vegetable juice concentrates.

Recognizing the need for a more concentrated pigment source, Adams et al. (1976) used the yeast, Candida utilis, to ferment a beet juice extract. They chose Candida utilis because of its ability to ferment the carbohydrates and nitrogenous compounds found in beet juice extracts as well as its approved use in food and feeds.

Fermentation removes the carbohydrates, nitrites, nitrates, and the compounds responsible for the typical beet odors and flavors. The

resulting yeast cells, which contain about 50% protein, can be used for food or feed. The alcohol obtained from the fermentation can be used industrially or as a substitute for grain alcohol. Adams *et al.* (1976) reported a 5 to 7 fold increase in pigment concentration after fermentation.

This study was undertaken to evaluate the economic feasibility of producing a food colorant from beets.

EXPERIMENTAL

Production of beet colorant was conducted at the Food Engineering Pilot Plant, University of Wisconsin-Madison and at Amber Laboratories, Division of Milbrew, Inc., Juneau, Wisconsin. The production at both facilities was split into three separate operations because of equipment location but it is assumed that under commercial conditions, the process would be continuous. A continuous process would be desirable because of the pigment's senstivity to heat and oxygen. Further, any commercial operation would properly size and locate equipment for a continuous operation. Therefore, our calculations assume a continuous process.

The first operation was juice extraction. The beets were blanched for 10 min. at 100° C, abrasion peeled and washed. They were then diced into 3/8 in. cubes and immediately comminuted with a Fitzpatrick mill, model D, equipped with a 1/2 in. round hole screen. The product was pumped to a centrifugal separator (Bird solid bowl separator, 18 in. diameter and 28 in. long) to separate the pulp from the supernate, which was passed through a 150 mesh screen to remove any remaining solids. This clarified juice was sent to a plate heat exchanger pasteurized at 88° C for 2 min. and cooled to 2° C. Energy consumption and pigment degradation were monitored and product flow measured.

The second operation was the fermentation of the clarified beet juice. In addition, for comparison purposes, we obtained clarified beet juice from a commercial source, which employed countercurrent extraction. In both instances, the initial juice was standardized at about 14% (w/w) total solids prior to fermentation. The fermentation method was essentially that of Adams *et al.* (1976). The temperature was maintained at 30 ± 2° C. The pH was maintained at 5.0 ± .2 by the addition of citric acid or ammonia. Dissolved oxygen content was maintained at 20% saturation or less by controlling air flow to the fermentor. The 450 gal. fermentor containing 300 gal. of juice was operated in a continuous mode after starting in a batch mode to build

up yeast concentration. Energy consumption, pigment degradation, and product flow were measured.

In the third operation, the fermented juice was centrifically separated (Self-cleaning Clarifier, De Laval PX309) to obtain clarified juice and a yeast cell slurry. The clarified juice was vacuum concentrated in a single effect falling film evaporator (Arthur Harris Co.) to 30% soluble solids, cooled to 16° C and spray dried in the University of Wisconsin dryer (Amundson 1967). The yeast cell slurry was also spray dried.

Energy Measurements

Electrical consumption was measured every 15 min for at least 2h to determine an average hourly rate. For operations which continued for several days, consumption was measured hourly and averaged. An amprobe was used to measure both volts and amps. In single phase applications, volts $\times$ amps = watts. In three phase applications, volts $\times$ amps from either of the three power wires $\times \sqrt{3}$ = watts. By multiplying the watts consumed by hours of operation, watt-hours of electrical consumption was computed. Electrical costs were calculated at $.05 per kilowatt-hour. Steam consumption was measured with condensate meters (Cadilac Condensation Meter, model B) or calculated using a modified Napier's formula as described by Witzel and Berry (1976) or a formula by Hall (1963). Steam costs were assumed to be $3.00 per 1000 lb of steam. Natural gas to the spray dryer was measured with an in-line meter installed by Madison Gas and Electric Co., and calculated at $1.90 per 1000 cubic feet of gas.

Chemical Analysis

Pigment. Pigment concentration was determined by measuring light absorbances at 476, 538 and 600 nm and using the absorbances to calculate pigment concentrations according to a formula developed by Nilsson (1970).

Total solids. Six gram juice samples were weighed in aluminum pans and total solids were determined according to AOAC (1970) procedures for vegetables.

Ethanol. 50 or 100 ml of the fermented broth was distilled according to AOAC (1970). The concentration of alcohol was then measured with a hydrometer or with gas chromatography.

RESULTS AND DISCUSSION

Extraction of the juice from one ton of beets used 69.3 ± 0.2 KWH of electricity and 499 ± 30 lb of steam (Table 1). It took 95 ± 5 min and yielded 1210 ± 100 lb of juice at 7% solids. During the extraction, the red

Table 1. Calculated energy costs to process one ton of beets

Operation	Product Processed (lb)[a]	Time to Complete (min)[b]	Steam (lb) ± 30[c]	Electri- City KWH ± .2[c]	Gas (feet)³ ± 50[c]
Extraction					
Blanching	2000	96	328	.5	
Peeling	2000	96		7.8	
Dicing	1842	96		1.9	
Milling	1842	96		5.9	
Separation-Bird	2428	96		24.8	
Separation-Sweco	1210	96		4.0	
Pasteurization	1210	96	171		
Cooling	1210	96		15.1	
Pumps, conveyors				9.3	
Concentration					
Evaporator	1210	62	756	5.1	
Continuous Fermentation					
Agitation	706	119		1.7	
Aeration	706	119		5.4	
Refrigeration	706	119		1.6	
Pumping	706	119		1.5	
Yeast Harvest					
Desludger	684	18		3.4	
Metering pump	684	18		.3	
Pumping, agitation	684	18		.9	
Washing yeast	51	1.3		.3	
Concentration					
Evaporator	636	48	872	4.6	
Spray Drying					
Yeast product	51	4.5		2.5	941
Pigment product	55	5		2.8	1045
Totals			2127	99.4	1986
Cost in dollars			$6.38	$4.97	$3.77

[a]Maximum estimated error = 10%
[b]Based on slowest part of operation. Maximum estimated error = 10%
[c]Maximum estimated error

pigments were degraded 18 ± 9% and the yellow pigments were degraded 27 ± 8%. Most of the pigment losses were observed during pasteurization.

During continuous fermentation the juice extracted from one ton of beets used 10.2 ± 0.2 KWH at a cost of $.51 and required 119 min to complete. Prior to fermentation, the juice was vacuum concentrated to 14% total solids (Adams 1976). This used 756 ± 30 lb of steam and 5.1 ± 0.2 KWH at a cost of $2.52. Aeration and refrigeration accounted for most of the fermentation costs. Fermentation yields, defined as percent of sugar conversion efficiency into a product on a dry weight basis, were 18 ± 2% for yeast cells and 36 to 45% for ethanol. The maximum productivity rates, defined as the weight of product produced by the unit of fermentation volume of the fermenter per unit time, were 4.9 g per liter per h for the yeast cells and 9.5 g per liter per h for the ethanol. The above yields and productivities are based on a dilution rate of .16 and a fermenter volume of 450 gal. Pigment losses ranged from 18 to 27%. The majority was lost with the harvested yeast cells. The fermentation removed about 80% of the solids with a resulting 3 to 5 time increase in pigment concentration expressed as a percent of solids.

Desludging the fermented juice to remove the yeast cells took 4.9 ± 0.2 KWH at a cost of $.25. Desludging the fermented juice from one ton of beets took 18 min.

Vacuum evaporation accounted for an additional 10 ± 4% loss of pigment. The operation used 872 ± 30 lb of steam and 4.6 ± 0.2 KWH at a cost of $2.83 to concentrate the juice from one ton of beets. Spray drying the juice took 1045 ± 50 cubic feet of gas and 2.8 ± 0.2 KWH of electricity. Spray drying the yeast cells took 941 ± 50 cubic feet of gas and 2.5 ± 0.2 KWH of electricity. Total spray drying costs were $4.04 per ton of beets.

The total energy cost to process one ton of beets was $15.12 plus an estimated $.45 to recover the ethanol by column distillation (Tables 1 and 3). The energy data contained in this study has been used to calculate plant design including all fixed and variable costs for a full size plant producing three million pounds of beet colorant per year. This information is contained in NSF-RANN Project AER76-24677 Report (1979).

Extraction pigment losses totalled 22 ± 10%. Pigment losses during fermentation, yeast harvest, vacuum concentration, and spray drying amounted to 36 ± 6% of the pigment available after extraction. Substantial post extraction losses are primarily a result of the pigment removed with the yeast cells. In spite of substantial pigment losses, the final product contained three to five times as much pigment as the clari-

Table 2. Pigment concentration as a function of processing step

Processing Step	Red Pigments (g/100g total solids) ± 0.1[a]	Yellow Pigments (g/100 g total solids) ± 0.1[a]	Total Pigments (g/100g total solids) ± 0.2[a]
Initial	0.54	0.26	0.80
After fermentation	3.00	0.93	3.93
After evaporation	3.10	0.98	4.08
After spray drying	2.69[b]	1.02[b]	3.71[b]

[a]Maximum estimated error
[b]Not actual; these figures are adjusted to account for Morex solids added at 37% of total solids

Table 3. Pigment production cost analysis[1]

Expense		$20.00
Raw Product		
Energy		
Extraction	$4.97	
Concentration	5.35	
Fermentation	.51	
Spray drying—beet juice	2.13	
Spray drying—yeast	1.91	
Desludging	.23	
Yeast washing	.02	
Alcohol distillation	.45	
Total Energy Costs		15.57
Tap Water and Sewer		.13
Cost Less Labor, Overhead and Capital Investment		35.70
Income		
Alcohol	5.31	
Yeast	.44	
Total By-Product Income		5.75
Cost to be Offset by 12.5 lb of Dried Powder		29.95

[1]Calculated in dollars on cost per ton basis

CONCLUSION

This pilot plant operation demonstrated it is possible to produce a beet colorant 3 to 5 times more concentrated than those commercially

available. It does not contain the organic compounds responsible for typical beet flavors and odors or the sugars associated with the presently available beet powders and concentrates. The fermentation provides an imporved product and two valuable byproducts, ethanol and single cell protein. Fermenting the beet juice from one ton of beets yeilds about 30 lb of ethanol and 12 lb of yeast worth approximately $5.75. The fermentation, desludging, yeast washing and drying costs about $4.80 per ton of beets processed. The estimated cost of alcohol recovery by distillation is $.45. This leaves $.50 in excess of the added cost of fermentation, harvesting, and drying (Table 3).

The pulp could also have marketable value as animal feed. At 50% solids (w/w), the pulp would contain approximately 6.8% protein, 5.7% fiber, and 30% fermentable sugars. It could be fermented as is to make silage, or yeast could be added for increased protein content.

ACKNOWLEDGMENTS

REFERENCES

ADAMS, J. P., VON ELBE, J. H. and AMUNDSON, C. H. 1976. Production of a betacyanine concentrate by fermentation of red beet juice with *Candida utilis*. J. Food Sci. *41*, 78.

AMUNDSON, C. H. 1967. Spray drying dairy and food products. ASHRAE J. *9*, 70.

AOAC. 1970. *Official Methods of Analysis*. 11th Ed. Association of Official Analytical Chemists, Washington, D.C.

HALL, C. W. 1963. Evaporating and drying equipment. In *Engineering for Dairy and Food Products*, p. 394. John Wiley & Sons, Inc., New York.

MABRY, T. J. 1970. Betalaines, red-violet and yellow alkaloids of the Centrospermae. In *Chemistry of the Alkaloids*. p. 367. Van Nostrand Reinhold Co., New York.

NILSSON, T. 1970. Studies into the pigments in beet root. Lantbrukshogskolans Annaler *36*, 179.

NAS-RANN Project AER76-24677. 1979. Final Report.

RIBOH, M. 1977. Natural colors: what works ... what doesn't. Food Eng. *49*, 66.

VON ELBE, J. H. 1977a. Status of colors in the dairy industry. Dairy and Ice Cream Field. *161*(3), 60.

VON ELBE, J. H. 1977b. The betalaines. In *Current Aspects of Food Coloring*, p. 23. CRC Press, Cleveland, Ohio.

VON ELBE, J. H., KLEMENT, J. T., AMUNDSON, C. H., CASSENS, R. G. and LINDSAY, R. C. 1974a. Evaluation of betalain pigments as sausage colorants. J. Food Sci. *39*, 128.

WITZELL, O. W. and BERRY, R. H. 1976. The engineering core: thermodynamics, fluid flow, heat transfer. In *Engineering Manual*, section 2-29. McGraw-Hill Book Company, New York.

ENERGY COMSUMPTION IN STEAM BLANCHERS[1]

ELAINE P. SCOTT,[2] PAUL A. CARROAD,[3] THOMAS R. RUMSEY,[2] JEFFREY HORN,[4] JAMES BUHLERT[3] and WALTER W. ROSE[5]

University of California
Davis, California 95616

ABSTRACT

The energy consumption of several steam blanchers was monitored to identify design characteristics which are most energy conserving. Hydrostatically sealing the units to prevent escape of steam was shown to be significant in reducing energy usage. Results are compared with estimates of energy efficiency found in the literature and are shown to be in agreement.

INTRODUCTION

Blanching has been shown to be an energy intensive unit operation, accounting for example, in the case of spinach processing, for 34% of all energy used (Chhinnan *et al.* 1980). Very little quantitative information is available in the literature concerning energy utilization by different types of blanchers. What information is available is summarized by J. L. Bomben (1977, 1979).

In its simplest design, a steam blancher is a shrouded conveyor which transports vegetables through a steam atmosphere. The hood of the blancher may be open at both ends and along the sides or water sprays may be incorporated at the ends to condense escaping steam.

---

[1]Data presented in this paper were collected to identify measures which could be taken to effect energy conservation in such processes. Because of the relatively small data base and with variation in product and operator practices in different plants, it is not possible to generalize from these results in evaluating all blanchers of similar design or to compare directly one piece of equipment or process with another.

Reference to a company or product name does not imply approval or recommendation of the product to the exclusion of others that may be suitable.

[2]Department of Agricultural Engineering

[3]Department of Food Science & Technology

[4]UOP Process Division, Experiment Development, Riverside, Illinois

[5]National Food Processors Association, Berkeley, California

Modifications to the basic design may also include hydrostatically sealing the ends and sides of the blancher and using venturi nozzles to recirculate steam within the unit (Layhee 1975; Ray 1975).

Individual quick blanching (IQB) systems represent another modification in which the food is heated in an atmosphere of condensing steam after which it is held in an adiabatic chamber. This allows the product temperature to become uniform which results in the desired enzyme inactivation (Lazar *et al.* 1971). IQB has been applied directly by Cumming and Stark (1980). Bomben applied IQB to a vibratory type spiral blancher in which a vibratory conveyor transports product through the system (Bomben 1977, 1979).

Bomben (1977, 1979) has estimated blancher energy efficiencies using a theoretical steam requirement of 134 kg steam per 10^3 kg of raw vegetables, and an arbitrary product temperature rise of 72° C. This theoretical estimate equals 302 kJ/kg of product (130 BTU/lb). On this basis, the conventional steam blancher was estimated to have an energy efficiency of only 5%, the hydrostatic steam blancher 27%, and the vibratory spiral blancher-cooler 85%.

This paper summarizes data and information gathered on energy use in steam blanchers, based on measurement of four blanchers of differing designs.

METHODS

In performing the energy analyses, the critical measurements were of thermal energy (i.e., steam) input and mass flow. Product and blancher temperatures were recorded to calculate theoretical energy requirements, as well as convective and radiative heat losses. Where appropriate, determination of associated water flow rates and electrical energy consumption were made. All measurements were conducted over several shifts for each blancher to provide representative data for the units. Monitoring production operation resulted in considerable nonuniformity among operating parameters, which were not subject to control of the project investigators.

Thermal Energy

Accutubes (Meriam Instrument Co., Cleveland, Ohio) inserted in steam pipes through welded couplings were used to quantify steam flow. The mass flow rate of steam in a pipe was determined by the upstream and downstream pressure difference across the tube.

The pressure difference was monitored by connecting the high and

low pressure sides of the accutube to an electronic differential pressure cell (Westinghouse) by copper tubing filled with water. The cell emitted a 4 to 20 milliamp signal proportional to the steam flow rate. The milliamp signal was wired across a known resistance to produce a voltage signal which was recorded by a battery-operated data acquisition system (Campbell Scientific Co., Model CR5). The datalogger had capability for recording data on both paper tape and magnetic tape for subsequent analyses, and was equipped with variable scan speed and capability to integrate data over time between printouts.

Steam characteristics of temperature and pressure were measured with thermocouples which fit into the accutubes in the steam line and with pressure gauges on the steam lines and on the differential pressure cell. Steam density was determined with such temperature and pressure data from saturated steam tables. Steam quality was determined by a calorimentic method in which live steam was injected into cold water in an adiabatic chamber and the increases in mass and temperature were measured.

Temperature

Temperatures of blancher surfaces and water lines were monitored during processing with copper-constantan thermocouples attached to the data acquisition system. Mass average product temperatures were determined by collecting samples in an insulated plastic beaker, and inserting a metal thermometer into the center of the pack.

Electrical Energy

Large motors were monitored for electrical energy use by wiring transducers (Ohio Semitronics) into the electrical circuits. The transducers emitted a millivolt signal proportional to power demanded by the motor. The signal was monitored continuously by the data acquisition system and the power demand was integrated over time to yield energy consumption.

Mass Flow

Samples were taken intermittently from product lines during energy monitoring and weighed to determine product flow rate. Product flow manually determined agreed within 3% with the processor's record of product packed during the monitoring operation. Close agreement was expected since in all cases studied, there was no sorting or waste removal between the blancher, the freezer, and the pack-

ing machine, although there was some product dehydration during freezing. All trimming and waste removal occurred before blanching. To systematize results for processors, mass flow is based on the average hourly packed weight output of product according to plant records during the monitoring period.

Analysis Methodology

Energy inputs were quantified for the blanchers studied. The principal basis on which results are expressed is total energy supplied per mass of vegetable blanched. A secondary basis is efficiency defined as the theoretical requirement divided by total thermal energy input. This theoretical requirement represents the energy required to heat adiabatically the vegetables from input temperature up to the blancher set point. Since it was not possible to measure the maximum temperature achieved by the product for both the hydrostatically sealed units as well as the open unit with water sprays, the energy needed to heat product to the blancher set temperature was selected arbitrarily as a basis for comparison among the four units. Results for the blancher with no end seals were expressed similarly for consistency. Energy losses were determined either by estimating or measuring flow and temperature of effluent, and by using conventional engineering correlations to estimate heat transfer losses by convection and radiation. Unaccounted for losses included escape of steam, loss due to evaporation from water surfaces, and energy used to heat certain make-up water flows which were variable and not quantified.

RESULTS AND DISCUSSION

Steam Blancher/No End Seals

Physical Description. The steam blancher without end seals was bascially a conveyer with a stainless steel hood. The unit was not sealed on the ends, and the hood fitted into 2.5 cm (1 in.) water seals on the sides. Steam entered the blancher through a manifold system fed by one 5.0 cm (2 in.) line. Steam flow was through an air-to-open control system and a by-pass line. The unit was 15.2 m (50 ft) long and 1.3 m (4.2 ft) wide, with 0.5 m (1.5 ft) vertical sides and sloped top of .7 m (2.2 ft) from the vertical wall to the highest point. Product was conveyed on a mesh belt, driven by a 1.5 kW (2 HP) motor. This small motor was not monitored.

Results for Steam Blancher Without End Seals. Spinach was blanched at a mass flow of 5,490 kg/h (12,110 lb/h) for 1.5 min. Spinach entered the blancher at 25° C (77° F), and was blanched at a set temperature of 96° C (205° F). The surface temperature of the blancher shell averaged 84° C (183° F) along the top, 91° C (196° F) along the bottom, and 90° C (194° F) along the sides. Ambient air temperature was 14° C (57° F). The stainless steel conveyor belt exited the blancher at a temperature of 95° C (203° F) and was sprayed for cleaning along the return pass, during which it cooled to 18° C (64° F).

The steam to the blancher had the following characteristics: 159° C (318° F), 0.60 M Pa (87.2 psia), and quality 76%. Flow rate was 5,180 kg/h ± 170 kg/h (11,410 lb/h ± 380 lb/h), which is equivalent to a thermal energy input of 11.625 GJ/h ± 0.383 GJ/h (11.019 × 10⁶ BTU/h ± 0.363 × 10⁶ BTU/h). Since the blancher was not sealed, a very large quantity of steam escaped from the unit.

The total convective and radiative heat losses were calculated to be 0.055 GJ/h (52,360 BTU/h) and 0.023 GJ/h (21,370 BUT/h), respectively (Henderson and Perry 1976; Perry and Chilton 1973). With respect to convective losses, 53% occurred from the top of the blancher, 34% from the sides, and only 13% from the bottom. Radiative heat losses amounted to only 42% of convective losses. Energy was also lost during reheating the conveyor belt, amounting to 0.512 GJ/h (485,630 BTU/h). The energy used to reheat the moving stainless steel conveyor belt from 18° C to 95° C was based upon the belt speed of 10.2 m/min (33.3 ft/min) and physical properties of the steel. The theoretical energy requirement for blanching the spinach, based on product temperatures and physical properties of product (ASHRAE 1977), was 1.537 GJ/h (1,456,800 BUT/h).

Table 1 lists an energy balance for this blancher with no end seals. Losses which were unaccounted for were attributed to escaping steam whcih was visually observed to be considerable. The loss of energy in steam which escaped the system as uncondensed vapor is highly significant.

Steam Blancher/Blancher with Water Curtains

Physical Description. The steam blancher with water curtains at its ends was of similar design as the blancher with no end seals. The stainless steel hood fitted into shallow troughs on the sides of the unit. Inside the ends of the blancher were water sprays whose primary purpose was to condense steam which might escape into the processing area and which thus would create an unsanitary condition. Also, the sprays at the outlet facilitated cooling of product.

Table 1. Thermal energy balance for steam blancher with no end seals

	BTU/h	GJ/h	%
Energy consumed by product for blanching (theoretical)	1,456,800	1.537	13.2
Energy lost by convection	52,360	0.055	0.5
Energy lost by radiation	21,370	0.023	0.2
Energy lost by conveyor belt reheating	485,630	0.512	4.4
Energy lost in steam condensate effluent	217,400	0.229	2.0
Unaccounted for losses (i.e., energy lost by escaping steam)	8,785,160	9.269	79.7
Total thermal energy input	11,019,000	11.625	100.0

Energy required per mass of product = 2.12 MJ/kg (910 BTU/lb)

The blancher was 15.2 m (50 ft) long, but the sprays reduced the effective blanching length to 12.2 m (40 ft). The widths of the sloped hood and bottom trough of the blancher were 1.5 m (4.9 ft) and 1.45 m (4.75 ft), respectively. The sides of the blancher were 0.43 m (1.42 ft) high. A 0.75 kW (1 HP) motor drove the mesh conveyor belt which carried product through the blancher. The steam entered the blancher thorugh one 5.0 cm (2 in) line and an air-to-open controller. The thermocouple sensor of the controller was located inside the blancher near the bottom.

Results for the Steam Blancher with Water Curtains. The product mass flow of 4,830 kg of cut green beans (2.5 cm cut, 1.0 in. cut) per hour (10,650 lb/h) required a saturated steam flow of 3,090 kg/h ± 150 kg/h (6,820 lb/h ± 330 lb/h) with steam conditions of 0.55 MPa (80.0 psia) and quality of 85%. Product entered the blancher at 20° C (68° F). The blanching temperature and time were 99° C (210° F) and 3.75 min, respectively. Ambient air temperature was 21° C (69° F). Total water spray flow rate at the ends of the blancher was 8,160 kg/h (18,000 lb/h), entering at 21° C (70° F). This water combined with steam condensate and exited through a single pipe at 36° C (97° F). During monitoring of energy, the water spray flow rate was constant at the highest values possible since the control valves were adjusted to their maximum opening. The average surface temperature of the blancher was 90° C (194° F). The stainless steel conveyor belt entered the blancher at 27° C (80° F) and was heated to 99° C (210° F) within the unit.

The steam flow did not vary significantly because the steam con-

trol valve rarely changed from a completely open position. This may have been the result of large steam demand in a blancher in which tremendous amounts of uncondensed steam escaped through vent ducts through the roof. Another contributing factor may have been placement of the termocouple control sensor on the bottom of the blancher where a locally low temperature may have caused a continuously open valve position.

A summary of information is presented in Table 2. Of the total thermal energy input to the blancher only 19% was needed to fulfill the theoretical energy requirement to blanch the beans. Approximately 60% of the energy input was not accounted for and, presumably, escaped as uncondensed steam or was condensed by the water sprays. The energy required per mass of product averaged 1.56 MJ/kg (670 BTU/lb).

Steam Blancher/Blancher with Hydrostatic Water Seals

Physical Description. The steam blancher with hydrostatic water seals at the entrance and exit of the unit conveyed product into and out of the steam chamber on dunking and discharge belts which passed the product under water seals. In addition, the sides of the hood fitted into shallow troughs which acted as water seals. Process steam was thereby not permitted to escape directly from the blancher, although overflow lines on the water seals presented a route for loss of hot water. The main conveyor belt was completely enclosed within the unit and only short sections of the dunking and discharge belts were exposed. Water sprays at the inlet end aided in loading product

Table 2. Thermal energy balance for steam blancher with water curtains

	BTU/h	GJ/h	%
Energy consumed by product for blanching (theoretical)	1,363,500	1.438	19.0
Energy lost by convection	32,800	0.035	0.5
Energy lost by radiation	25,600	0.027	0.4
Energy lost by heating of water sprays	486,000	0.513	6.8
Energy lost in steam condensate effluent	784,300	0.827	10.9
Energy lost by conveyor belt reheating	230,400	0.243	3.2
Unaccounted for losses (i.e., escaping steam)	4,244,100	4.478	59.2
Total thermal energy input	7,166,900	7.561	100.0

Energy required per mass of product = 1.56 MJ/kg (670 BTU/lb)

onto the dunking belt and sprays at the outlet end helped to cool the product. These water streams flowed into the water seals and were recycled through a cleaning reel. The blancher was 25.6 m (84 ft) long, 0.79 m (2.6 ft) high and 1.7 m (5.4 ft) wide. Steam entered the manifold through an air-to-open control system which was fed by a single 0.15 m (6 in.) pipe. The entire processing plant operated with hydraulically driven conveyors and pumps. Based upon consideration of electric motors used with blanchers of similar size, estimation of equivalent energy needed to power the conveyor belt through the blancher and to operate the recycle pumps was judged unnecessary. Further monitoring of a similar blancher with hydrostatic seals and nozzles operating on the venturi principle confirmed the judgment as correct.

Results for the Steam Blancher with Hydrostatic Seals. Spinach was transported through the blancher at a rate of 12,800 kg/h (28,200 lb/h). Steam with 85% quality and 0.80 M Pa (116.7 psia) pressure was injected at a rate of 4,960 kg/h ± 830 kg/h (10,900 lb/h ± 1,830 lb/h) so that thermal energy input was 12.196 GJ/h ± 2.05 GJ/h (11,560,000 BTU/h ± 1,940,000 BTU/h). Product entered at 33°C (92°F). Blanching temperature and time were 98°C (209°F) and 1.5 min, respectively. Ambient air temperature was 23°C (73°F).

The data is summarized in Table 3. The assumed rise in spinach temperature of 65°C for blanching required only 27% of the total energy input. Energy lost in steam condensate effluent was appreciable. The surface temperature of the blancher was 86°C (188°F) from which convective and radiative heat losses were calculated to be only a small percentage of total energy usage. The energy required in this

Table 3. Thermal energy balance for steam blancher with hydrostatic water seals

	BTU/h	GJ/h	%
Energy consumed by product for blanching (theoretical)	3,142,700	3.316	27.2
Energy lost by convection	80,700	0.085	0.7
Energy lost by radiation	40,000	0.042	0.3
Energy lost in steam condensate effluent	1,934,000	2.040	16.7
Unaccounted for losses	6,362,600	6.713	55.1
Total thermal energy input	11,560,000	12.196	100.0

Energy required per mass of product = 0.95 MJ/kg (410 BTU/lb)

case is much reduced over that demanded by open blancher designs, amounting to 0.95 MJ/kg (410 BTU/lb).

Steam Blancher/Blancher with Hydrostatic Water Seals and Venturi Nozzles

Physical Description. The hydrostatically sealed steam blancher with venturi nozzles was generally similar to the previously described blancher with hydrostatic seals except for incorporation of special steam injection nozzles of venturi tube design. When steam is injected, the increase in flow velocity at the constriction causes a pressure decrease which is used to draw steam from the top of the blancher through a recycling tube and back through the nozzles and into the product area. The blancher was 1.2 m (40 ft) long, 0.79 m (2.6 ft) high, and 1.6 m (5.3 ft) wide. Steam entered the venturi nozzle manifold system through an air-to-open controller in a single 0.076 m (3 in.) pipe. The blancher was equipped with two 7.5 kW (10 HP) pumps for recirculation of water in the entering seal area, a 3.7 kW (5 HP) conveyor motor, and two small 0.75 kW and 0.2 kW (1 HP and 0.25 HP) motors which operated paddles to submerge spinach through the entering and exit seals. The water level in the inlet seal was maintained by addition of fresh water and flow of steam condensate. Water level in the discharge seal was maintained by flow of water from cooling sprays, plus steam condensate.

Results for Steam Blancher with Hydrostatic Water Seals and Venturi Nozzles. The spinach mass flow rate of 5,900 kg/h (13,000 lb/h) required a steam flow of 2,180 kg/h ± 220 kg/h (4,800 lb/h ± 470 lb/h) at a pressure of 0.86M Pa(125 psia) and quality of 99%. The thermal energy input was 5.37 GJ/h ± 0.53 GJ/h (5,093,600 BTU/h ± 500,000 BTU/h). Product eneted at 24° C (75.3° F). Blanch temperature was set at 95° C (203° F). Ambient air temperature was 28° C (65° F). Thermocouple measurements on the blancher surface showed the surface temperature' to be 93° C (200° F). The blanch time was 0.75 min, a low value which corresponded to the light loading of the spinach on the conveyor belt. The throughput of spinach during monitoring was less than 50% of the design capacity of the unit.

A summary of results is listed in Table 4. Based on the temperature rise from 24° C to 95° C, the theoretical energy requirement for blanching was 1.66 GJ/h (1,577,600 BTU/h), which represents 30.9% of the energy input. Losses in steam condensate were approximately 16% of energy input. Convective and radiative heat losses represent relatively small percentages. The energy required per mass of product

Table 4. Thermal energy balance for steam blancher with no end seals

	BTU/h	GJ/h	%
Energy consumed by product for blanching	1,577,600	1.66	30.9
Energy lost by convection	61,200	0.06	1.1
Energy lost by radiation	27,600	0.03	0.6
Energy lost in steam condensate effluent	821,900	0.87	16.2
Unaccounted for losses	2,605,300	2.75	51.2
Total thermal energy input	5,093,600	5.37	100.0

Energy required per mass of product = 0.91 MJ/kg (390 BTU/lb)

was determined to be 0.91 MJ/kg (390 BTU/lb).

Monitoring of electrical energy with transducers showed that the two large pumps required 5.32 kW (7.1 HP) total and that the conveyor motor required 1.53 kW (2.1 HP). On a fossil fuel equivalent basis the measured electrical energy use is equivalent to 75.8 MJ/h (7,200 BTU/h) (Chhinnan et al. 1980). This is equivalent to 0.11 GJ/h assuming a 70% efficient boiler. The electrical energy input is negligible, amounting to only 2.0% of total energy input.

SUMMARY OF STEAM BLANCHER RESULTS

The results indicate the energy conservation to be achieved by sealing the blancher to minimize escape of live steam. Despite the variation in operating conditions among the four units, the open blanchers are approximately 10% less efficient than the sealed units; the similarity of efficiencies shown in Table 5 for open and for sealed units suggests that the hydrostatic seals are a primary factor responsible for the difference.

Table 5 lists three energy efficiency values for each blancher. The measured values derive from the energy balances already presented. The calculated values are the quotient of Bomben's theoretical requirement of 302 kJ/kg (130 BTU/lb) and the measured energy required per mass of product (Bomben 1977). The estimated value of Bomben was based on available literature results and reports by industrial users of the units (Bomben 1977; Layhee 1975; Ray 1975). Bomben's theoretical requirement assumes a product heat capacity of 1.0 kcal/°C gm, a temperature rise 0f 72°C, and use of saturated steam at atmospheric pressure. Basing the energy usage on heat input rather than mass of steam corrects for steam inputs at different

Table 5. Comparison of energy efficiencies for steam blanchers

Steam Blancher	T, °C	C_p^a J/g·°C	Energy/Mass MJ/kg	Thermal Energy Efficiency		
				Measured[b]	Calculated[c]	Estimated[d]
No end seals (spinach)	71	3.98	2.12	13	14	5
Water curtain (green beans)	78	3.81	1.56	19	19	5
Hydrostatic (spinach)	65	3.98	0.95	27	32	27
Hydrostat/Venturi (spinach)	71	3.98	0.91	31	33	27

[a]Heat capacity (ASHRAE 1977)

[b]Efficiency equals theoretical requirement based on operating conditions divided by total measured energy input.

[c]Efficiency calculated as defined by J. L. Bomben (1977); based on theoretical requirement of 302 J/g (130 BTU/kb), $C_p = 4.19$ J/g·°C (1.0 BTU/lb·°F), $\Delta H_{steam} = 2.256$ J/g (970 BTU/lb), $\Delta T = 72$°C

[d]Efficiency estimated by Bomben (1977)

conditions of temperature, pressure, and quality. The actual temperature increases and reported heat capacities (ASHRAE 1977) are listed in Table 5, and differences between these values and Bomben's assumptions are clear. Nevertheless, the measured and calculated efficiencies are not very different which indicates that Bomben's definition, while arbitrary, is a useful basis on which to compare blanchers. The measured and calculated efficiencies are greater than estimated by Bomben, but only slightly so for the hydrostatically sealed units.

ACKNOWLEDGMENT

REFERENCES

American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (ASHRAE) 1977. *Handbook and Product Directory: 1977 Fundamentals.* ASHRAE, New York.

BOMBEN, J. L. 1977. Effluent generation, energy use and cost of blanching. J. Food Proc. Eng. *1*, 329-341.

BOMBEN, J. L. 1979. Waste Reduction and Energy Use in Blanching. In *Food Processing Waste Management*, (J. H. Green and A. Kramer, eds.), AVI Publishing Co., Westport, Connecticut.

CHHINNAN, M. S., SINGH, R. P., PEDERSEN, L. D., CARROAD, P. A., ROSE, W. W. and JACOB, N. L. 1980. Analysis of energy utilization in spinach processing. Transactions of the ASAE *23*(2), 503-507.

CUMMINGS, D. B. and STARK, R. 1980. The development of a new blanching system. J. Can. Diet. Assoc. *41*(1), 39-44.

HENDERSON, S. M. and PERRY, R. L. 1976. *Agricultural Process Engineering*, 3rd Ed. AVI Publishing Co., Westport, Connecticut.

LAYHEE, P. 1975. Engineered FF line yeilds 5 big production benefits. Food Eng. *47*(2), 61-62.

LAZAR, M. E., LUND, D. B. and DIETRICH, W. C. 1971. IQB: A new concept in blanching. Food Technol. *25*, 684-686.

PERRY, R. H. and CHILTON, C. H. 1973. *Chemical Engineer's Handbook,* 5th Ed. McGraw-Hill Book Co., New York.

RAY, A. 1975. Steam blancher uses 50% less energy. Food Proc. *36*(1), 64.

THE THERMAL PROPERTIES OF FROZEN
INVERT SUGAR SOLUTIONS

R. A. KEPPELER and JOSE R. ARBOLEDA

Department of Agricultural Engineering
Pennsylvania State University
249 Agricultural Engineering Building
University Park, Pennsylvania 16802

ABSTRACT

The thermal conductivity, thermal diffusivity, apparent heat capacity and density of frozen invert sugar solutions were found for 40, 50, 60 and 95% sugar inversion, each in concentrations from 2 to 35%, between −40° C and 3.9° C at 2.78° C temperature intervals. The apparatus and instrumentation used was identical with that reported by Keppeler and Boose (1970).

INTRODUCTION

Sucrose is a disaccharide composed of two molecules of the monosaccharides, dextrose (glucose) and fructose. By hydrolysis, catalyzed by acid and heat, sucrose can be split into its own molecular consituents in equal proportions, called the invert sugars. Fructose and dextrose also occur abundantly in nature in various proportions with sucrose because of the slow natural process of inversion.

Sucrose fills the human's needs in daily living in the form of a household sweetening agent processed from sugar cane or sugar beets, while fructose and dextrose are found not only in sugar cane or sugar beets but also abound naturally in raisins, grapes and flower nectars (Liener 1966). These sugars, plus lactose and corn syrup solids, constitute a major portion of the sweetening agents in processed, sweetened frozen food products.

Although limited information is available about the thermal properties of frozen sugar or mixed sugar solutions, manufacturers continue making frozen, sweetened food products using mixes of various proportions of sugars to achieve the least cost of materials, possibly improve quality and satisfy the increasing demand for the product and

its variations. Since all sugars have their own chemical and molecular structure, any combination of different amounts of these sugars will affect the thermal properties of the frozen aqueous solution. The enormous number of possible combinations of these sugars makes nearly impossible the determination of the thermal properties of the individual sugars at various concentrations and temperatures and a good estimate can be made of the thermal properties of a sugar mixture at a given concentration from these known thermal properties at various temperatures and concentrations (Bard and Keppeler 1970; Keppeler and Hall 1968).

Knowledge of those thermal properties could greatly increase the flexibility in choosing sugars in making frozen food mixes to satisfy the consumer's demands and improve quality and processing equipment.

REVIEW OF RELATED LITERATURE

Interest in the determination of thermal properties of food started in 1892 when Seibal reported specific heats of some foods based upon his calculations made from the assumption that foods were composed of water and solid matter.

Using calorimetry, Short et al. (1942) and Staph (1949) found that the assumption of a weighted average for the value of specific heat by Seibel was not correct. They said that specific heats of frozen foods and sugar solutions increased sharply as the temperature increased to the thawing region.

Lentz (1961) determined the thermal conductivities of gels and meats for temperatures between $-25°$ F to $5°$ F ($-31.7°$ C to $-15°$ C). Moline et al. (1961) described a method that can continuously determine the specific heat of foods over a wide temperature range below the freezing point. They found that an estimate of the specific heat of foods could be made based on their compositions with an appropriate correction factor.

Working with sugar solutions, Keppeler (1968) adapted the method of Moline et al. (1961) along with the mathematical solutions of the Fourier heat transfer equation by Thomas (1957) to determine the thermal diffusivity and apparent heat capacity of sucrose, corn syrup solids, lactose, corn syrup solids-lactose and sucrose-lactose solutions over a temperature range from -20 to $+20°$ F ($-28.9°$ C to $-6.7°$ C). He found that the apparent specific heat was not linear with temperature; that it was possible to predict the apparent specific heat of mixed solutions using the specific heat of the ingredients of the solution and the regression equation for each mixture; and that the thermal diffusivities of the mixture could be predicted by calculation

using the thermal diffusivities of the ingredients and a parallel electrical resistance analogy (Bard and Keppeler 1970).

Keppeler and Boose (1970) continued that work and determined the thermal diffusivity, apparent heat capacity, thermal conductivity and density of a number of concentrations of frozen sucrose solutions.

(Bard and Keppeler 1970) studied further the initial findings of Keppeler and Hall (1968) and Keppeler and Boose (1970) and developed a method of predicting the thermal properties of sugar solutions at various concentrations over the temperature range from −40 to 25° F (−40° C to −3.9° C).

No previous study on thermal properties of invert sugar has been reported.

OBJECTIVES

The object of this work was to study 4 levels of sucrose inversion to dextrose and fructose at concentrations from 2 to 35% each at the temperature range from −40° to −3.9° C at 2.78° C intervals and determine the thermal diffusivity, apparent heat capacity, thermal conductivity and density.

PROCEDURE

The relationships, equipment and procedures for usage of that equipment are detailed in the paper by Keppeler and Boose (1970) and Keppeler and Hall (1968).

In the determination of thermal properties of invert sugar, four inversion levels of sucrose (40, 50, 60 and 95%), with each inversion in aqueous solution from 2 to 35% concentrations, were used in the study. At 40% sugar inversion five concentrations (2, 10, 16, 25 and 35%) were used, while at the other levels (50, 60 and 95%) thirteen concentrations (2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 25, 30 and 35%) for each inversion were made for the study.

The solutions used in the study were mixed from pure sucrose (household sugar and the commercially available pure dextrose and fructose, taking into account the change in molecular weight of the monosacchande moieties because of the water addition in the hydrolysis reaction for example. For a solution of 20% concentration at 60% sugar inversion, the 20 g of sugar for a 100 g aqueous solution is made up of 12 (20 × 0.6) combined weight of dextrose and fructose and 8 g of sucrose. From the balanced chemical equation, the amount of

dextrose or fructose (x) is

$$x = \frac{180}{342} \times 12 \text{ g}$$

$$= 6.316 \text{ g}$$

thus, the amounts of sugars and distilled water to be added to from the 100 g aqueous solution would be: 8, 6.316, 6.316 and 79.368 of sucrose, dextrose, fructose and distilled water, respectively.

The apparatus designed by Keppeler and Hall (1968) and constructed by Keppeler and Boose (1970) was used to determine the thermal diffusivity, apparent heat capacity, thermal conductivity and density of the frozen, mixed solution. The apparatus used consisted of the following: (1) Aluminum tubes (5.08 cm O.D., 4.83 cm I.D., 25.4 cm long) with welded bottoms and plugged at the top. The tubes were wired with 28 gage copper-constantan thermocouples to measure the temperature at the geometric center of the sample. Paired 24 gage iron-constantan thermocouples were used for measurement of the temperature difference between the geometric center and the outside surface of the sample; (2) Polystyrene foam containers (20.32 × 20.32 × 40.64 cm) divided into halves and drilled at the center to receive the aluminum tubes. When in use the two halves were held together by a light wooden frame and the open end was plugged by a roll of polyurethane foam; (3) A Brown recording potentiometer (−51° C to 32° C range sensitivity 1% of range) measure and record the temperature at the geometric center of the sample; (4) A Honeywell Deviation Amplifier No. 811-11 to amplify (approximately 10,000 times) the signal from the 24 gage iron-constantan thermocouples. An attenuator was used for calibration purposes; (5) A Brown recording potentiometer with a range of 0-50 millivolts (sensitivity 1% of range) to record the signal coming from the Deviation Amplifier; (6) A room with temperature maintained at 21° C ± 1° C by an air conditioner to contain the samples during the warming period; and (7) A thick-walled (1.5 cm) aluminum bar, 15.24 cm long, with a hole 3.56 cm in diameter and 12.45 cm deep for density measurements.

Four hundred grams of the aqueous solution were poured into each of the three aluminum tubes, enclosed in the polystyrene foam containers and placed in the freezer overnight to freeze to −51° C. The following day they were closed, covered and connected to the

recorders in the controlled 21°C temperature room and allowed to warm to −4°C. The warming time varied from about 8 h to 24 h for the lowest and highest concentrations, respectively. The thermal properties of the aqueous solutions were determined over a temperature range of −40°C to −4°C by 2.79°C intervals.

The temperature difference between the center and outer surface of the sample and the rate of change of the core temperature were measured to calculate the thermal properties of the solutions. The rate of temperature change at the geometric center for each 2.78 degree increment was the temperature change divided by the length of time for accomplishing the change. The temperature difference between the core and the outer surface of the sample during a particular 2.78 degree change in the core temperature was found by locating the appropriate time interval on the temperature difference chart and converting the average millivolt values to temperature using 50.36 millivolts per 1°C (28 millivolts per 1°F). The thick-walled aluminum tubes were used to determine the density of the solutions. Solutions were prepared, poured into the tubes and frozen. The excess ice was removed with a wood plane blade until the surface was flush with the top of the tube and the tube and ice were immediately weighed. Knowing the volume, tare and final weight, the density was determined. Freezer temperatures of −12°C, −26°C and −42°C were used. (More information can be gained from references 2 and 3).

RESULTS AND DISCUSSION

The thermal diffusivity, heat capacity, thermal conductivity and density of 40, 50, 60 and 95% sugar inversions, each in concentrations from 2 to 35% and analyzed between −40°C and −3.9°C at 2.78°C temperature intervals are plotted and discussed below. Some data obtained at higher concentrations and temperatures between −12°C and −3.9°C were not included because the differential millivolt recorder values went off the chart. The high temperature at the outer surface of the sample is caused by the slow dissipation of the incoming heat energy because of the relatively low values of the thermal conductivity and diffusivity along with a steep increase in heat capacity at the higher concentrations and temperatures.

Thermal Diffusivity

The thermal diffusivity of all the sugar inversions studied decreased as the temperature increase. Also, for a particular temperature interval, the thermal diffusivity values decreased with increase in concentration. This trend was also reported by Keppeler and Boose (1970) for sucrose solutions. The decrease in the value of the thermal diffusivity with increasing temperature indicated that the warming time of the solution increased.

Forty Percent Sugar Inversion. Inversion. The plot of the thermal diffusivity versus temperature in Fig. 1, show the decrease in the value of the thermal diffusivity with increase in temperature and
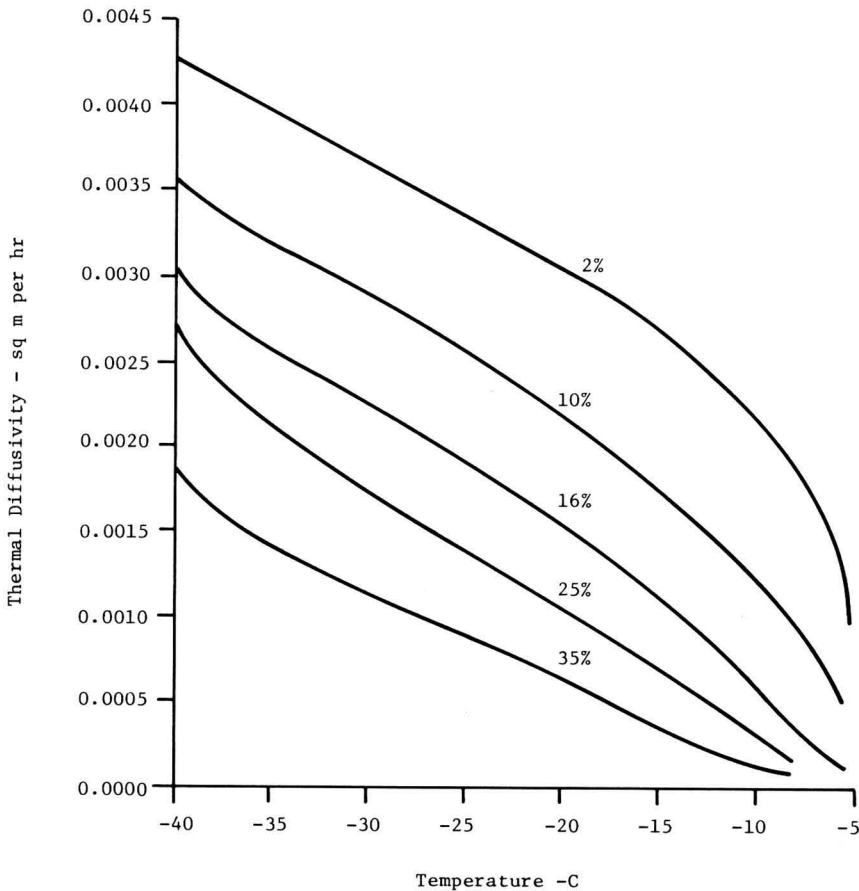
FIG. 1. THERMAL DIFFUSIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF 40% SUGAR INVERSION OF NOTED CONCENTRATIONS

concentration as mentioned above. The values are approximately 21% lower than those found by Keppeler and Boose (1970) for sucrose at the same concentrations and temperature intervals.

Fifty Percent Sugar Inversion. Thermal diffusivities for 60% sugar inversion (Fig. 3) are approximately 1% lower than those for the 50% sugar inversion (Fig. 2).

FIG. 2. THERMAL DIFFUSIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF 50% SUGAR INVERSION OF NOTED CONCENTRATIONS

Ninety-five Percent Sugar Inversion. Thermal diffusivities for 95% sugar inversion (Fig. 4) were found to be approximately 6% lower when compared to the values obtained at 60% sugar inversion.

No explanation was found for the crossover of the curves of the 8% and 10% solutions nor the 12% and 14% curves.

FIG. 3. THERMAL DIFFUSIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF
60% SUGAR INVERSION OF NOTED CONCENTRATIONS

Apparent Heat Capacity

Sugar in solution decreases the freezing point to an extent dependent upon the concentration. During the thawing process for the frozen sugar solution, a very limited amount of melting takes place at the lower temperature and increases with increase in temperature. The heat required by the frozen solution to thaw includes both the specific heat and heat of fusion needed to change it from solid to liquid state at the same temperature. This heat needed to increase the temperature of the frozen solution and the heat of fusion to change it from solid to liquid at the same temperature are included and reported as apparent heat capacity.
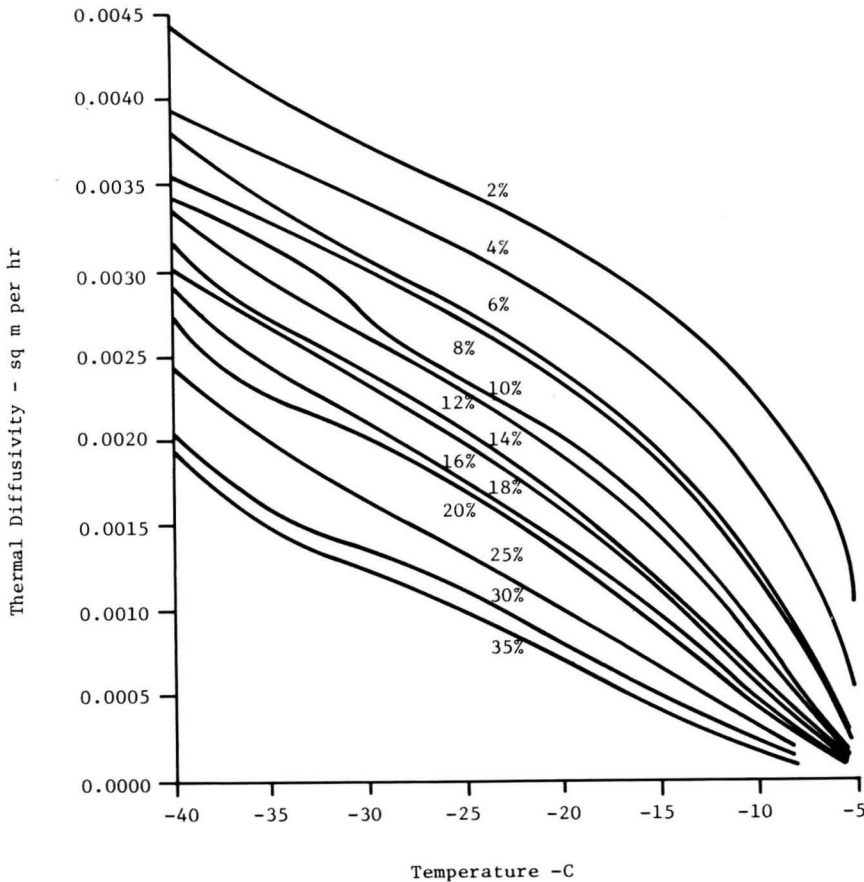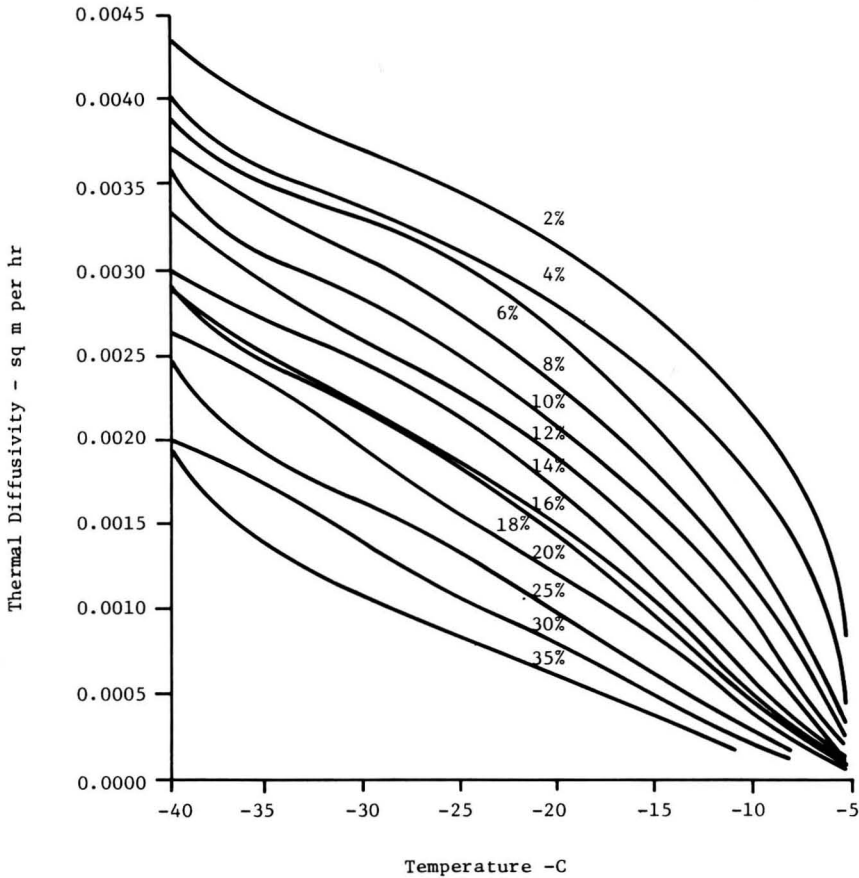
FIG. 4. THERMAL DIFFUSIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF
95% SUGAR INVERSION OF NOTED CONCENTRATIONS

The apparent heat capacity increased with temperature, but more
prominently at the higher temperatures. Also, for any particular
temperature interval studied, the apparent heat capacity values
increased with concentration. This same trend was also reported by
Keppeler and Boose (1970) for sucrose solutions. The high rate of
increase could be attributed to the increased melting of the solutions,
requiring more heat (heat of fusion) for a small increase in
temperature.

Forty Percent Sugar Inversion. Figure 5 shows the apparent heat
capacities versus temperature of the 40% sugar inversion at 2, 10, 16,
25 and 35% concentrations. The plot shows a steep increase in the

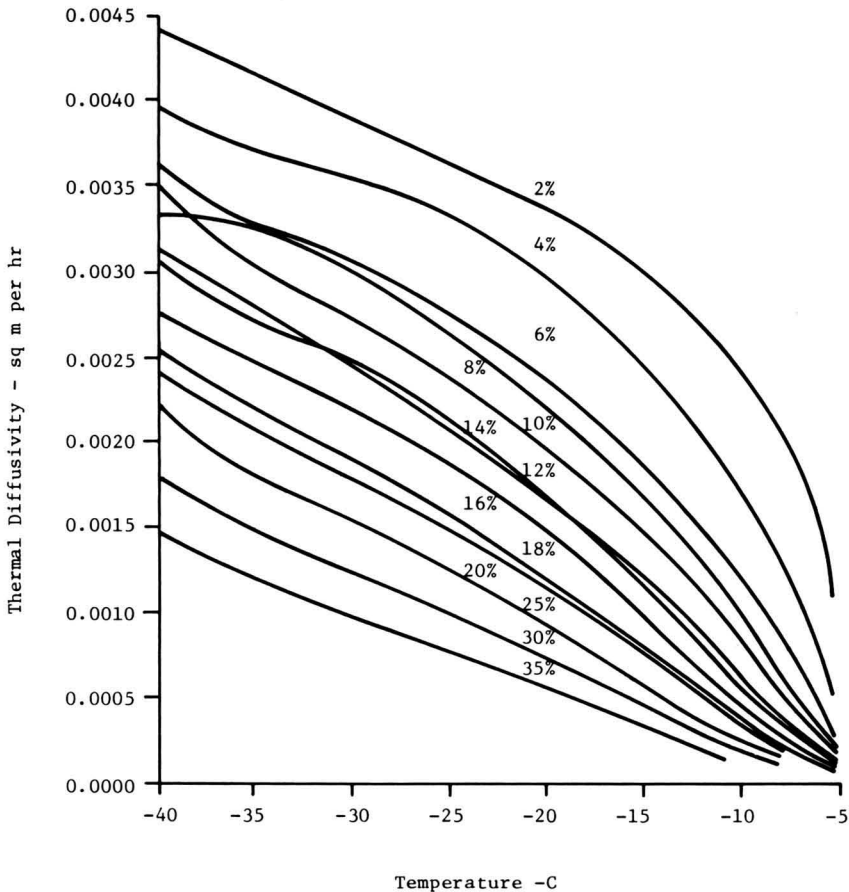FIG. 5. APPARENT HEAT CAPACITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
OF 40% SUGAR INVERSION OF NOTED CONCENTRATIONS

apparent heat capacity values as the temperature of the solutions
approaches −5° C. The apparent heat capacity values are approxi-
mately 52% higher when compared to those found by Keppeler and
Boose (1970) for the same concentrations and temperature intervals
with the sucrose solutions.

FIG. 6. APPARENT HEAT CAPACITY VERSUS TEMPERATURE INTERVAL FOR FROZEN
SOLUTIONS OF 50% SUGAR INVERSION OF NOTED CONCENTRATIONS

Fifty Percent Sugar Inversion. For the 50% sugar inversion, (Fig.
6), the values of the apparent heat capacity are approximately 2.5%
higher than those found at 40% sugar inversion for the same concen-
trations and temperatures.

FIG. 7. APPARENT HEAT CAPACITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
OF 60% SUGAR INVERSION OF NOTED CONCENTRATIONS

Sixty Percent Sugar Inversion. Apparent heat capacities for the
60% sugar inversion (Fig. 7) are approximately 2.5% higher than the
values for 50% inversion.

Ninety-Five Percent Sugar Inversion. Increasing the amount of
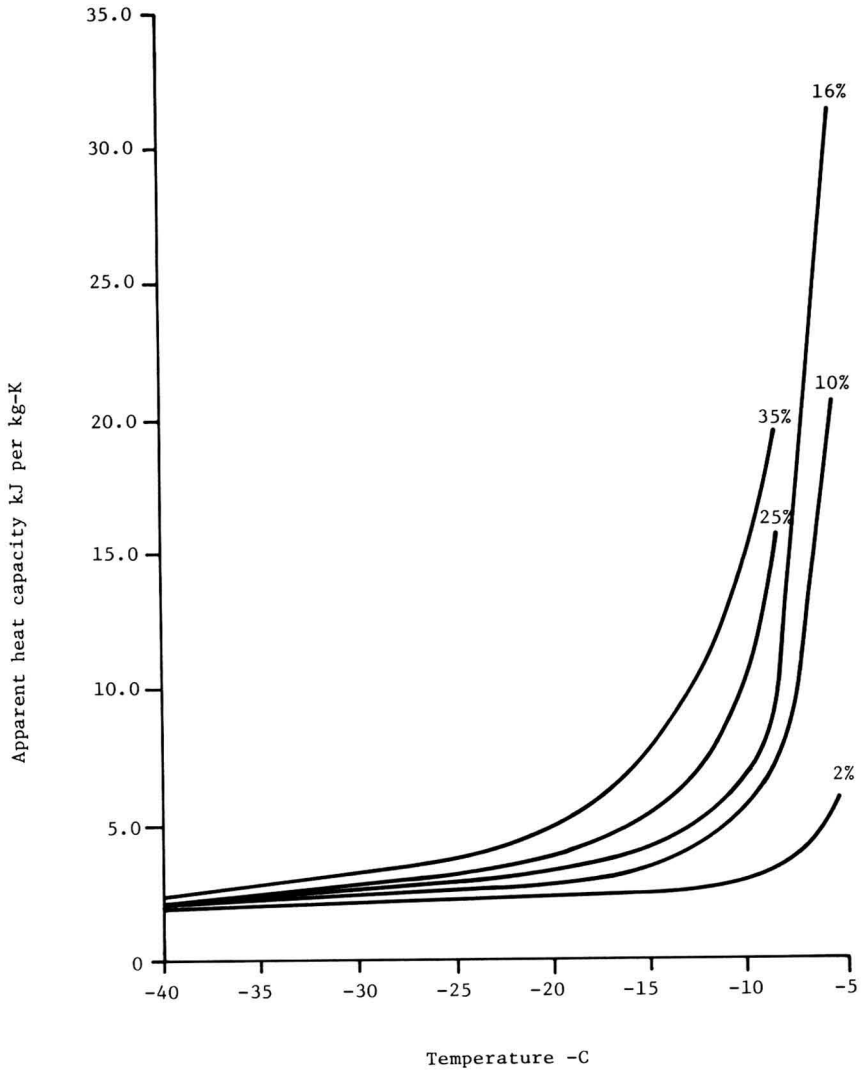invert sugar in solution increases the apparent specific heat of the
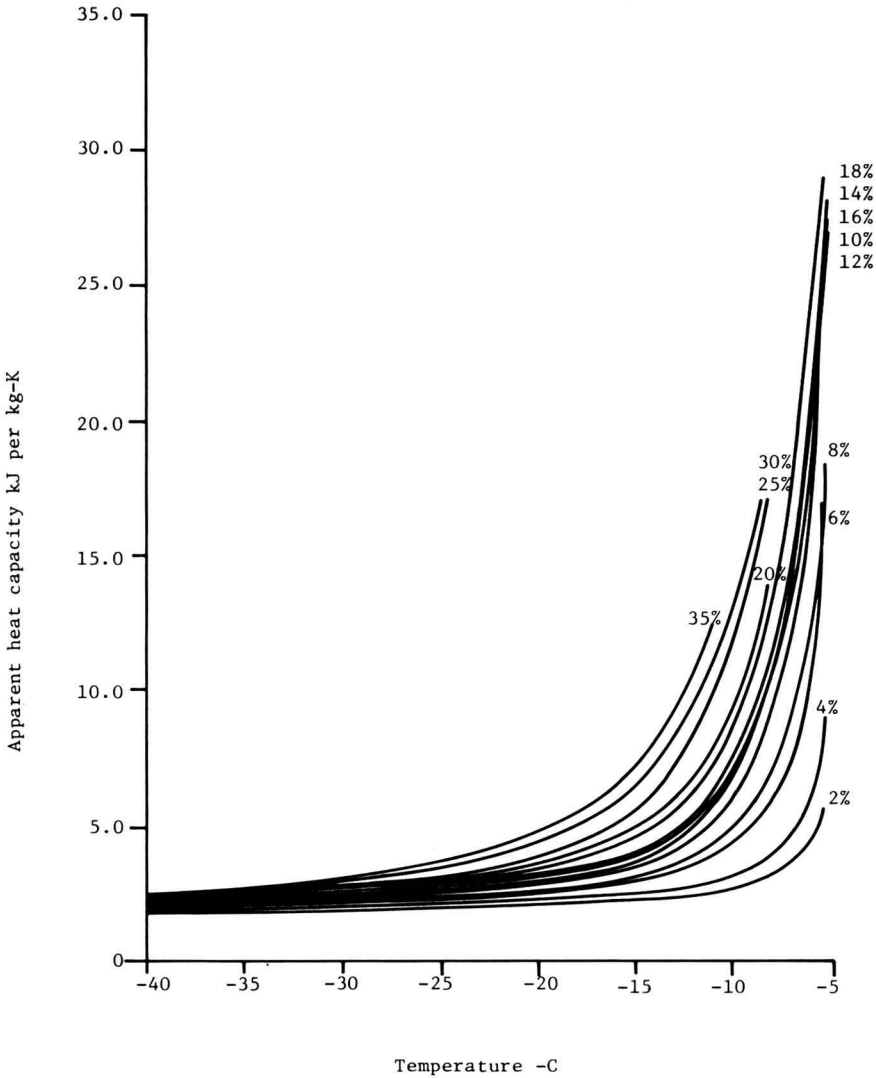
FIG. 8. APPARENT HEAT CAPACITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
OF 95% SUGAR INVERSION OF NOTED CONCENTRATIONS

frozen solution as shown by the other three sugar inversions discussed.
The values obtained from the 95% sugar inversion shown in Fig. 8 are
higher by approximately 5% than those for the 60% sugar inversion.

Thermal Conductivity

For the four degrees of sugar inversions studied, the thermal con-
ductivity decreased with increasing temperature and for a particular

temperature the thermal conductivity decreased with increased concentration. This tendency with respect to concentrations and temperature is the same as in sucrose solutions for the same concentrations and temperature.

Forty Percent Sugar Inversion. The thermal conductivities of the 40% sugar inversion (Fig. 9) were found to be lower than sucrose by about 5%. These curves show a decrease in the thermal conductivity with increase in temperature and concentration for a particular temperature.

Fifty Percent Sugar Inversion. For the sugar inversion of 50%, (Fig. 10) were less than 1% higher than the 40% sugar inversion. Again, there is no explanation for the crossover of the 8% and 10% solution curves.
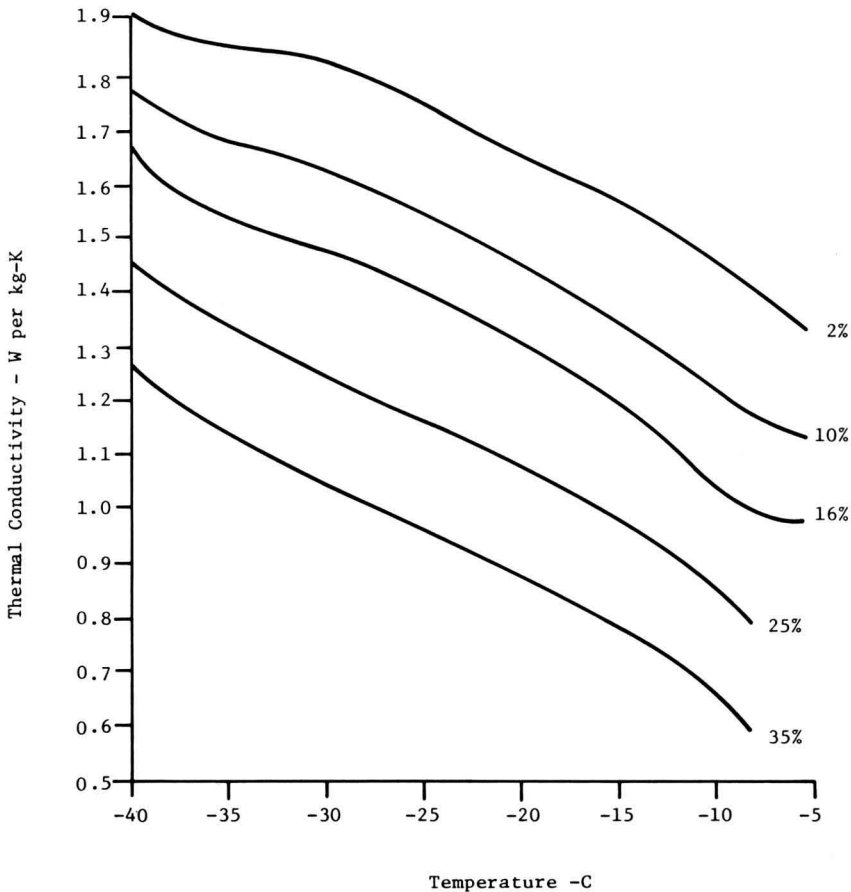
FIG. 9. THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
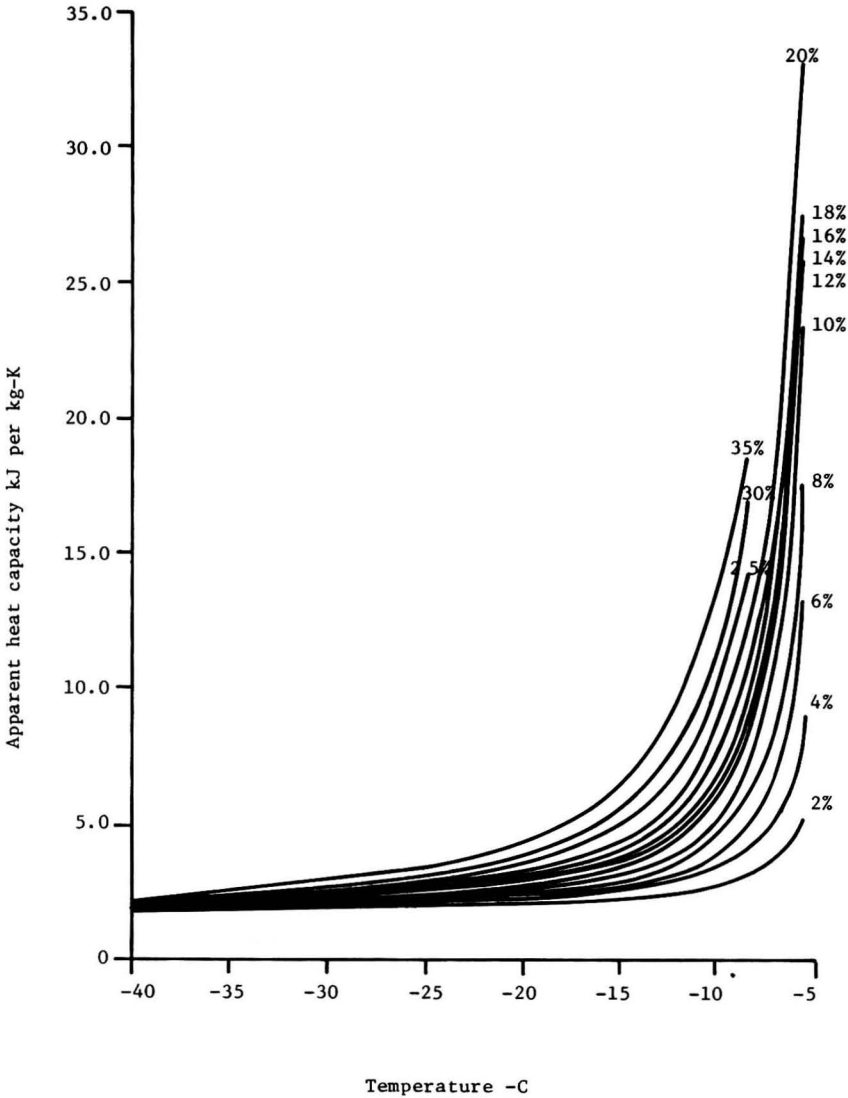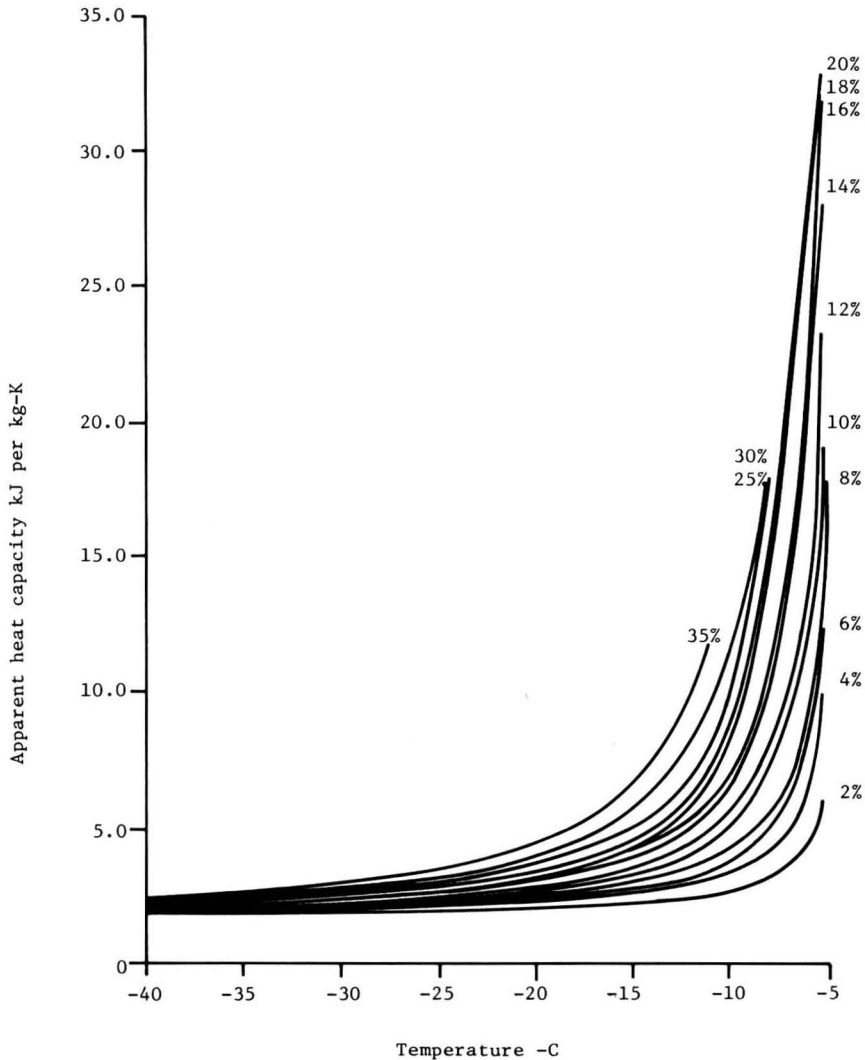OF 40% SUGAR INVERSION OF NOTED CONCENTRATIONS
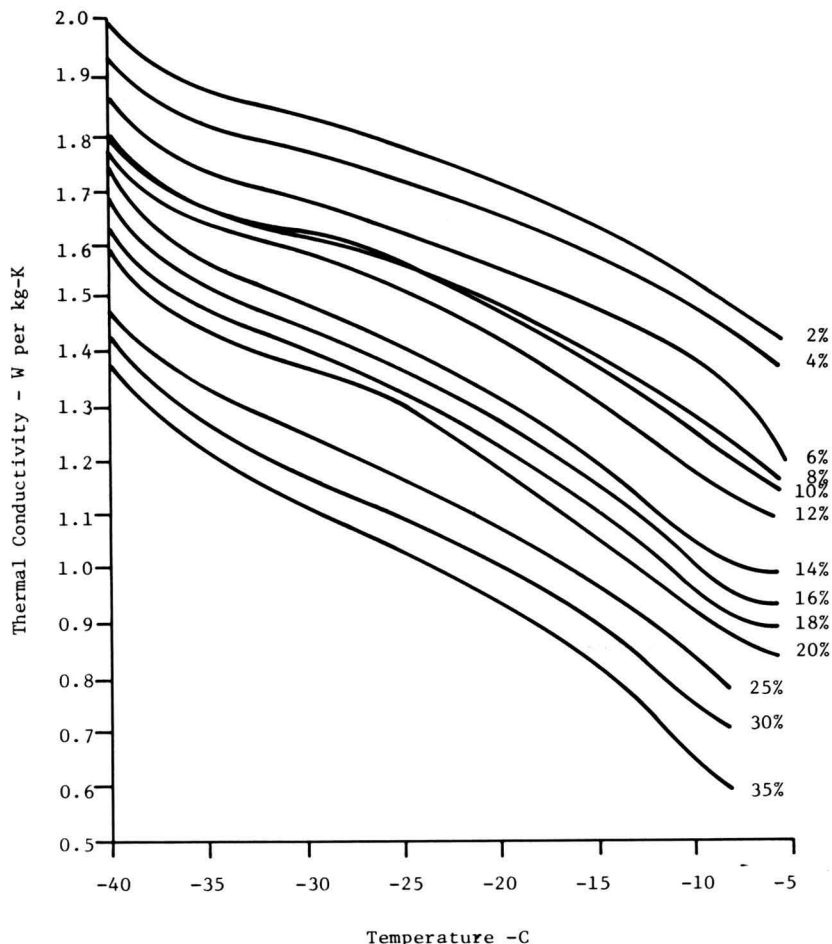
FIG. 10. THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
OF 50% SUGAR INVERSION OF NOTED CONCENTRATIONS

Sixty Percent Sugar Inversion. **Figure 11 shows that the thermal
conductivity for the 60% sugar inversion is approximately 1% higher
than for the 50% sugar inversion. The thermal conductivity-
temperature interval curves show overlapping values at concentra-
tions of 4, 6 and 8% and a higher value for the curve of the 18% than
for the 16% concentrations at lower temperature range. The tests on
these concentrations were repeated and the results were similar to
those reported. The cause of this crossover is not known.**
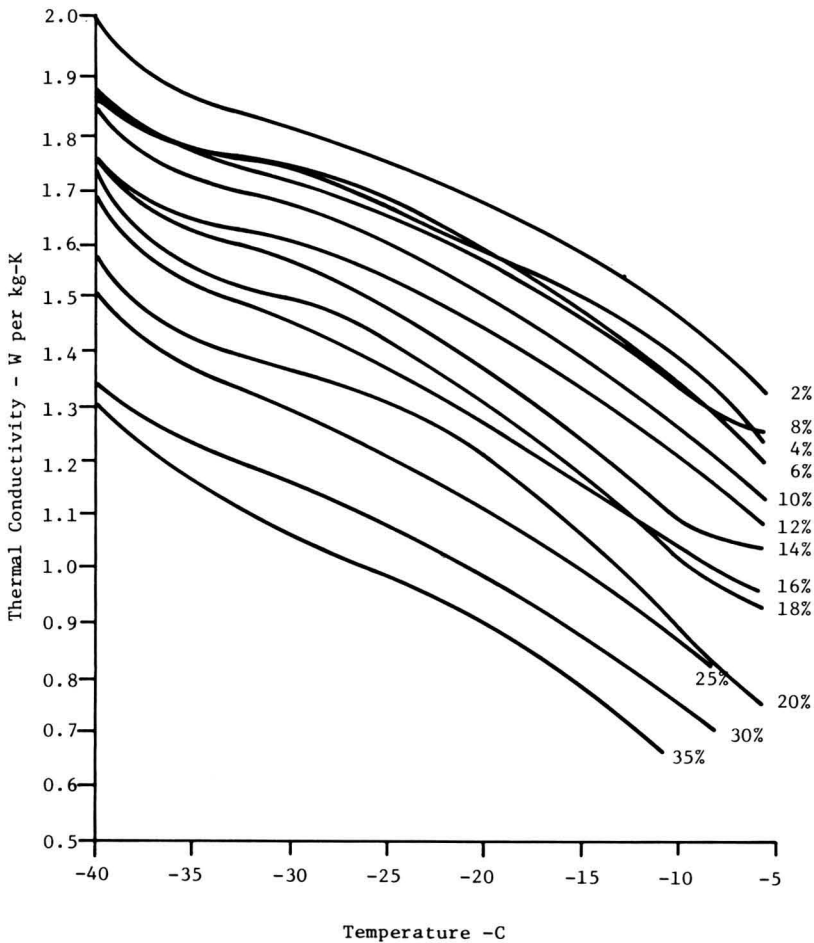
FIG. 11. THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
OF 60% SUGAR INVERSION OF NOTED CONCENTRATIONS

Ninety-Five Percent Sugar Inversion. The thermal conductivity
values for 95% inversion (Fig. 12) were found to be approximately
2.5% lower than the 60% sugar inversion. Again, overlapping of
values at 8, 14 and 20% concentrations were repeated with similar
results.

Density

The densities of the sugar solutions used at various inversions and
concentrations were determined at temperatures of -12, -26 and
$-42°C$ as outlined in the procedure. The computer library program,
POLY 2, at The Pennsylvania State University Computation Center
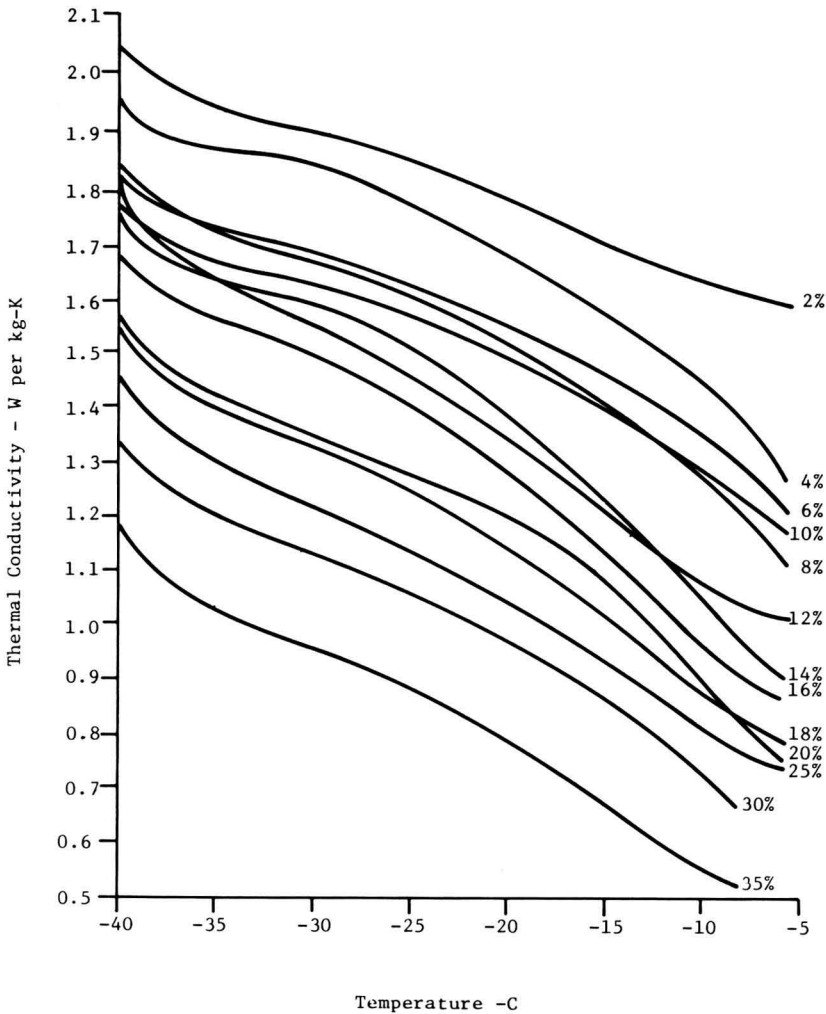
FIG. 12. THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS
OF 95% SUGAR INVERSION OF NOTED CONCENTRATIONS

fit the data obtained to a second order polynominal equation and the
plotting points for the curves were computed from those equations.

Forty Percent Sugar Inversion. The density of the solutions
increased with concentration (Fig. 13), but not all solutions exhibited
an increase in density with increased temperature. An increase was
shown by the solutions with 25 and 35% concentrations, while the
lower concentrations decreased in density with increase in tempera-
ture. Similar behavior was also reported by Keppeler and Boose (1970)
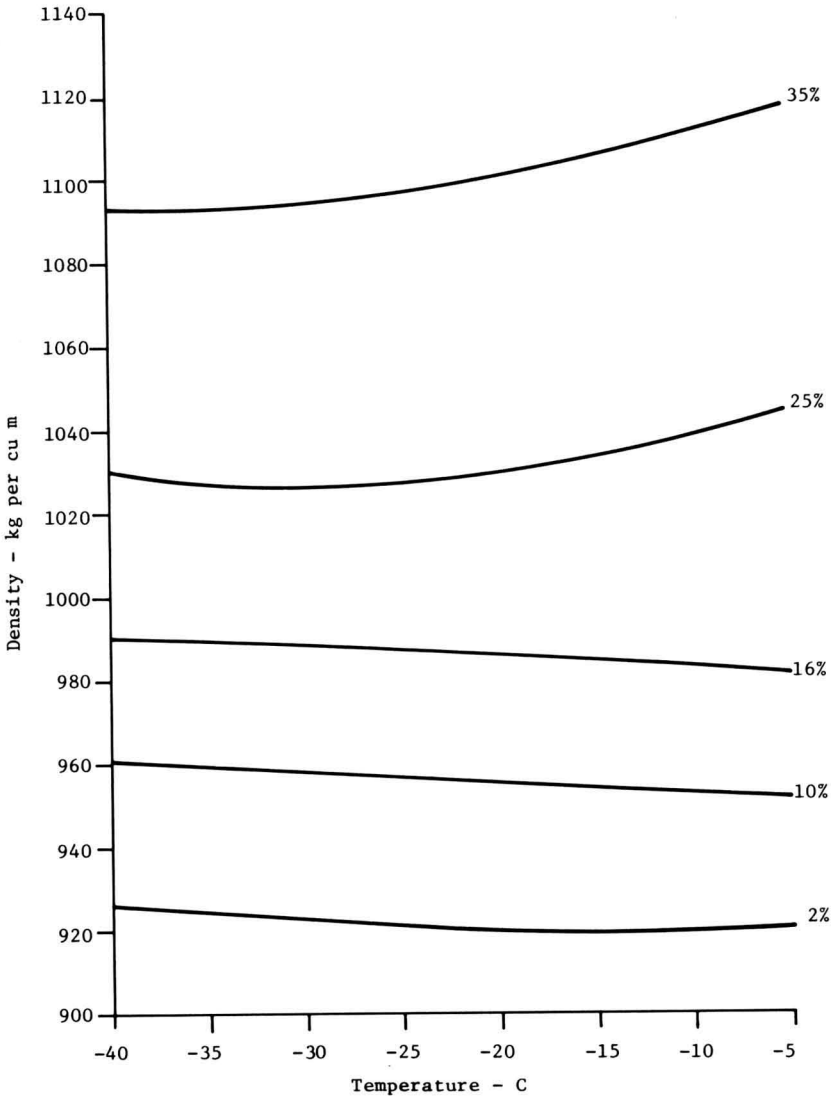
FIG. 13. DENSITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF 40% SUGAR
INVERSION OF NOTED CONCENTRATIONS

for sucrose solutions where the slope was negative slope for frozen
solutions below 30% but positive above 20% concentration.

Fifty Percent Sugar Inversion. The curves of Fig. 15 for 60% inver-
sion on the graph of the density versus temperature show positive
slopes at 18% concentration and above and negative slopes for the
solutions below 18%.
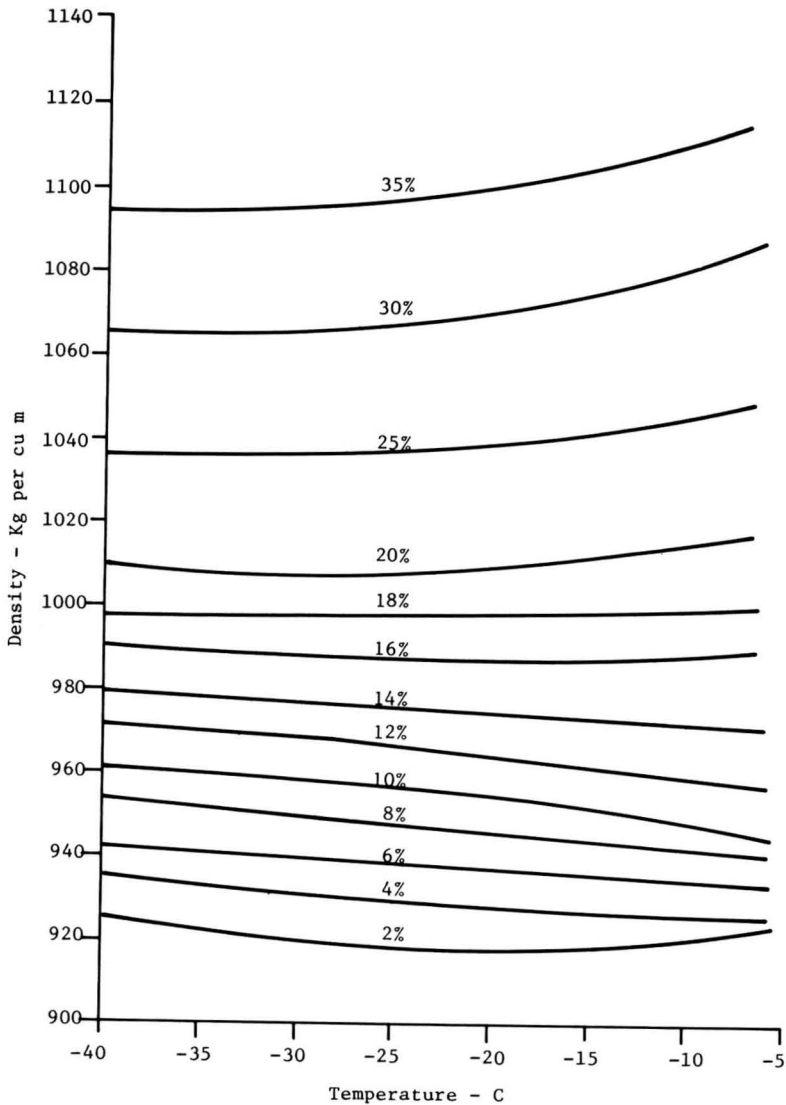
FIG. 14. DENSITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF 50% SUGAR
INVERSION OF NOTED CONCENTRATIONS

Ninety-Five Percent Sugar Inversion. The density values for the
95% sugar inversion (Fig. 16) are higher by less than 1% when com-
pared to those on Fig. 15 for th 60% sugar inversion. The curves in
Fig. 16 exhibit the same behavior as those of the 50 and 60% sugar
inversion.
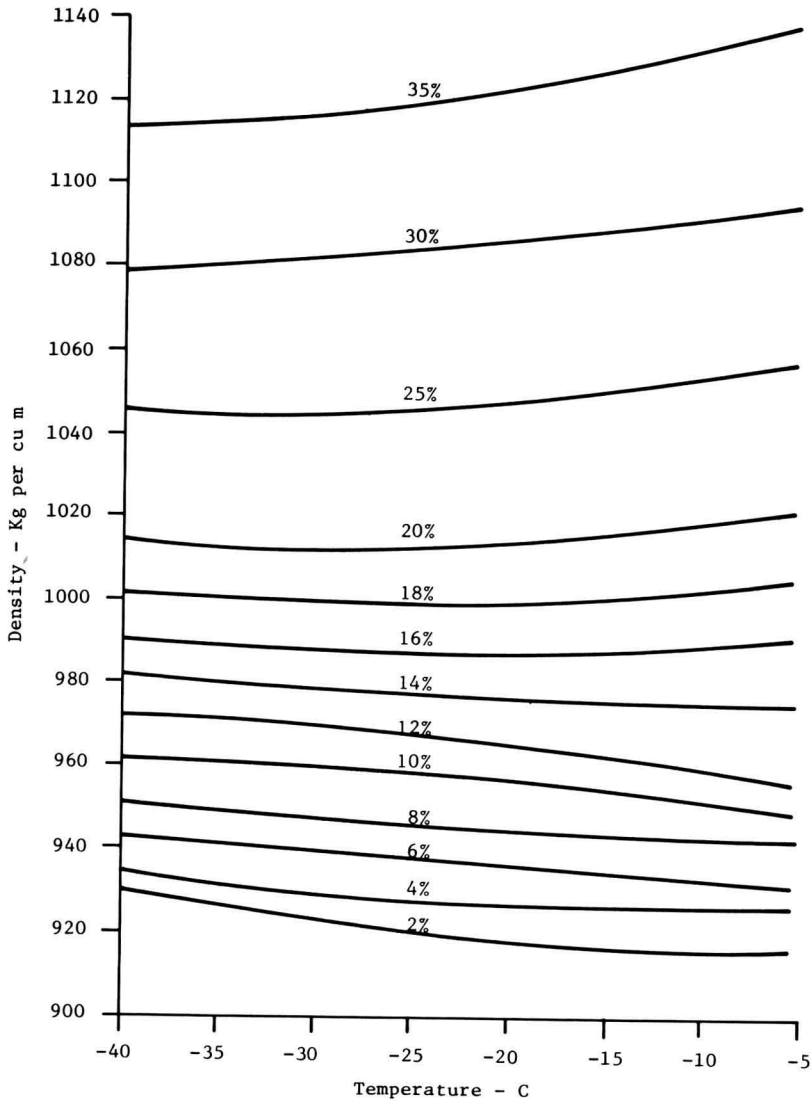
FIG. 15. DENSITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF 60% SUGAR
INVERSION OF NOTED CONCENTRATIONS

CONCLUSIONS

(1) The thermal diffusivity of all the sugar inversions studied decreased as the temperature increased and at any given temperature interval the thermal diffusivity decreased with an increase in concen-
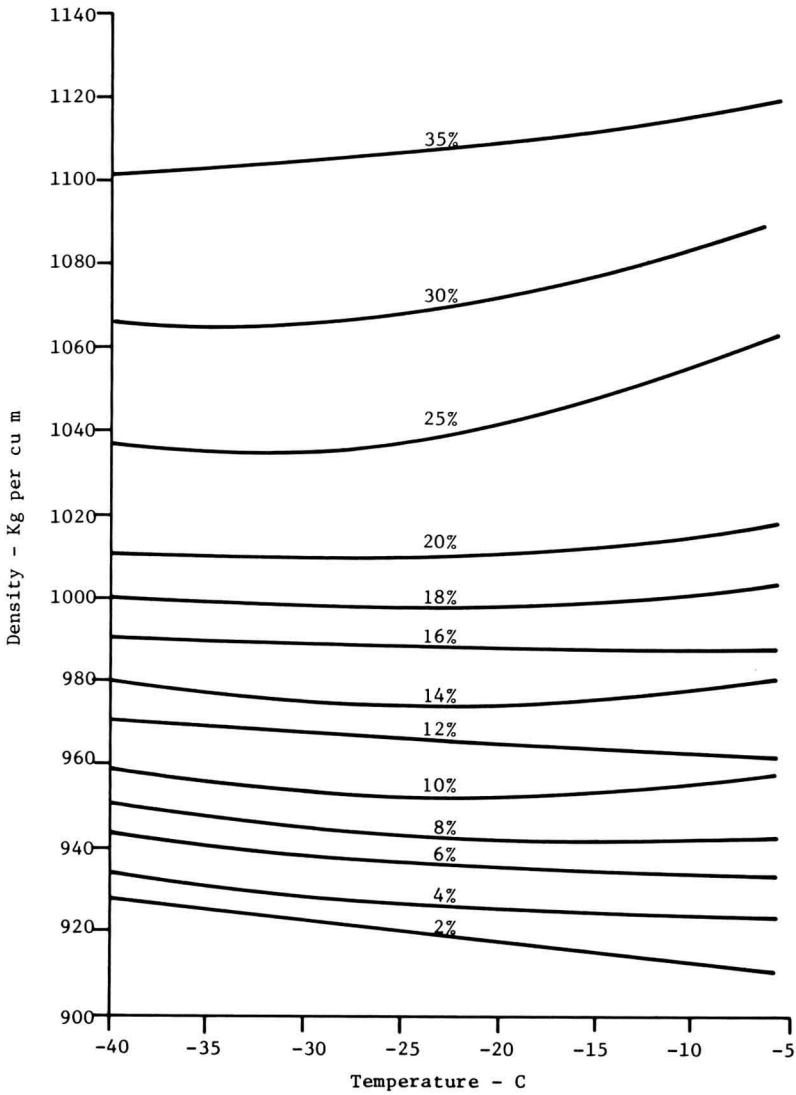
FIG. 16. DENSITY VERSUS TEMPERATURE FOR FROZEN SOLUTIONS OF 95% SUGAR
INVERSION OF NOTED CONCENTRATIONS

tration. (2) The apparent heat capacities of the sugar inversions stu-
died increased with temperature, but more prominently at higher
temperatures and for any particular temperatures increased with
concentration. Increased sugar inversion showed further increase in
apparent heat capacity. (3) The thermal conductivity, for all the

inversions studied, decreased with increase in temperature and for a particular temperature the thermal conductivity decreased with incresed concentration; and (4) The densities of the four inversions studied increased with concentration. Inversion of sucrose did not seem to affect the densities of the solutions because variation of densities between sucrose, 40, 50, 60 and 95% sugar inversion were less than 1%.

REFERENCES

BARD, F. E. and KEPPELER, R. A. 1970. Method of Predicting Thermal Properties of Frozen Sucrose-Corn Syrup Solids Solutions. Trans. ASAE, *13*(5), 554.

BURKE, H. 1954. A Mollier 1-4 diagram for sucrose solutions. Kaltetechnick *6*, 156.

HELDMAN, D. R. 1974. Predicting the relationship between unfrozen water fraction and temperature during freezing using freezing point depression. Trans. ASAE *17*, 63-66.

HELDMAN, D. R. 1975. *Food Process Engineering*. AVI Publishing Co., Westport, Connecticut.

KEPPELER, R. A. and BOOSE, J. R. 1970. Thermal Properties of Frozen Sucrose Solutions. Trans. ASAE, *13*(3), 335-339.

KEPPELER, R. A. and HALL, C. W. 1968. Determining Thermal Constants of Crystallizing Solutions. Food Technology *22*, 784-787.

LENTZ, C. P. 1961. Thermal Conductivity of Meats, Fats, Gelatin, Gels and Ice. Food Technology *15*(5), 243-347.

LIENER, I. E. 1966. *Organic and Biological Chemistry*, pp. ix + 466.

MOLINE, S. W., SAWDEYE, J. A., SHORT, A. H. and RINFRET, A. P. 1961. Thermal Properties of Food at Low Temperatures. Food Technology *15*(5); 228-321.

RHA, C. 1975. Thermal properties of food materials. In *Theory Determination and Control of Physical Properties of Food Materials*, (C. Rha, Ed.) pp. 311-355. Reidel Publ. Dordrecht., Netherlands.

RIEDEL, L. 1949. Thermal conductivity measurements on sugar solutions, fruit juices and milk. Chem. Ing. Tech. *21*, 340-342.

RIEDEL, L. 1950. The refrigeration requirements during freezing of fruits and vegetables. Kaltetechnik *2*, 195-202.

RIEDEL, L. 1960. A test substance for freezing research. Kaltetechnik *12*, 222-225.

SCHWARTZBERG, H. G. 1976. Effective heat capacities for freezing and thawing of food. J. Food Sci. *41*, 152-156.

SCHWARTZBERG, H. G., ROSENAU, J. R. and HAIGHT, J. R. 1977. The prediction of freezing and thawing temperature vs. time behavior through the use of effective heat capacity equations. Int. Refrig. Comm. C1, C2, Karlsruhe, 1977-1, 311-318.

SHORT, B. E., WOOLRICH, W. R. and BARTLETT, L. H. 1942. Specific Heats of Foodstuffs. Refrigeration Engineering *44*(6), 385-388.

SIEBEL, J. S. 1892. Specific Heat of Various Products. Ice and Refrigeration, *2*(4), 256.

STAPH, H. E. 1949. Specific Heat of Foodstuffs. Refrigerating Engineering *57*(8), 767-771.

THOMAS, T. S. E. 1957. A Method of Measuring the Thermal Constants of Granular Materials. British Journal of Applied Physics *8*(10), 403-405.

POTENTIAL FOR UTILIZING 11S SOY GLOBULAR PROTEIN TO STUDY TEXTURE FORMATION[1]

D. P. BRESNAHAN, J. C. WOLF and D. R. THOMPSON

Department of Agricultural Engineering
University of Minnesota
St. Paul, Minnesota 55108

ABSTRACT

A corn meal based model food system was successfully utilized in experiments designed to measure the influence of protein type on product integrity. The food systems were processed using either a capillary rheometer or an extrusion capillary rheometer to produce the texturized product. The Warner-Bratzler Shear test and the Ottawa texture measuring tests were utilized to indicate product integrity. The purified 11S soy protein produced a product with greater integrity as measured by maximum shear value than an equivalent amount of soy protein isolate from which it was derived.

INTRODUCTION

The potential food market for novel proteins such as single cell or oilseed sources has not been achieved. The production costs (low when compared to meat products), the amino acid makeup (high in essential amino acids such as lysine) and the need for providing a balanced protein intake argue for food products utilizing novel proteins. However, providing products with high consumer acceptability has not been completely successful.

For a product to be accepted it must conform to the tastes of the intended purchasing group (Bowdidge 1935). Therefore, products have been developed utilizing novel proteins; these include meat analogues, extenders and snacks which have been imparted with textures and flavors consistent with consumer demand. While these products have had some success in the market place, the potential novel protein market could be greater. One reason for under usage is the

---

inability to develop products which can successfully mimic both the flavor and textural characteristics of current protein sources. The textural characteristics might be improved with additional knowledge of plant protein polymerization during food processing.

A retort stable extruded food requires that the compositional variables be within certian percentage limits. Generally protein content is between 30% and 75% with 50% being the preferred level (British Patent 1979). Carbohydrate content is between 25% and 40%, and lipid content is less than 5% (Jenkins 1970). Although each compositional variable influences the final structure, protein appears to be the major factor in product physical stability. Maurice and Stanley (1978), for instance, demonstrated that protein content, when varied independently of moisture, explained 77% of the variation in a modified Warner-Bratzler shear test. The picture which emerges from physical tests (British Patent 1969; Jenkins 1970; Smith 1974; Cumming et al. 1972) and microscopic studies (Taranto et al. 1978; Smith 1975; Cegla et al. 1978) is that of a product consisting of a protein-lattice structure with embedded carbohydrates. Water plays a multi-faceted role in the process. It solubilizes the protein and carbohydrates and provides a means to insure their even distribution. The water is also the transit vehicle to distribute solubles and thus may control the cell size in the final product (Smith 1974).

Food research devoted to studying texturization and protein polymerization has followed several pathways. The approaches have been empirical, developing methods and procedures which provide specific information for a system, but are limited in application (Taranto et al. 1975; Aguilera and Kosikowski 1976; Jao et al. 1978; and Maurice and Stanley 1978). Other research (Lee and Rha 1979) has examined protein polymerization but has employed simple model systems such as protein solutions. Specific information was obtained, but its application to more complex systems such as that of a food undergoing an extrusion process is limited. A third approach attempted to apply theory gained from plastics and nylon (Nielsen 1977) to protein. Finally, researchers such as Aguilera et al. (1976) and Taranto et al. (1978) have used electron microscopy in order to examine products and describe the completed structure.

An alternative approach is to examine protein polymerization by using a complex system. Besides examining the effects of engineering parameters such as shear rate, shear stress, pressure and temperature on textural characteristics, the effects of these variables plus chemical effects on protein polymerization as a function of time should be examined. Only by knowing how proteins polymerize, the nature and preference of binding sites and how process parameters

influence the reactions can specific control over the process be achieved.

This study sought to determine if a purified soy globular protein in the presence of a high carbohydrate matrix would form a retort stable textured body upon extrusion. If successful, such a system would provide a vehicle for studying protein polymerization under defined conditions.

MATERIALS AND METHODS

Purification of Soybean 11S Globular Protein

The 11S globular protein from soybean was employed as the test protein for this study. The isolation procedure based upon the procedure of Eldridge and Wolf (1967) is as follows: Promine D (Central Soya), a protein isolate, was solubilized (1:100/W:V) in a 0.6 ionic strength (μ), pH 4.6 acetic acid sodium chloride buffer containing 0.01M mercaptoethanol (M.E.), stirred overnight and then strained through 10 layers of cheesecloth to remove the nonsoluble material. The supernatant solution was stored in a cold room (2 to 4° C) for 72h. This resulted in the preferential precipitation of soy 2, 7 and 15S proteins. The precipitated protein was removed by straining the mixture thorugh cheese cloth. The ionic strength of the solution was then lowered to 0.3 μ by the addition of an equivalent volume of 0.01M M.E. and stored in a cold room for 72 h. The 11S globular protein is insoluble at an ionic strength of 0.3 at 2° C. Therefore, the supernatant solution was discarded. The precipitate was frozen, freeze-dried and stored at −20° C until required. The isolation procedure left residual salt in the preparation. Therefore, all samples were brought to the same electrical conductivity level.

The precent 11S protein in the extract was determined by ultracentrifugal analysis. A standard buffer, comprised of 0.0325M K_2HPO_4, 0.026M KH_2PO_4, 0.4 M NaCl and 0.01M M.E., pH 7.6, $\mu = 0.5$, was used. Two grams of freeze-dried protein were solubilized. Nonsoluble material was removed by centrifugation at 2000 rpm for 10 min. The analysis was performed at room temperature in a Spinco Model E ultracentrifuge at 50,470 rpm. A double-sector centerpiece was used in the centrifuge cell to allow sample and solvent to run in the same cell. Therefore, the base line used in the calculations were present. Areas were corrected for radial dilution and the 11S component was determined as a percent of the total area.

D. P. BRESNAHAN ET AL.

Table 1. Influence of process variables and 11S protein levels on product integrity as measured in Werner-Bratzler shear cell

	Code Values		Max. Force (WBS)[a]	
11S Protein	Cook Time	Cook Pressure	Mean (N)	Stand. Dev. (N)
1	1	0	283.3	43.1
1	0	1	297.1	24.5
1	0	−1	275.5	14.7
1	−1	0	372.5	41.2
0	1	1	439.2	18.0
0	1	−1	420.6	37.3
0	−1	1	384.3	3.9
0	−1	−1	391.2	11.8
0	0	0		
0	0	0	385.3	23.5
0	0	0		
−1	1	0	318.6	26.5
−1	0	1	383.3	24.5
−1	0	−1	293.1	29.4
−1	−1	0	317.6	37.3

	Actual Value		
Code Value	11S (% of Total Protein)	Cook Time (min)	Cook Pressure (MPa)
1	75	3	15.52
0	52	2	12.24
−1	30	1	9.31

[a]Dry exudates were tested

Table 2. Influence of 11S protein level and salt on product integrity as measured by the OTMS maximum force and water adsorption

	Max. Force (OTMS)[a]		g H₂O Absorbed/ g Product	HSD Range Test[b] for Water
11S Level	Mean (N)	Stand. Dev. (N)	Mean	Absorbence
1	296.6	60.8	1.2	1
0	239.2	56.9	1.3	1
−1	46.1	3.9	2.0	2
−1 no salt	54.9	8.82	2.0	2

[a]Product retorted before testing
[b]Treatments with different numbers are significantly different (p × .05)

Sample Preparation. The base system consisted of corn meal (Buckeye Pure Gold Yellow Corn Meal) containing 30% moisture on a wet basis. Protein was added to the base system. The protein was dispersed first by hand mixing, followed by a 25S mix using a blender at slow speed. The samples were stored in plastic bags in a cold room until used.

Corn meal and soy protein levels were each kept at 50% of the base system on a dry basis. The desired 11S protein levels were achieved by diluting the purified 11S protein (75% purity) with the appropriate amount of Promine D protein isolate. The amount of 11S protein in the protein isolate was considered in the dilution process so that the desired amount of 11S protein was present. In this manner, the total protein content was held constant although the 11S level varied.

Sample Processing. Samples were processed using either a Monsanto capillary rheometer plugged at the discharge end (nonextrusion) or an extrusion capillary rheometer.

Nonextrustion. The Monsanto rheometer was equilibrated at 150° C before an experiment was initiated. A 5 g sample was introduced into the equilibrated rheometer. One-half minute after sample introduction, the plunger was activated and the desired force was applied. The piston force was controlled via a regulator connected to a nitrogen gas cylinder. The experiment was terminated by removing the plunger. Normally the sample was ejected by the release of the pressure, but occasionally it was necessary to remove the plug and push the sample out.

Extrusion. The extrusion capillary rheometer was equilibrated at 150° C before initiating the experiments. Three-fourths of a minute after introducing a 20 g sample, the plunger of a floor model Instron was pushed into position to provide the cooking pressure listed in Table 3. The experiment was terminated at the desired time by extruding the sample at 5 cm/min.

Both extrusion and nonextrusion experiments examined the influence of 11S protein level, cooking pressure and cooking time on product integrity. In addition, the extrusion experiments considered extrusion pressure and the nonextrusion experiments included salt level.

Process and Product Analysis

Pressure versus time curves were generated for each run. The pressure during the cooking phase (designated as cook pressure) was

Table 3. Influence of 11S protein level, cooktime, extrusion pressure on product integrity as measured by the OTMS maximum force

| | Variable Levels | | | Results[a] | | | |
11S %	Cooktime (min)	Press Cook (kPa)	Extrusion Pressure (MPa)	Max Force (N) Mean	Max Force (N) Stand. Dev.	g H₂O Absorbed/ g product Mean	Extrusion Pressure (MPa)
52	4.5	—	15.80	59.8	1.9	1.2	
52	1.5	—	15.60	70.6	1.9	1.1	
75	3.0	—	15.60	69.6	7.8	1.1	
30	3.0	—	15.10	10.8	0.0	2.4	
52	3.0	—	15.30				
52	3.0	—	16.10	45.1	5.9	1.4	
75	—	310	13.30	101.2	1.9	1.2	
52	—	290	16.95	59.8	0.0	1.3	
30	—	248	25.52	14.7	1.9	2.0	
75	—	290	17.50	52.4	6.9	1.3	
30	—	972	25.13	15.7	1.0	2.0	
52	—	517	15.69	36.3	1.0	1.4	
75	—	517					8.69
75	—	517					9.27
52	—	621					10.58
30	—	621					10.48
30	—	621					14.64

[a]Product retorted before testing

recorded for both extrusion and nonextrusion experiments. During the cooking phase, there was no increase in cook pressure. This indicates that the mechanical pressure was sufficiently high to prevent water vapor formation. The average pressure of extrusion (designated as extrusion pressure) was calculated by dividing the area under the pressure-time curve by the extrusion time. The initial point for the extrusion portion of the pressure curve was taken at the beginning time of product extrusion. The final point was placed at the termination of the extrusion phase. Therefore, the average extrusion pressure excludes the pressure utilized during the cooking phase.

The maximum shear force for either a Warner-Bratzler Shear (WBS) or an Ottawa Texture Measuring System (OTMS, 11 cm^2 cell with 8 wire grid insert device) in an Instron Universal Testing Machine was determined for all products as an indication of product integrity.

Samples tested using the WBS device were sheared three times along the length of the sample. samples tested using the OTMS extrusion cell were broken into pieces approximately 1 cm long and sized as suggested by Breene and Barker (1975). The 4 to +20 mesh pieces were placed into distilled water (2:1, V/W) for 1 h and the amount of water absorbed was calucated after the excess water was drained off. The samples were then retorted at 121°C for 20 min, cooled and stored at 2°C until analyzed. The maximum shear force was then measured as described by Breene and Barker (1975). Two replicate analyses were performed for each sample.

RESULTS AND DISCUSSION

In defining the model food system, protein type and ease of its isolation were considered. Soy protein, specifically the 11S soy protein, was chosen because it is a subunit containing globular protein which loses subunit structure and polymerizes during processing. Finally, it can be isolated without losing subunit structure or undergoing polymerization. Corn meal was chosen as the carbohydrate source because it is easily extruded and forms a nonretort stable texturized product. The low protein content of corn meal along with its lack of retort stability, allows the effects of exogenous proteins to be measured.

The extrusion and nonextrusion experiments (Tables 1, 2, 3) consistently indicated two things. First, the corn meal/soy protein model system did form a retort stable product as measured by the maximum

D. P. BRESNAHAN ET AL.

Table 4. Regression models relating process and compositional variables to product integrity

			Regression Summary				
Process	Table No.	Parameter No.	C(P) (Statistic)	R^2 (Adjusted)	F	DF (Residual)	Model
Nonextrusion	1	7	5.7	.63	12.7	37	$F = 386.3 - 16.7 * G + 13.4 * P - 74.5 * G^2 + 24.5 * C^2 - 16.7 * G * P$
Nonextrusion	2	—	—	.90[a]	25.8	6	$F = 239.2 + 111.8 * G - 81.4 * G^2$
Extrusion	3	5	5.0	.83	56.0	6	$F = 40.9 + 29.4 * G - 5.1 * C - 5.0 * G^2 + 20.0 * C^2$
Extrusion	3	3	1.2	.65	10.5	8	$F = 43.7 + 31.4 * G + 2.6 * G^2$
Extrusion	·3	4	4.0	.88	14.0	2	$E = 16.2 + .250 * G - .850 + 3.942 * G^2 - 2.7 * P$
Extrusion	3	5	4.0	.87	11.4	2	$E = 17.416 - .5142 * G + 3.942 * G^2 - 2.7 * P$
Extrusion	3	—	—	.99	181.0	2	$E = 10.578 - 2.788 * G + .012 * G^2$
Extrusion	3	—	—	1.00	181.0	2	$E = 24.783 - 3.978 * G - .023 * P$

F = Maximum Shear Force (N); E = Average Extrusion Pressure (MPa); G = 11S Protein Level; P = Pressure of Cook; C = Cooking Time
a = Nonadjusted R^2-value
The first force model predicts Warner-Bratzler force. The remaining force models predict the OTMS Cell Extrusion

shear force value in the WBS and OTMS. Second, all equations (Table 4) indicate that the 11S protein influenced the product integrity. Although the equations differ as to what quantity of 11S protein produced the greatest product integrity, they all suggest a maximum value based upon coefficient values and variable terms. The non-extrusion models also suggest that the pressure of cook influenced product integrity. The extrusion experiments were not designed to confirm this possibility although in one extrusion experiment where the pressure of cook was monitored, no relationships were noted between integrity and cooking pressure.

The amount of water absorbed by the texturized products was related to the amount of 11S globular protein in the system (Table 2). The correlation between water absorption and 11S protein level for the data were 0.9. This is interesting in that protein type rather than quantity altered water absorption. The inverse relationship between 11S protein level and water absorption when combined with the integrity tests suggests that increasing the 11S protein during extrusion until some maximum level occurs, results in a smaller cell structure than does a mixture of protein types (Promine D). This would explain both the higher maximum force values in both types of shear tests and the different water absorption. The explanation is supported by both WBS (Table 1) results for dry product and OTMS (Table 2, 3) results for retorted products. The WBS demonstrated that product integrity was independent of absorbed moisture. The increase in OTMS extrusion force values with increasing 11S protein was due to the reduction of free water in the product. It is also possible that the 11S protein in its polymerized form is less hydrophillic, thereby attracting less water. These possibilities could be tested by utilizing a technique such as scanning electron microscopy to examine cell sizes.

There appears to be a large difference between the maximum shear force developed during the nonextrusion and extrusion processes (Table 4). However, it was not possible to conclude if the differences were due to the increased shear during sample extrusion (Aguilera *et al.* 1976), thereby producing a less fibroid structure, or if the differences were caused by product shape (Breene and Barker 1975).

During the 11S protein purification procedure, salts were introduced. Some salt remained after the purification and, in order to reduce the influence of salt, the salt was removed as a variable in the study by bringing all samples to the same conductivity level. However, in two experiments, the maximum shear force and extrusion pressures were compared for samples Promine D with and without added salt. In the presence of salt, the maximum shear force decreased

from 161.8 N to 83.3 N and extrusion pressure decreased from 17.6 MPa to 14.6 MPa. In the second experiment (Table 2), the same trend, although not as great, in maximum shear force occurred. Salt stabilizes the 11S globular protein sturcture by preventing the breakdown into subunits (Hashizume *et al.* 1975). Thus, the absence of salt should increase polymerization, sample extrusion pressure and the maximum shear force value.

The average extrusion pressure regression (Table 4) demonstrated the effectiveness of 11S protein in altering average extrusion pressure. This would be expected if the degree of polymerization varies with protein type. It also implies that mathematical models, employed to predict viscosity and texture, should consider how the protein polymerizes.

While the 11S protein alters the average extrusion pressure, there is a lack of consistency in the equations. Three equations suggest that increasing 11S protein decreases the average extrusion pressure, and one states the opposite. Decreasing average extrusion pressure and increasing product integrity appears contradictory, but possibly the polymerized 11S protein excludes bound water and this freed water either acts as a lubricant during extrusion or possibly it reduced viscosity. If this effect is real, it should be possible to reduce energy consumption during extrusion with concomitant increased product integrity.

CONCLUSIONS

The purified 11S soy globular protein both increased product integrity and reduced the average extrusion pressure when compared to a soy protein isolate. The increase in integrity plus the decrease in water absorption by the extruded product suggests that the 11S soy protein containing food system forms a smaller cell structure body during extrusion when compared to the soy isolate.

REFERENCES

AGUILERA, J. M. and KOSIKOWSKI, F. V. 1976. Soybean extruded products: A response surface analysis. J. Food Sci. *41*, 647.

AGUILERA, J. M., KOSIKOWSKI, F. V. and HOOD, L. F. 1976. Ultrastructure changes occurring during thermoplastic extrusion of soybean grits. J. Food Sci. *41*, 1209.

BOWDIDGE, E. 1935. *The Soya Bean.* Oxford University Press, London.

BREENE, W. M. and BARKER, T. G. 1975. Development and application of a texture measurement procedure for textured vegetable protein. J. Texture Studies *6*, 459.

British Patent, 1,174,906. 1969. Assigned to Ralston Purina Corporation, December 17th.

CEGLA, G. F. TARANTO, M. V., BELL, K. R. and RHEE, K. C. 1978. Microscopic structure of texturized cottonseed flour blends. J. Food Sci. *43*, 775.

CUMMING, D. B., STANLEY, D. W., and deMAN, J. M. 1972. Texture-structural relations in textured soy protein. 2. Textural properties and ultrastructure of an extruded soybean product. Can. Inst. Food Sci. Technol. J. *5*, 124.

ELDRIDGE, A. C. and WOLF, W. J. 1967. Purification of the 11S component of soybean protein. Cereal Chem. *44*, 645.

HASHIZUME, K., NAKAMURA, N. and WATANABE, T. 1975. Influence of ionic strength on conformational changes of soybean proteins caused by heating and relationship of its conformation changes to gel formation. Ag. Bio. Chem. *35*, 449.

JENKINS, S. L. (For Ralston Purina Corp.) 1970. Method for preparing a protein product. U.S. Patent 3,496,853. February 24th.

JAO, Y. C., CHEN, A. H., LEWANDOWSKI, D. and IRWIN, W. E. 1978. Engineering analysis of soydough rheology in extrusion. J. Food Proc. Eng. *2*, 97.

LEE, C. H. and RHA, C. 1979. Rheological properties of proteins in solution. In *Food Texture and Rheology*. J. Food Proc. Eng. *2*, 97.

MAURICE, T. J. and STANLEY, D. W. 1978. Texture-structure relationships in texturized soy protein. IV. Influence of process variables on extrusion texturization. Can. Inst. Food Sci. Technol. J. *11*, 1.

NIELSEN, L. E. 1977. *Polymer Rheology*.

SMITH, O. B. 1974. Extrusion cooking. In *New Protein Foods*, Vol. 2, technology, Part B. (A. M. Alschul, ed.), Academic Press, New York.

SMITH, O. B. 1975. Textured vegetable proteins. In *World Soybean Research*, (L. D. Hill, ed.), Interstate Printers and Publishers, Inc., Danvers, IL.

TARANTO, M. V., MEINKE, W. W. CARTER, C. M. and MATTIL, K. 1975. Parameters affecting production and character of extrusion texturized defatted glandless cottonseed meal. J. Food Sci. *40*, 1260.

TARANTO, M. V., CEGLA, G. F., RHEE, K. C. 1978. Morphological, ultrastructural and rheological evaluation of soy and cottonseed flours texturized by extrusion and nonextrusion processing. J. Food Sci. *43*, 973.

LITERATURE ABSTRACTS

ABSTRACTS FROM JOURNAL OF FOOD SCIENCE

CHANGES IN PHYSICAL PROPERTIES OF MEAT BATTERS DURING HEATING. J. M. Schweid and R. T. Toledo. J. Food Sci. *46*, 850-855 + 859.

Techniques for measuring changes in physical properties of meat batters during heating that would be suitable for studying kinetics of gelation were studied. Change in absolute molulus as measured by a dynamic tester was too variable to be useful in studying gelation kinetics. However, differences in consistency show up as significant differences in the absolute moduli of the raw batters. Increase in volume during heating was strictly a temperature effect and the rate of expansion at the same heating medium temperature was the was same for a batter that was gelling compared to a gelled batter in the same mold. Pressure change on heating of a batter at constant volume showed a pattern consistent with expected behavior of proteins on heating. Plots of pressure against temperature were a series of linear sections with the transition points occurring at $33-36°$C and at $57-67°$C. These temperature ranges are known to start insolubilization of muscle proteins and start solubilization of collagen respectively. Plots of unaccomplished pressure change against time on semi-logarithmic coordinates was used to calculate a time constant for each stage of the process thereby giving a measure of the rate of gelation.

RHEOLOGICAL PROPERTIES OF PRUNE JUICE. H. R. Bolin. J. Food Sci. *46*, 886-888.

The effect of preparation procedures, raw material and additives on prune juice viscosity was investigated. Prune juice preparation procedure had the greatest effect on juice viscosity of any parameters studied, with the disintegration process producing juice having higher viscosity than the diffusion process. Juice viscosity decreased during elevated storage temperatures. Also, prune size and maturity influenced viscosity, with smaller prunes harvested early in the season producing juice with higher viscosities. In diffusion juice extraction, the first leach product had a lower viscosity, lighter color and higher potassium content than the rest. Prune concentrate over $45°$ brix exhibited dilatant properties.

HEATING CHARACTERISTICS OF WHOLE KERNAL CORN PROCESSED IN A STERITORT. M. R. Berry Jr. and R. W. Dickerson, Jr. J. Food Sci. *46*, 889-895.

Cans of whole kernal corn in brine and vacuum-packed corn were heated in an FMC Steritort and in a still retort. Two can sizes for each product were processed to simulate two commercial agitating processing machines. The sterilization values (F_0) and heat penetration factors (j, f_h, f_2) were determined from time-temperature data and were influenced by reel rotational speed, corn fill

weight, and brine fill or container headspace. For both products, optimum heat penetration for agitated processing occurred at a ratio of brine-to-corn fill weights of about 35% (normal for vacuum-packed products). Above a threshold value, increasing reel rotational speed did not significantly enhance heating, and with the accompanied reduction in retention time in continuous retorts, F_0 values would actually be lowered. Sterilization values were somewhat reduced because of overfills of both corn and brine. For the vacuum-packed product, vacuum level significantly influenced heat penetration only for the still processes.

COMBINING AQUEOUS EXTRACTION AND MEMBRANE ISOLATION TECHNIQUES TO RECOVER PROTEIN AND OIL FROM SOYBEANS. J. T. Lawhon, L. J. Manak, K. C. Rhee, K. S. Ree and E. W. Lusas. J. Food Sci. *46*, 912-916 + 919.

Two relatively new protein isolation techniques (the Aqueous Extraction Process and the Membrane Isolation Process) were combined to obtain a single isolation procedure to produce protein and oil food products from undefatted soybeans. Three lots of soybeans were processed using aqueous extraction, centrifugation and industrial ultrafiltration membranes to obtain either a full-fat, low-fat or intermediate-fat product and an oil cream. Proximate and amino acid analyses, nitrogen solubility profiles, and storage tests were made on spray-dried products. Mean membrane permeation rates achieved ranged from 20-42.6 gfd. Protein products possessed high nitrogen solubilities below pH 3.5 and above pH 7, and were desirably light in color.

A PROXIMITY EQUILIBRATION CELL FOR RAPID DETERMINATION OF SORPTION ISOTHERMS. K. W. Lang, T. D. McCune and M. P. Steinberg. J. Food Sci. *46*, 936-938.

Sorption isotherm data are obtained by instrumental determination of water activity at a known moisture content or determination of moisture content after equilibration against a saturated salt solution. The latter method is simpler and the salt solutions are primary standards. However, the equilibration takes a long time, one to ten weeks, depending upon food composition. Thus, the objective of this work was to devise a method that retains the saturated salt solution but accelerates the rate of equilibration. In an equilibration environment between a food product and a saturated salt slurry, the driving force is the difference in vapor pressure; therefore the faster the vapor space is the difference in vapor pressure; therefore the faster the vapor space reaches equilibrum with the saturated salt slurry, the quicker the maximum driving force for water absorption will be applied to the sample. It was felt that a reduction in the size of the usual large desiccator to a single sample size would provide the necessary area to volume ratio. The vessel chosen was a small plastic chamber (65 mm/53 mm).In this chamber, the surface area to vapor volume ratio was 0.3101 as compared to 0.0335 for the standard desiccator. The sample was contained in a standard aluminum weighing tray

modified by removing a 44 mm diameter circular section from the bottom. This was replaced with a 47 mm diameter circle of Whatman No. 1 quantitative filter paper to support the sample and at the same time allow transmission of moisture. This would allow water molecules to travel in a straight line and thus the shortest distance between the saturated salt slurry and the sample. This small vessel with a single sample supported on a filter paper will be referred to as a Proximity Equilibration Cell (PEC). Using this technique, it was found that a 2/mm deep sample of corn starch required only 6 days for complete equilibration, as compared to 21 days for the conventional desiccator. Thus, the PEC satisfied the obejctive by reducing time by 70%. In making comparisons with the same salts in conventional and the PEC, it was noted that the end point was higher in the latter. Evidently, absorption in case of the conventional desiccator was so slow at the end that no weight gain could be detected in 24 hr but equalibrium had not yet been attained. In contrast, the PEC equalibrated so rapidly that it allowed a closer evaluation of true equilibrium.

DRYING OF APPLE PURÉES. A. L. Moyls. J. Food Sci. *46*, 939-942.

Various factors influencing the drying rate of apple puree were investigated. A heated airstream passed over the purée which was contained on a large flat tray. The drying rate could be inceased by raising the air temperature, by increasing the air velocity, by promoting turbulence at the tray entrance, by increasing the vertical spacing between trays, and by using metal instead of wooden trays. Three distinct modes of moisture removal were observed during the transition from wet purée to dried apple leather. It was possible to obtain a suitable apple leather product in about 3 hr using $107°C$ air at 4.6—7.6 m/sec.

CORRELATION OF WATER ACTIVITY DATA IN WHOLE TOMATO CONCENTRATES. J. Chirife, C. Ferro Fontan and R. Boquet. J. Food Sci. *46*, 947-949.

It is shown that water activity (a_w) data in whole tomato concentrates of varying total solids content may be well correlated using a simple equation derived from knowledge of the a_w lowering behavior of nonelectrolytes. The proposed equation has practical value because it allows a_w prediction in tomato concentrates (in the a_w range of most practical interest) from measurement of the °Brix value.

EFFECT OF COOKING ON THE THERMAL CONDUCTIVITY OF WHOLE AND GROUND LEAN BEEF. M. S. Baghe-Khandan and M. R. Okos. J. Food Sci. *46*, 1302-1305.

The probe method was used to measure thermal conductivity of beef through a temperature range of $30-120°C$. Thermal conductivity of beef increases with temperature up to $70°C$ followed by a decrease during the denaturation of proteins and subsequent loss of water. The thermal conductivity of beef

again increases with temperature after protein denaturation. The thermal conductivity of cooked beef is lower than raw beef up to about 80°C. The rate of increase for cooked meat thermal conductivity is fairly constant with temperature at a given moisture content. Models based on composition and temperature were found to predict the thermal conductivity of meat during cooking at an average standard percent error of 7%.

LINEARIZATION OF THE WATER SORPTION ISOTHERM FOR HOMOGENEOUS INGREDIENTS OVER a_w 0.30—0.95. K. W. Lang and M. P. Steinberg. J. Food Sci. 46, 1450-1452.

Many attempts have been made to quantitate the water sorbed by a material as a mathematical function of water activity (a_w). Based upon a theory of polymolecular absorption, the Smith model states that moisture content is proportional to ln $(1 - a_w)$. Subsequent workers showed this to be accurate to 1% but only between about 0.6 and 0.9 a_w. It was hypothesized that the validity of this model could be extended over a much broader a_w range by applying the model to a single homogeneous ingredient. This was tested by obtaining sorption data for nine materials, including four noncrystalline macromolecules as well as five crystalline solutes, including both sugars and salts. Results showed the model to describe the sorption isotherm for these macromolecules to within 2% over the a_w range 0.30—0.95. The model was shown to be valid in the case of each solute to within 2.5% between the a_w of a saturated solution and 0.95. Correlation coefficients (r) for the nine materials were all greater than 0.995, showing excellent linearity for the model. Fructose showed the highest "% $(error)_{AV}$", only 3.26.

THE "INTRINSIC" THERMAL CONDUCTIVITY OF WET SOY PROTEIN AND ITS USE IN PREDICTING THE EFFECTIVE THERMAL CONDUCTIVITY OF SOYBEAN CURD. T. Yano, J. Y. Kong, O. Miyawaki and K. Nakamura. J. Food Sci. 46, 1357-1361.

The applicability of four heat conduction models to heterogeneous materials was examined for defatted soy protein curd with various water contents. Only the series model was applicable to both frozen and unfrozen soy protein curds. The "intrinsic" thermal conductivity of wet soy protein was determined on the basis of the series model to be 0.300 W/m-K for unfrozen curd and 0.488 W/m-K for frozen curd. By using the series model and the "intrinsic" thermal conductivity values of soy protein, the effective thermal conductivity of fat-containing soybean curd, unfrozen or frozen, was predicted satisfactorily. The "intrinsic" thermal conductivity values of wet soy protein were independent of temperature in the ranges from 0° to 20°C and from −5° to −20°C.

IMPROVED LINE HEAT SOURCE THERMAL CONDUCTIVITY PROBE. M. S. Baghe-Khandan, Y. Choi and M. R. Okos. J. Food Sci. 46, 1430-1432.

An improved line heat source thermal conductivity was made to simplify the construction and extend the life of thermal conductivity probes. The accuracy

of thermal conductivity measurement is also improved. The better linearity of temprature versus logarithm of time was obtained as compared to published techniques. The probe made with the heater wire and thermocouple on the outside of a sewing needle instead of inside of a hypodermic needle was checked by measuring the thermal conductivity of known samples. Results obtained with the improved probe show lower temperature rise and lower standard deviation.

A METHOD FOR THE DETERMINATION OF DIFFUSION COEFFI-CIENTS OF FOOD COMPONENTS IN LOW- AND INTERMEDIATE MOISTURE SYSTEMS. W. Naesens, G. Bresseleers and P. Tobback. J. Food Sci. *46*, 1446-1449.

A simple set-up to measure translational diffusion of components in low moisture systems is described. The tracer technique was tested on the diffusion of ^{14}C-labeled tripalmitin and palmitic acid in a model system containing paraffin oil, microcrystalline cellulose and gum arabic. Different methods to evaluate the apparent diffusion coefficients from the experimental diffusion curve were compared. Good results were obtained using a curve-fitting procedure based on the sum of least squares. The technique appears to be suitable for measuring diffusion coefficients up to 10^{-9} cm^2/sec. The procedure offers the possibility to quantify the mobility of chemical compoents in dried foodstuffs in order to elucidate the mechanisms and kinetics of reactions occurring during storage.

F
N
P
JOURNALS AND BOOKS
IN
FOOD SCIENCE AND NUTRITION

Journals

JOURNAL OF FOOD SERVICE SYSTEMS, G.E. Livingston and C.M. Chang

JOURNAL OF FOOD BIOCHEMISTRY, H.O. Hultin, N.F. Haard and J.R. Whitaker

JOURNAL OF FOOD PROCESS ENGINEERING, D.R. Heldman

JOURNAL OF FOOD PROCESSING AND PRESERVATION, T.P. Labuza

JOURNAL OF FOOD QUALITY, M.P. DeFigueiredo

JOURNAL OF FOOD SAFETY, M. Solberg and J.D. Rosen

JOURNAL OF TEXTURE STUDIES, M.C. Bourne and P. Sherman

Books

FOOD PRODUCT DEVELOPMENT IN IMPLEMENTING DIETARY GUIDELINES
G. E. Livingston, R. J. Moshy, and C. M. Chang

SHELF-LIFE DATING OF FOODS, T.P. Labuza

RECENT ADVANCES IN OBESITY RESEARCH, VOL. III,
P. Bjorntorp, M. Ciarella, and A.N. Howard

RECENT ADVANCES IN OBESITY RESEARCH, VOL. II,
G.A. Bray

RECENT ADVANCES IN OBESITY RESEARCH, VOL. I,
A.N. Howard

ANTINUTRIENTS AND NATURAL TOXICANTS IN FOOD, R.L. Ory

UTILIZATION OF PROTEIN RESOURCES, D.W. Stanley, E.D. Murray and
D.H. Lees

FOOD INDUSTRY ENERGY ALTERNATIVES, R.P. Ouellette, N.W. Lord and
P.E. Cheremisinoff

VITAMIN B$_6$: METABOLISM AND ROLE IN GROWTH, G.P. Tryfiates

HUMAN NUTRITION: 3RD ED., R.F. Mottram

DIETARY FIBER: CURRENT DEVELOPMENTS OF IMPORTANCE TO HEALTH,
K.W. Heaton

FOOD POISONING AND FOOD HYGIENE, 4TH ED., B.C. Hobbs and R.J. Gilbert

FOOD SCIENCE AND TECHNOLOGY, 3RD ED., M. Pyke

POSTHARVEST BIOLOGY AND BIOTECHNOLOGY, H.O. Hultin and M. Milner

THE SCIENCE OF MEAT AND MEAT PRODUCTS, 2ND ED., J.F. Price and
B.S. Schweigert

1. TITLE OF PUBLICATION	A. PUBLICATION NO.								2. DATE OF FILING
Journal of Food Process Engineering	0	1	4	5	8	3	7	6	Oct. 1, 1982

3. FREQUENCY OF ISSUE	A. NO. OF ISSUES PUBLISHED ANNUALLY	B. ANNUAL SUBSCRIPTION PRICE
Quarterly	4	$55.00

4. COMPLETE MAILING ADDRESS OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP Code) (Not printers)*

1 Sconset Square, Westport, Fairfield, CT 06880

5. COMPLETE MAILING ADDRESS OF THE HEADQUARTERS OR GENERAL BUSINESS OFFICES OF THE PUBLISHERS *(Not printers)*

1 Sconset Square, Westport, Fairfield, CT 06880

6. FULL NAMES AND COMPLETE MAILING ADDRESS OF PUBLISHER, EDITOR, AND MANAGING EDITOR *(This item MUST NOT be blank)*

PUBLISHER *(Name and Complete Mailing Address)*

John J. O'Neil, 1 Sconset Square, Westport, CT 06880

EDITOR *(Name and Complete Mailing Address)*

Dr. Dennis R. Heldman, Michigan State University, Dept. of Agricultural Engineering, East Lansing, Michigan 48823

MANAGING EDITOR *(Name and Complete Mailing Address)*

7. OWNER *(If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding 1 percent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a partnership or other unincorporated firm, its name and address, as well as that of each individual must be given. If the publication is published by a nonprofit organization, its name and address must be stated.) (Item must be completed)*

FULL NAME	COMPLETE MAILING ADDRESS
Food & Nutrition Press, Inc.	1 Sconset Square, Westport, CT 06880
Technomic Publishing Co.	265 Post Road West, Westport, CT 06880
Melvyn A. Kohudic	265 Post Road West, Westport, CT 06880
John J. O'Neil	1 Sconset Square, Westport, CT 06880

8. KNOWN BONDHOLDERS, MORTGAGEES, AND OTHER SECURITY HOLDERS OWNING OR HOLDING 1 PERCENT OR MORE OF TOTAL AMOUNT OF BONDS, MORTGAGES OR OTHER SECURITIES *(If there are none, so state)*

FULL NAME	COMPLETE MAILING ADDRESS
None	

9. FOR COMPLETION BY NONPROFIT ORGANIZATIONS AUTHORIZED TO MAIL AT SPECIAL RATES *(Section 411.3, DMM only)*
The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes *(Check one)*

(1) HAS NOT CHANGED DURING PRECEDING 12 MONTHS	(2) HAS CHANGED DURING PRECEDING 12 MONTHS	*(If changed, publisher must submit explanation of change with this statement.)*

10. EXTENT AND NATURE OF CIRCULATION	AVERAGE NO. COPIES EACH ISSUE DURING PRECEDING 12 MONTHS	ACTUAL NO. COPIES OF SINGLE ISSUE PUBLISHED NEAREST TO FILING DATE
A. TOTAL NO. COPIES *(Net Press Run)*	600	600
B. PAID CIRCULATION 1. SALES THROUGH DEALERS AND CARRIERS, STREET VENDORS AND COUNTER SALES	0	0
2. MAIL SUBSCRIPTION	306	309
C. TOTAL PAID CIRCULATION *(Sum of 10B1 and 10B2)*	306	309
D. FREE DISTRIBUTION BY MAIL, CARRIER OR OTHER MEANS SAMPLES, COMPLIMENTARY, AND OTHER FREE COPIES	25	25
E. TOTAL DISTRIBUTION *(Sum of C and D)*	331	334
F. COPIES NOT DISTRIBUTED 1. OFFICE USE, LEFT OVER, UNACCOUNTED, SPOILED AFTER PRINTING	269	266
2. RETURN FROM NEWS AGENTS	0	0
G. TOTAL *(Sum of E, F1 and 2 - should equal net press run shown in A)*	600	600

11. I certify that the statements made by me above are correct and complete	SIGNATURE AND TITLE OF EDITOR, PUBLISHER, BUSINESS MANAGER, OR OWNER John J. O'Neil, Publisher

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.

CONTENTS