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FOAM MAT DEHYDRATION OF SAUERKRAUT
JUICE.

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FOAM MAT DEHYDRATION
OF
SAUERKRAUT JUICE

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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M. S. Thesis, Ohio State University, 1966
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INTRODUCTION

Large quantities of sauerkraut juice are discarded as waste. The quantity thus disposed of, in excess of the market requirements for this product as a canned beverage, are estimated to be several million pounds annually in the state of Ohio alone (9).

This product is recognized by many as a nutritious palatable beverage as well as a valuable food preparation additive. It is with the latter aspect of this product that this investigation will be concerned. The goal of this study was to determine the possibility of producing a more convenient form of the product - a powder consisting primarily of sauerkraut juice solids. In this form the product would be more readily adaptable to a greater variety of uses: such as, a flavor additive in potato chip dips, stews, soups, gravies and sauces.

Attempts to spray dry sauerkraut juice indicated that this method was not feasible (9). Freeze dehydrat-
ing this raw material likewise had not resulted in a satisfactory product (13). Preliminary investigations (30) concerning concentration and drying sauerkraut juice in a vacuum pan system were also unsuccessful. Concentration by fractional freezing and draining of enriched liquid was unsuccessful (30).

The results of attempts to foam mat dry sauerkraut juice indicated the feasibility of using this method (31). Construction of equipment to develop and optimize a system to produce foam suitable for a foam mat drying process for dehydration of sauerkraut juice was instigated.

It was the purpose of this investigation to produce foam mat dried sauerkraut juice solids, to identify one or more additives which will make this feat possible and to establish parameters for the formulation of these ingredients.
LITERATURE REVIEW

An exhaustive search of the literature failed to yield any information on the subject of foam mat dehydration of sauerkraut juice. It likewise failed to reveal success in efforts or continued interest in or application of foam mat dehydration of any low solids product without prior concentration of the product to levels of 25 percent to 55 percent soluble solids content.

History

The earliest patents found concerning foam mat drying of a food product were issued to Wink (17, 18). These patents present a total of 51 claims relative to foaming, drying and reconstituting egg white.

The second patent located on foam mat drying a food product was issued to A. I. Morgan et al. (25) for producing a powdered product from concentrated milk using glycerol monopalmitate and glycerol monostearate as foam stabilizers.
The previous year, 1959, Morgan et al. (24) reported on work done at the Western Regional Research Laboratory concerning foam mat drying 25 percent solids tomato paste, 36 percent solids milk and 40 percent solids orange juice using egg albumin, fatty acid monoglycerides and diglyceride mixture and sucrose fatty acid esters at a level of about one percent of the substrate solids content.

Subsequently additional patents based on this work were issued to Morgan as follows: a process patent (19) described in detail the method used to mechanically produce foam and to dry it and listed many foaming or stabilizing agents. This patent claimed the foam mat drying process for fruit and vegetable juice concentrates.

A patent issued to Morgan (20) listed claims for foam mat dehydration of concentrated fruit and vegetable juices with addition of egg white and of albumin as well as using temperatures between 130° F and 180° F to affect the drying. The additional information and claims in the remainder of the patents were: the use
of surface active agents, (19, 22, 26) the use of a volatile solvent to assist in removal of water (21) and ten claims in support of foam mat drying mashed potatoes (22). The last of the series (27) described the dehydration of concentrated coffee. This series of patents described a solid layer of foam on a tray or belt to be subjected to a current of heated air.

In 1961, Morgan et al. (23) reported application of the foam to a solid tray or belt in a ribbon or spaghetti like form prior to dehydration and the application of the foam to a perforated tray or a belt then producing craters in the foam mat layer by forcing air thru these perforations. This latter scheme introduced the technique now considered the preferred method of presenting the foam to the dehydrating medium and is referred to as "cratered foam mat drying". This technique increased the capacity of a given area of belt or tray by a factor of five.

The first commercial operation using the cratered foam mat system (16) went on stream in 1962, with a capacity of 200 pounds of tomato powder per hour using
tomato paste with glycerol monostearate as the foaming agent.

Further work on the mechanics of the foam mat dehydration equipment concerning foam production, tray loading, detraying and air temperature and velocities was published by Rockwell et al. (29).

Progress in foam mat dehydration techniques and equipment had been the product of the United States Department of Agriculture Western Regional Laboratory until Sjogren (30) in 1962, published concerning the interest of a commercial engineering firm in this work describing the capabilities of a commercial dehydrator of their design which had a capacity to evaporate 700 pounds of water per hour. He described the art as well as the technology of foam mat dehydration using the crater method.

Products

Ginnette (11) reported specifically in great detail on foam mat dehydration of tomato paste. He noted particularly the lack of flavor loss from foam mat drying as evaluated by gas liquid chromatography in compar-
son to the paste used in the production, but likewise noted the great loss of flavor in concentrating the pulp to a paste, and suggested the add back of recovered distillates to the paste. Much of the early work on foam mat dehydration was concerned with tomato products.

Using essentially the methods of Morgan (19, 20) or Ginnette (10), Bissett et al., and Graham et al. (7) at the Southern Utilization Research and Development Laboratory in 1963, reported on foam mat dehydration of orange juice concentrate. The major contribution of this report was to the instrumentation and the quality control methods applied to the process. Time required for dehydration, temperature of the drying air and the residual moisture of the product were compared with color, flavor, storage stability and ascorbic acid content of the product. Temperature of dehydrating air, foam temperature and moisture content of the foam during dehydration were reported.

Time - temperature dehydration studies were conducted by Berry (3) on foam mat dried grapefruit juice using the "spaghetti" method of applying the product
to a belt in a tunnel type dehydrator. The product was
whipped using 53° Brix grapefruit concentrate with
1.02 percent Methocel as stabilizer based on solids con-
tent, producing foams of 0.31, 0.33 and 0.28 specific
gravities which were dried at temperatures of 160, 170,
180 and 190°F, for varying lengths of time. Within the
parameters used in his work foam density was a more sig-
nificant influence on dehydration rates than was a 30
percent change in belt loading.

In 1967, Berry (5) again published on foam mat
dehydrated grapefruit crystals using a Food Machinery
Corporation dehydrator designed to dehydrate cratered
foam; the foam for which was produced using an Oakes
mixer. A description of densification by pressure rolls
to increase bulk density of the resultant powder was
also described. He recommended optimum conditions of
50 percent Brix juice, and the use of nitrogen as the
gas in the foam. He furthermore justified use of re-
frigeration to reduce the relative humidity of the dry-
ing air in the final stage of the dryer to at least ten
percent.
Graham (12) reported on foam mat dehydration of orange concentrate and demonstrated the use of a Mills soft ice cream machine for foam conditioning following production of the foam in an Oakes high shear mixer to produce a foam which had superior drying characteristics. This improvement in dehydrating characteristics was related to a decrease in bubble size and to cooling the foam before dehydrating it. A 60° Brix orange concentrate - methocel - soya protein foam as well as a 52° Brix lemon juice concentrate foam responded well to this treatment. Bulk specific gravity was increased from 0.3 to 0.8 by pressing a foam mat dried powder which contained two percent moisture between heated (less than 212°F.) steel rolls. This densification process produces a product which resulted in an improved color and appearance in the reconstituted juice.

Bates (1) reported in detail on a variety of substrates subjected to foam mat dehydration. His paper reported: sucrose solutions from 20° Brix to 60° Brix, pineapple juice concentrate, passion fruit juice at 17 and 47° Brix, guava puree at both 8 and 40° Brix, acerola puree at 8° Brix, papaya puree at 14° Brix, banana
puree, mango puree at 14° Brix, avocado puree and coconut milk each in conjunction with soya protein and or glyceryl monostearate and or Methocel. He found that high Brix and high solids content were necessary to produce a satisfactory foam and that products with a high lipid content could not be foamed. He concluded that factors other than lipid content and soluble or insoluble solids contents influence both the quantity of additives necessary to produce a foam and the ultimate stability of the foam.

Factors Affecting Foam Stability

Hart et al. (14) used both batch and continuous methods of foam production for foam mat drying of 34 food and beverages incorporated additives from a list of 12 foam inducing and foam stabilizing agents. Data were presented in tabular form showing commodity, soluble solids, additives used, foaming temperature, foam density and foaming time and the device used to create foam. Foam densities listed range from 0.15 to 0.55 gms. per ml. It was stipulated that these foams were not necessarily susceptible to successful drying operations.
Foam stability was related as follows: decrease in soluble solids required an increase in quantity of additives and a decrease in pulp content required whipping to a low specific gravity.

Berry (4) on methods of evaluating foams from citrus concentrates found that the most suitable foams for dehydrating were those with the smallest bubble size and the greatest homogeneity. He also stated that the best foams were produced using monoglycerides, although the use of soy albumin and methyl cellulose produced an orange powder that when reconstituted resulted in a superior beverage.

Berry (4) reported that the "static and dynamic" foam meters of Clark and Ross (3) which relied on foam drainage and change in foam volume had no value in determining differences in degree of suitability of foams for foam mat dehydrating among those foams that could be dehydrated. Likewise the methods that relied on changes in surface viscosities were useless in this study. He also negated the reliability of foam density as an index for predicting the drying behavior of a foam being dehydrated but found that an index which he developed relat-
ing the bubble size in a foam to the suitability of a foam for drying was applicable. This index was arrived at by dividing a specific area of microscopic observation by the number of bubbles therein. Foam stability was evaluated by noting change in the index with time. The bubble size index was shown to relate directly to residual moisture in the dehydrated product.

LaBelle (15) in a paper on characterization of foams for foam mat dehydration observed that most of the objective tests developed for evaluation of foams dealt with foams of low density such as those which had a specific gravity of less than 0.1, whereas successful foam mat drying operations apparently required foams having a specific gravity of 0.25 to 0.50.

His research involved viscosity measurements with a Rheomat (RM - 15) and density measurements by an aluminum cup method. Drainage rate was determined by means of a conical cylinder in which the amount of drainage liquid could be measured, and by a filter paper method which used the area of the paper that was wet by the drainage liquid from a given quantity of foam applied
to the paper in a specified manner. He also determined
the bubble size distribution by both photographic methods
and by light transmission measured by a photo-electric
colorimeter. All methods used to characterize foam did
yield information concerning the structure of the foam.
The data, however, did not relate to the applicability
of the foam to the success of the foam mat drying opera-
tions.
MATERIALS AND METHODS

Sauerkraut Juice

Raw, unfiltered sauerkraut juice was obtained directly from the wall well in a freshly opened tank of sauerkraut. The juice was drawn from a wall well rather than a bottom drain in order to obtain a more uniform juice. Bottom juice was less satisfactory in salt acid ratio than juice in contact with the sauerkraut, according to Tressler and Joslyn (33).

The juice was drawn into 18 liter glass carboys and within four hours of filling, the head space was flushed with nitrogen, the carboy was sealed and stored in the original corrugated box at 5°C. Prior to use, the juice was standardized to 2.2 percent acid as lactic acid using reagent grade (90 percent) lactic acid and 2.6 percent salt using a saturated NaCl solution which had been permitted to clear of anti-caking agents. This standardization was to obtain a raw product that would have an acceptable ratio of acid and
salt (28) at a maximum level that could be anticipated in juice from any commercial source.

The sauerkraut juice was withdrawn from the inverted carboy as required while maintaining the headspace under nitrogen at a pressure of about five centimeters water.

A sample of juice from each new carboy as it was opened was processed to powder using standardized production methods to determine whether or not any change had occurred during storage of the juice or any inherent difference existed among containers of juice that could be detected by this means.

**Sauerkraut**

Fresh, drained sauerkraut was obtained from the same fermentation tank that was the source of the juice. This material was obtained to be used as conditioned solids to be added to juice as required. Different portions of the sauerkraut were frozen, canned and preserved with sodium benzoate. The remainder was stored at 5°C in triple wall plastic bags.
Samples of the sauerkraut were subsequently chopped in a Hobart food grinder using the finest blade, or comminuted in a Waring Blender at high speed for periods varying from one to twenty minutes to produce products of different degrees of disaggregation to enable investigation of the effect of the particle size of solids added to formulations involving this additive. For this operation, 100 percent additional juice had to be added to maintain the cutting action. For periods of comminution that exceeded five minutes duration, a cooling period in a low temperature cabinet was required to cool both the sauerkraut puree and the blender before continuing the operation. This method of comminution yielded a product which contained 12 percent total solids when drained.

Additives

Materials which might conceivably influence viscosity or surface tension or serve to increase solids content, or be useful as protective colloids to reduce the adverse effect of salt and acid on foam stability, or form useful rheological systems were
solicited from many suppliers. These materials, generically, may be classed as gums, sugars, glycerol esters of fatty acids and proteins.

The additives obtained were evaluated as to their solubility, or dispersability in sauerkraut juice, and as to the degree of anticipated activity exhibited in the substrate when used according to the manufacturer's directions or suggestions.

When evaluating the products for which the literature reviewed or the manufacturer involved claimed or suggested that synergistic effects could be obtained to overcome the deleterious effects of low pH or high concentration of electrolytes by using additional additives these combinations were included in the evaluation.

From this list three items were selected as most worthy of additional investigation: carboxymethyl cellulose, carrageenan and Myverol 1800.

The selection of these additives was not intended to specify that they were applicable or even that they offered the ultimate solution to the problem. This
selection only signified that they responded most appropriately to the evaluation procedure used, which was as follows: sauerkraut juice was formulated to a 0.5 percent solution with active ingredient. Viscosity was measured with a Brookfield viscosimeter using a H-2 spindle at 20 revolutions per minute. Foam stability was measured by initial height in a tube 160 by 3.5 centimeters and noting rate of drainage.

The products selected for further study exhibited high viscosity or considerable foam production and good stability.

**Procedure and Equipment for Production of Foam Mat Dehydrated Sauerkraut Juice**

The flow chart for the production of foam mat dehydrated sauerkraut juice is illustrated in Figure 1. Also indicated are items and points of evaluation during this production. This organization was followed throughout the development of this report insofar as possible.

**Mixing Equipment**

The operation for preparing the foam mix formulations was carried out in an Iona 8-6 blender (Plate 1) equipped with a 250 watt immersion type heating
Figure 1. Flow Chart for Freeze-Drying of Sauerkraut Juice.

Sauerkraut Materials

- Single Strength Juice
- Concentrated Juice
- Condensed Solids

Additives

Mix

Blend - Heat - Fold - Cool

\[\text{Foam} \quad \rightarrow \quad \text{Evaluate} \quad \rightarrow \quad \text{Specific Gravity} \quad \rightarrow \quad \text{Viscosity} \quad \rightarrow \quad \text{Tray and Crater} \quad \rightarrow \quad \text{Evaluate} \quad \rightarrow \quad \text{Judge Condition Relative To Index} \quad \rightarrow \quad \text{Dehydrate} \quad \rightarrow \quad \text{Calculate Moisture Loss Rate} \quad \rightarrow \quad \text{Residual Moisture} \quad \rightarrow \quad \text{Hygroscopicity} \]
Plate 1. Foam Mix Preparation Equipment
coil, a cooling coil and a thermometer which were assembled on a single head clamped to a ringstand bar and by this means held in position immediately above the blades of the blender. The blender speed was controlled by a Superior Powerstat. The voltage to the heater was controlled by a second Superior Powerstat. Tap water at 70°C. was circulated through the cooling coil as needed. The heating coil was constructed of 37 centimeters of 3.97 millimeter diameter aluminum utility tube with a wall thickness of 0.457 millimeters wound into a helix with an internal diameter of 25 millimeters and a length of 26 millimeters. This aluminum tubing served as a housing for a chromel resistance wire coil which was attached to a heavy wall glass tube 12 millimeters in diameter and 28 centimeters long to enable attachment of the heating coil to the unit head.

The cooling coil was made of a 60 centimeter length of 4.76 millimeter diameter aluminum utility tube with a wall thickness of 0.533 millimeters wound into a helix having an internal diameter of 25 centimeters and a length of 45 millimeters. The helix began
40 centimeters from the inlet end of the tube and terminated 40 centimeters prior to the discharge end of the tube. These two straight lengths of the tube, parallel to and fastened to the glass support of the heating coil, passed through the header to the water supply and the waste system respectively.

A thermometer, mounted through the header in a manner for the bulb to be positioned at maximum distance from both the heating and cooling coils yet have adequate immersion in the matrix completed the mixer temperature control device to be operated in conjunction with the Superior Powerstats and a needle valve controlled water supply.

This unit had the capability of heating 400 grams of water from $7^\circ$ C. to $70^\circ$ C. in seven minutes and cooling this same load to $27^\circ$ C. in six minutes at a heat control setting on the one Powerstat index of 110 volts and a speed control setting on the other Powerstat index of 30 volts.
Mixing Procedure

400 grams of sauerkraut juice at room temperature (21°C.) were placed in the blender. The speed control Powerstat at a setting of 30 volts was turned on to start the blender. The remaining ingredients of the formula were added at a rapid uniform rate to the shoulder of the vortex in the substrate. In the event of any clumping or apparent lack of uniformity of dispersion of additives, the speed of the blender was very briefly increased.

The immersion unit was inserted in the blender bowl. The heat control Powerstat voltage was turned on at 110 volts. The respective voltages were maintained as initiated except when high viscosity was encountered. This situation required increase of voltage to the blender to maintain agitation and reduction of voltage to the heater to prevent the more viscous product from depositing a burned coating on the heating coil. As the end point of the operation was approached, as indicated by the temperature, the voltage to the heater was reduced stepwise by 5 volt decrements for each degree.
change in temperature reading beginning four degrees below the end point temperature of 63° C. At this temperature, the heating coil was turned off and the voltage to the blender was increased to 110 volts and maintained for one minute. At this point, the mixture was cooled. The voltage setting on the speed control Powerstat was reduced to 30 and the needle valve which controlled the flow of water to the cooling coil was immediately opened to permit 0.5 liters of water per minute at a temperature of 7° C, to enter the coil. When the temperature had been reduced to 27° C, this operation ceased and the contents of the blender bowl were transferred to the foam producing unit. This procedure was invariably followed in all mix operations for the preparation of foam for which the data were reported unless otherwise stipulated.

**Foam Production Equipment**

A Hobart Model C - 4 planetary type mixer with wire whip was used to produce the foam by incorporating air into the mix. This device, however, was extensively modified, (Plate 2), to record the torque imparted to the bowl of the mixer by the whipping action of the wire
Plate 2. Modified Hobart C-4 Mixer with Torque - Time Recorder
whip as the character of the foam developed during its formation.

The modification of the Hobart machine required the removal of the bowl retaining device and by suitable machining operations to remove a small area of the mixer base casting, an S. K. F. 18 - OP - 2 double row precision ball bearing was mounted under the mixer base casting concentric with the mixer bowl retainer recess. Into the bearing bore was then fitted a two inch shaft which terminated on the upper end (nearest the position of the bowl retainer) in a three armed spider, each arm of which was tapped and countersunk to receive the fillister head screw which held the bowl retainer to the casting in the original situation. The hole in each arm was so located that when the bowl retainer was affixed to the spider instead of the mixer base holes provided, the mixer bowl retainer was situated 0.25 millimeters above its original position. This new position provided a clearance of 0.1 millimeter between the mixer bowl retainer and the mixer bowl retainer recess wall. This permitted free rotation of the mixing bowl and retainer within a 30° arc. This limitation was imposed by the necessity of
interleaving the spider arms with the original bowl retainer mounting holes which were located in stub posts cast integrally with the mixer base.

To the bottom of the shaft which extended thru and beyond the lower edge of the bearing, approximately 5 millimeters, was affixed a steel shaft 9.4 millimeters in diameter and 24 centimeters long. For a distance of 7 centimeters from one end of this rod it was forged flat and finished smooth 2 millimeters thick and one centimeter wide. This flat length enabled attachment of the rod by means of machine screws parallel to the plane of the base of the mixer in the vertical plane that bisected the mixer lengthwise. The center of attachment of the rod to the shaft was 5 centimeters from the flattened end of the rod. The flat extension of the rod was drilled with five holes approximately 1 millimeter diameter spaced 5 millimeters apart beginning 2 centimeters from the center of the attachment of the rod to the shaft and continuing on toward the end of the flat portion of the rod. These holes were for the purpose of attaching a spring resistance
mechanism to the rod to counter the torque of the mixing bowl. By changing the point of attachment of resistance, the degree of rotation of the bowl and the resultant torque reading could be attenuated by equal increments. The remaining round portion of the rod carried an aluminum housing 5 centimeters long by 3 centimeters square which was bored longitudinally to retain needle bearings at the extremities of the bore hole which was centered 8 millimeters from one longitudinal face of the housing. These bearings, 9.4 millimeter inside diameter and 14 millimeter outside diameter afforded both rotary and longitudinal movement of the housing on the rod. When, by experiment, the optimum location longitudinally of the housing on the rod was found it was locked in place by a set screw collar on each side of the housing. This housing was drilled and tapped transversely to the carrier rod on a center located 7 millimeters from the housing face opposite the reference face for the carrier rod bore. A 6.6 millimeter rod was suitably threaded for a distance of 12 centimeters from one end and forged to enable clamp-
ing a recording pen at the other end. This pen carrier rod was then screwed through the tapped hole in the housing to expose 9 centimeters of threaded rod extending from the side of the housing opposite the side facing the pen at its extremity. A 100 gram lead cylinder 2 centimeters long was drilled and tapped so that this weight could be screwed onto the threaded end of the rod at the proper distance to nearly counter balance the weight of the pen carrier arm and its pen which was free to rotate about the axis of the pen arm housing carrier.

The rubber feet were removed from the mixer base and the rubber feet retainer holes tapped for 9/16 inch 18 thread cap screws. These cap screws then became the method of attaching the mixer to the base which was constructed to accommodate the recording device.

The base for this torque - time recording whipping device consisted of a 37 by 60 by 2 centimeter hardwood plywood platform mounted on which were two parallel 6 by 12 centimeter aluminum "I" beams 60 centimeters long. The "I" beams were reduced to the form of inverted
"I" bars 6 centimeters by 5 centimeters for a length of 40 centimeters.

The Hobart C-4 was mounted by means of four 9/16 inch 13 thread cap screws through the top rail of the remaining "I" beam section to locate its base 12 centimeters above and parallel to the base platform. In a position parallel to the base platform and on the opposing faces of the web of the "I" beam "T" bar of each structural member was affixed an aluminum angle bar supported Teflon guide designed to support and permit easy longitudinal transport of a chart carrier in a plane midway between the base of the platform and the mixer base.

The chart carrier, fitted with chart locator guide and clamp, was transported from the zero point of the pen contact on a properly positioned chart to a position more remote from the Hobart machine at a rate of 14 millimeters per minute.

The chart carrier motion was accomplished by connecting the carrier to a 5 watt 1/12 revolutions per minute synchronous motor by means of a 1 - A ladder
chain and sprocket set through a double fall differential mechanism. The chart carrier could be returned to zero position by actuating a sprocket-chain separating device and manually moving the carrier.

The electrical system of this machine was designed with interlock and by-pass circuits to enable independent chart action or whipping action or simultaneous operation of the two.

Positioned between the Hobart assembly and the chart carrier was an acrylic splash pan to prevent possible spillage from soiling a chart as it passed beneath the assembly. The edge of this pan nearest the pen also served as an adjustable upper and lower limit stop for the pen arm.

An assembly of concentric coil tension springs designed to give maximum uniformity of distance between uniform increments of torque throughout the arc of pen travel was attached between the platform frame and the multi-holed flattened end of the torque arm rod. This was done in a manner to permit adjustment of spring tension as required. A pen arm lifting bail was installed
to facilitate manipulation of the charts. A 4 millimeter acrylic plastic cover for the whipping bowl was fabricated so that it was readily removable yet adequately sealed to the bowl by means of a sponge rubber gasket. This cover held firmly in place by friction fit of the gasket was designed to prevent overflow and splashing and also permit addition of ingredients as desired during the foaming operation.

This whipping torque recording device proved very sensitive and recordings of the torque exerted by such items as water, 5 percent cane sugar solutions, 10 percent corn syrup solids solution and cake batter were precisely reproducible. The recording made during operation was indexed as torque. The torque was measured as the force necessary, when applied to the pen holder, to effect a measured displacement of the pen in arc times the distance from the pen holder to the pivot point of the bowl retainer assembly. The torque developed during the course of whipping was registered relative to time from zero of its occurrence.
Foam Production Procedure

The mix from the preceding operation was poured from the Iona container into the Hobart bowl, the wire whip and bowl cover appropriately positioned and with the Hobart speed control set at 10, the main control switch was turned to "on". The foaming operation was continued until the desired information was obtained, or the torque value indicated that subsequent operations should be undertaken.

Upon completion of the foaming operation, a specific gravity measurement was made by carefully filling a glass container having a large bottom to wall inside radius, this assisted in enabling the filling operation to be performed without voids near the bottom. The dimensions of this container were 75 millimeters deep by 73 millimeters diameter and would contain 251 grams of water. It became apparent that this shape and size of this container could be filled more accurately than larger or smaller containers with much different depth to diameter ratios. A manipulative technique was developed that resulted in the ability to duplicate fill weights
of even the stiffest foam to within plus or minus 0.5 grams. The dimensions of the specific gravity container were also adequate for insertion of the Brookfield H - 2 spindle.

This sample in the same container was also evaluated using the Brookfield viscosimeter. The H - 2 spindle, a 48 millimeter disk, was selected for maximum resistance in preference to the H - 1 spindle, a cup, the shape of which suggested the possibility of inclusion of entrapped air pockets causing a variation in values obtained. A speed of 20 revolutions per minute was selected as the highest speed that could be used that might not permanently alter the character of the foam and at the same time the lowest speed that could give observable differences in the range of value anticipated by preliminary trials. The readings were recorded as the value indicated upon completion of the second revolution of the spindle at five minute time intervals from zero to 30 minutes.
Traying and Cratering Equipment

The next operation in the process program was traying and cratering. Only those samples which prior evaluation indicated a reasonable probability of success in this operation were further utilized.

This operation was performed on a device (Plate 3) constructed for accurate volumetric loading of trays and with readily adjustable air velocities for cratering.

A rectangular aluminum frame 23 by 60 centimeters was constructed of 25.4 millimeter by 25.4 millimeter aluminum angle bar so that the 90° angles of the members faced internally but with the 90° angles of the longitudinal members facing opposite the direction of the lateral members. This assembly was then mounted, with the 90° angle of the longitudinal members facing downward and fitting into milled lengthwise slots in the top edge of the vertical bar of each of four 5 centimeter lengths of a 6 by 6 centimeter aluminum "T" bar formed of 5 millimeter thick stock. These "T" bar feet were located near the ends of the longitudinal
members of the frame and permanently fastened to the laboratory bench. A 1.5 millimeter hole drilled through the slot and the inserted edge of the frame enabled secure attachment of the frame to the bench by insertion of a clevis pin. This feature also facilitated the clean up operation by permitting removal of the entire traying and cratering device to the laboratory sink for thorough hot water clean up.

Attached to the inside face of the vertical side of each of the longitudinal members of the frame, as mounted, was a 2 by 2 centimeter aluminum angle bar made of about 1 millimeter thick stock. This lightweight angle was fastened in a manner nearly congruent to the position of the longitudinal member of the frame by means of Phillips head machine screws which were inserted from the outside through vertical slots in the frame bar to engage tapped holes in the like face of the inner angle bar. This permitted vertical adjustment of the inner bar to provide a space between the lower face of the horizontal surface of the frame bar and the upper surface of the inner bar to serve as a support and guide for an aluminum plate 20 centimeters
wide, 40 centimeters long and 2.5 millimeters thick. On the upper surface of this plate an aluminum plate 18 centimeters wide, 35 centimeters long and 3.15 millimeters thick was fastened, by means of number 4-32 counter sunk machine screws, in a position to leave 1 centimeter of the longitudinal edge of the bottom plate extended past the edge of the upper plate on each side. This extension fitted into the guide slot on its side of the frame. The second or upper plate was then level with the horizontal surface of the longitudinal frame member and its width was exactly the distance between the innermost edge of the horizontal face of the longitudinal members of the frame, this contact area then served as the lateral guide for the compound plate.

The 5 centimeter length of the bottom plate not covered by the upper plate was perforated with several 15 millimeter diameter holes to enable the operator to secure a substantial grip on this plate in order to move it longitudinally in the guides.
Five centimeters from the lateral edge of this compound plate, opposite the end provided with the gripping area, a row of 0.9 millimeter diameter holes were drilled through both plates on 2 millimeter centers parallel to the reference edge and vertical to the plate surface. This row of holes began 1 centimeter from the edge of the upper plate and contained 80 holes extending to within 1 centimeter of the opposite edge of the upper plate.

A small cleaning head from a vacuum cleaner was altered and sealed to the bottom surface of the bottom plate over an area encompassing the row of holes. This served as a manifold for the air supplied for exit by way of the holes. This manifold was connected to an air supply by a spirally wound wire reinforced vinyl tube about 3.5 centimeters in diameter.

The air supply pressure was variable by means of a General Electric B. Y. - 5 voltage regulator used to control the speed of a centrifugal blower of unknown manufacture.
To complete the artifacts needed to accomplish the purpose of this device, a rectangular frame was constructed of 25.4 by 25.5 millimeter aluminum angle bar to dimensions of 34 centimeters long by 23 centimeters wide with the 90° angle of the frame member facing toward the interior of the rectangle. The exterior plate surface of this frame was then fastened to the flat surface of a plate 2.5 millimeters thick and having the same overall dimensions as the frame. This plate was perforated by a single rectangular hole 16 centimeters wide and 25 centimeters long located equidistant from each lengthwise edge of the plate but placed 14 centimeters off center relative to the lateral edges.

This frame and plate assembly was located on the base unit with the sides evenly matched and the open area of the framed plate near the line of holes in the plate of the base unit. Two 3 millimeter holes were drilled through the upper frame, the pierced plate and the longitudinal base frame angle. Tapered pins were inserted in the base frame hole to assure proper realignment of the upper frame and plate when subse-
Quantitatively removed and reinstalled. Eccentric latches were installed near each corner of the upper frame to secure the two units.

**Traying and Cratering Procedure**

To load and crater a tray of foam, a perforated tray was made for the dehydration cabinet, and drilled to fit the locator pins in the base assembly was placed on the base platform and the upper frame was placed in position on top of this tray. The latches then locked the three pieces together.

The perforated area in the tray matched the open area in the upper plate. The volume contained in the area 16 by 25 by .25 centimeters equaled 100 cubic centimeters. To place this volume on the tray, a quantity of foam was placed on the tray at one end of the open area in the upper plate and leveled smooth to a depth of 0.25 centimeters by scraping the pile of foam to the opposite end of the open area of the upper tray by the straight polished edge of a 9.9 millimeter thick acrylic scraper 7.8 centimeters wide and 10 centimeters high; the ends of the straight edge
sliding on the top surface of the top plate.

The air supply switch was turned on. The air pressure was regulated subjectively to anticipated requirements and the lower compound plate pulled through its guides so as to cause jets of air issuing from the line of holes in this plate to pass under and blow clear the holes in the tray and produce a crater in the foam above these tray holes. The latches were released and the loaded tray removed to the dehydration area or set aside for observation.

Observation of the craters as they formed or at the end of a five minute period after cratering gave valuable information concerning the character of the foam.

For those foams scheduled to be dehydrated, the desired number of trays were rapidly leveled, cratered and removed to the dehydrator area. A proficiency was developed in this operation that permitted traying and cratering at a rate of eight trays in four minutes.
Air Conditioning System Equipment

An adequate supply of precisely conditioned air was required for this operation. To achieve this a device was constructed with the capabilities in excess of anticipated maximum requirements. (Plate 4).

A plain steel 55 gallon open head drum was mounted on a channel iron frame. One side of the frame was made from a 60 centimeter length of a 6 by 20 centimeter by 2 centimeter thick channel iron. This served both as the primary structural unit and the pump and motor base. To the top surface of the motor base, parallel to the surface and at right angles to the lengthwise edge of this base, at the edge of the motor position end of the base, was welded a 2.5 by 5 centimeter by 9 millimeter thick channel iron 80 centimeters in length. 45 centimeters toward the pump end of this plate another channel iron which had the same dimensions as the proceeding one was welded parallel to the first one and extending in the same direction. To the ends of these members a third 2.5 by 5 centimeter channel iron 60 centimeters long was welded to close the rectangle thus formed and provide stabilizing extensions.
for mounting casters at the corners of the 60 by 80 centimeter area. The casters mounted at the ends of the 2.5 by 5 centimeter members were adjustable for height to enable leveling the device. The drum was mounted in dog clamps by the bead of its base seam to the 2.5 by 5 centimeter members.

The humidity control feature which used a liquid absorbent consisted of two systems: the intake system and the circulatory system. The circulatory system was constructed as follows: to the bottom of the drum, near the periphery, a 3 centimeter diameter hole was cut over which a 1 inch black iron pipe floor stand (black iron was used throughout the construction of the pumping system) was bolted with a hard rubber gasket intervening to prevent leakage. A 1 inch, 90° street ell led from this opening through a 1 inch by 6 inch nipple to a 1 inch tee. One branch of this tee was fitted with a valve to permit drainage of the system. The other branch, was of tube adapters and a 25 centimeter length of 34.4 millimeter inner diameter Tygon tube with 4 millimeter wall thickness, led to the intake part of a Loeffler 3 - C centrifugal pump. The
discharge port of this pump was then connected by 1 inch pipe tube adapters and 25 centimeters of Tygon tubing as previously described to a 1 inch street ell welded female end to the side of the drum to cover a 3.5 centimeter hole cut in the side of the drum 66 centimeters above the base of the drum. Inside of the drum a liquid distributing system consisting of a spider of six 1/8 inch pipe arms of sufficient length to nearly reach the periphery of the drum from their centrally located origin, drilled 3 millimeters on 8 centimeter centers, threaded into a 1 inch pipe cap with the drilled holes pointing downward 45° from vertical. The cap was then connected upward to a rotary joint by means of a close nipple. The top half of the rotary joint was connected by means of a 90° street ell to a length of 1 inch pipe of sufficient length to thread into the street ell, welded as previously described, and to support the spider at the center of the drum.

In operation absorbent liquid was pumped as needed from the bottom of the drum, through the distributing arms which thoroughly wet a packed 15 centimeter thick bed of iron lathe turnings in an expanded
metal basket which was sealed to the wall of the drum by a heavy sponge rubber gasket. This served to increase the capacity of the humidity control system at any concentration of absorbent used.

The air intake system could be regulated to use room air or scrubbed air or desired proportions of both. The scrubbed air was drawn into the drum through a 2½ inch stand pipe, the entrance and regulating valve of which extended above the top level of the drum for easy access. This pipe entered the drum through a 2½ inch street ell, the male end of which protruded through the drum wall was brazed to the wall of the drum in a hole, the center of which was 5 centimeters above the bottom rim of the drum. A 2½ inch pipe of sufficient length to connect a 90° 2½ inch ell located at the center of the drum to a coupling threaded onto the inward protruding male end of the entrance fitting.

The end of the centrally located ell was pointed upward. The rim of this opening served as a base to which affix a 1 millimeter thick circular steel plate by means of eight number 8-32 machine screws. This
steel plate mounted horizontally and extending to within 1 centimeter of the wall of the drum was perforated with concentric circles of holes which began with a 10 centimeter diameter circle of 40 holes each 3 millimeters in diameter. The diameter of the circles of holes increase by increments of 15 centimeters. The diameter of the holes in the circles increased by approximately 3 millimeters per circle.

This vertical section of the ell to which this plate was attached had drilled in it six 25.4 millimeter holes around its circumference to permit entrance of air into the system.

The depth of the absorbent liquid was maintained at about 9 inches deep in the drum, observable by a sight glass installed for this purpose. This level of liquid supplied a cover of about 2 inches of liquid over the top surface of the plate through which the air did bubble.

Relative humidity of from 10 percent to 100 percent could be obtained with this device by varying the solution used from pure water to a saturated sodium hydroxide solution.
At the center of the lid of the drum a 10 centimeter hole was cut. Over this hole a rigid polyvinyl-chloride flange was mounted by six \(\frac{1}{2} - 20\) stove bolts. A 15 millimeter thick sponge neoprene gasket between the flange and the lid permitted a substantial, airtight seal between the slight curvature of the lid and the flat face of the flange. To this flange a polyvinyl-chloride "T" was affixed by a 9 centimeter length of 3 inch polyvinyl-chloride pipe to the flange so that the top edge of the flange opening was in contact with the bottom edge of the straight through opening of the "T". The side opening of the "T" when covered with a clear acrylic plate afforded visual access to the relative humidity and temperature of the air entering the pump. The top opening of the "T" was fitted securely to cast aluminum intake screen of the air pump. The centrifugal air pump, an Ideal number 22 - 110, was then readily attachable to this mounted screen and locked in place by wing bolt keepers through the assembly. Thus, the pump was mounted so that the axis of the motor and pump vanes were horizontal and parallel to the plane of the drum opening. The discharge port
of the pump by way of a tapered aluminum housing, containing a 1000 watt heating element, terminated in a 28 millimeter outer diameter tip. This tip area was male threaded 1 inch National Pipe Thread and screwed into a 1 inch 90° aluminum street ell which returned the direction of the flow of air vertically downward toward the drum. This street ell was connected by means of a 1 inch gate valve and a pipe union to the main heating chamber.

This heating chamber was constructed as follows: a 10.5 centimeter inner diameter steel tube 90 centimeters long was fitted with cast aluminum plates at each end, each held in place by four 6-32 stud bolts and nuts.

This chamber throughout its length contained the following items in order: a vertical 1 inch pipe stub air inlet; a 22 Ohm resistance nichrome heating element; a support bracket for a 33 Ohm resistance nichrome heating element tapped at 11 and 22 Ohms; a bracket to support the end of the heating element; a vertical opening to which was welded the female half of a 1 inch pipe union which provided for external contact of the internal
heating elements; a filter packed with stainless steel turnings 6 centimeters deep; the temperature sensing chamber and two 18 centimeter lengths of 1 inch pipe welded horizontally to the tube as exits for the air.

Heating the air was, briefly, accomplished as follows. The 33 ohm resistance and taps were so connected by a combination of six switches to a 220 volt three pole power supply that a power consumption of from 300 watts to 3000 watts in 300 watt increments could be obtained. A high, medium and low range ballast circuit of 100 - 400 - 700 watts was used to control the exit air temperature by means of a mercury meniscus platinum contact actuated by a bimetallic coil temperature sensor through a two stage solid state electronic switch powered by a "C" and a "D" battery. This required a contact current of only 4 milliamperes at 1.5 volts to operate. The sensitivity and accuracy of this heat ballast and control system was such that variation in temperature of the exit air could not be detected, for any temperature used, by observing the 0.1° C. graduations on the mercury thermometer in the temperature sensing portion of the tube.
The quantity of air entering the dehydrating chamber was determined by a minature Pitot - static tube mounted in one of the heater tube exits and connected to a "U" tube differential manometer. This assembly was quantitatively calibrated at the range of temperatures used by a Sprague Model - G75 positive displacement gas meter.

The rate of air through the dehydrating cabinet was controlled by a Dayton 4X701 electronic motor speed control used to regulate the speed of the 1.3 horsepower air pump motor and additionally adjusted by the valve located between the pump and heater tube for very low velocities. This air supply was connected to the dehydration cabinet tube by means of a 1½ inch three way sanitary valve. This permitted diversion of the air either to the dehydration cabinet or to the atmosphere.

**Air Conditioning System Procedure**

In anticipation of performing a dehydration rate evaluation of a formula, the dehydrating conditions were selected and the air supply equipment adjusted to produce the desired operating conditions. Water or the
proper concentration of sodium hydroxide solution was placed in the humidity control chamber. The air source selector was opened to admit room air. The air pump was turned on to deliver air through the heater tube slightly in excess of the desired final rate. A suitable combination of heater units were turned on and the heat ballast system was actuated and adjusted to the desired temperature. As this temperature was approached within 5 degrees the air source selector was switched so that the air pump would draw air through the humidity control chamber and the humidity control solution was circulated through the secondary absorption bed. This added resistance in the air system required a final adjustment of the air delivery rate. The system was then allowed to equilibrate.

The standard conditions referred to throughout this paper relative to dehydration are air into the system at 21°C, and 40 percent relative humidity and air temperature at the dehydration cabinet entrance 80°C.

The Dehydration Cabinet and Recording System Equipment

The dehydrating cabinet (Plate 5) was constructed of 1 inch thick Dow Styrofoam. The inside dimensions
of the cabinet were 350 millimeters deep by 200 millimeters wide and 450 millimeters high. Slots by which to position the perforated trays in the cabinet were burned longitudinally in the side walls at vertical increments of 5 centimeters. The door of the cabinet, reinforced with aluminum angle bars and a continuous hinge was so fitted with sponge rubber strips that when closed was sealed to the cabinet opening and also sealed the individual trays in their respective positions in the cabinet. Observation ports fabricated from ¼ inch acrylic plastic 23 millimeters in diameter were recessed in both the door and the back of the cabinet at positions interposed with the product trays. Proper positioning of a 20 watt fluorescent light fixture and tube near the back of the cabinet afforded excellent observation of the cabinet contents.

Two inlet ports 36 millimeters in diameter located near the bottom on one side of the cabinet and four 36 millimeter exit ports in the top completed the cabinet which was then mounted on the product pan of a type 8000 Exact Weight Scale, and con-
connected to the air supply by means of a looped, wire reinforced vinyl tube which had an outside diameter of 36 millimeters.

Trays were then made to fit the cabinet and permit the cratered style of foam mat drying to be practiced as follows. Rectangular sheets of 1 millimeter thick aluminum 35 centimeters by 20.4 centimeters were perforated with 3 millimeter diameter holes spaced on 9 millimeter centers over a rectangular area 16 centimeters by 25 centimeters. The hole area totaled 147 square centimeters. The total loading area of the tray when loaded 2.5 millimeters deep would accommodate 100 cubic centimeters of wet product. Finally the trays were polished and coated with Teflon.

The dehydration recording system was shown on Plate 6. The Exact Weight Scale and dehydrating cabinet were mounted on an aluminum angle bar frame 19 centimeters wide and 90 centimeters long. This frame unitized the scale and a recording device mounted near the weight pan end of the scale.
Plate 5. A dehydration cabinet and moisture loss recording device.
The recorder consisted of a vertical frame work on which were mounted an upper and lower longitudinal and parallel guide tracks milled in aluminum angle bars which served to position and permit lateral movement of a vertical chart carrier 26.5 centimeters high and 35 centimeters long. A synchronous 1/20 revolutions per minute, 7 watt, 12 volt motor and transformer (110 volts to 12 volts) were mounted on the upper guide bar in such a position as to enable the motor, by means of a 1 - A ladder chain and sprocket to cause transverse of the chart carrier at a rate of 4 millimeters per minute. The recording assembly was completed by means of a tubular aluminum arm pivoted to the scale near the pivot point of the scale and supported by a suspension saddle mounted on the weight pan of the scale. The aluminum pivot tube terminated in an 8 millimeter by 0.5 millimeter tempered steel extension which carried a pen holder at its distal end. The positioning of the pivot, pivot arm suspension and pen holder magnified the vertical movement of the weight pan with change in load weight of the cabinet by a ratio of three to one in register on the recorder.
This entire system was then mounted on laminated rubber, sponge rubber feet and activated by the vibration of a 1/50 horsepower motor mounted on the base frame of the assembly and spinning a 20 gram eccentric weight at 1800 revolutions per minute.

The Dehydration Cabinet and Recording System Procedure

With the air supply established at the desired conditions, the trays loaded and crateded, the air supply was then diverted from the dehydration chamber. The loaded trays were inserted and sealed in the chamber, the recorder actuated and the air flow returned to the dehydration chamber.

Operation of the dehydrator was continued until either a suitable portion of the moisture loss rate curve was obtained, the curve indicated that an equilibrium had been reached in the system, or the temperature and relative humidity of the exhaust air from the system, as recorded immediately prior to the loading operation were again observed.

At the appropriate time the air supply was diverted from the dehydrator, the trays removed and
stacked to cool, or weighed hot into a vacuum dehydrator to determine residual moisture.
PRESENTATION OF RESULTS

The results have been presented in the order in which the selection of additives and the production and evaluation procedures were performed and concluded with a section on general investigation.

Screening Tests for Additives

Results of the screening tests as previously described were shown in detail for those items selected for the full study with which this paper was concerned. Also illustrated were several items for purposes of comparison which showed some activity in the area.

Surfactants

In Figure 2 are graphed the data for initial foam height, initial liquid quantity and rate of increase of the liquid quantity of a $\frac{1}{2}$ percent solution of the active ingredient in 400 ml. of sauerkraut juice. The additives selected for this presentation were sucrose, monostearate, sucrose palmitate, Myverol 1835, Myverol 1800 and saponin.
Figure 2. Foam Height and Foam Stability as Indicated by Liquid Quantity for Formed Squeakrant Juice-Emulsifier Mix.

- Liquid Quantity
- Synerol 1800
- Sucrose Palmitate
- Sucrose Stearate
- Synerol 1835
- Seponin

Time Minutes

Foam Height Ca. X 10

Entrapment Liquid M. X 100
Stabilizers

Listed in Table 1 are the viscosity data for some of the materials considered to be potential stabilizers. The data are presented for the products which the one percent level in sauerkraut juice indicated the most compatibility with sauerkraut juice and registered the highest viscosity. (Table 1 in Appendix)

Mixing the Ingredients

Illustrated in Figure 3 are the time temperature parameters of the mix during the preparation of the mixes prior to whipping. The indicated initial, maximum and final temperatures were used for the preparation of all products for which the data presented herein except as noted for results of determination of the effect of mixing temperature.

Mixing Operations Temperature Effect

The effect of variations of the temperature of the end point of the heating portion of the mixing cycle used in the preparation of a test formulation containing 0.3 percent Myverol 1900 and 0.7 percent carboxymethyl cellulose and one containing 0.3 percent Myverol and 0.7 percent carrageenan are shown in Figure 4.
Figure 3. Time-temperature Parameters of Heating and Cooling of Sauerkraut Juice-Additives Mix.
Figure 1. Torque-Time Chart of Shipping Characteristics of Sauerkraut Juice with 0.3% Hyverol and 0.7% Carrageenan or Carboxymethyl Cellulose Heated to Different End Points.
The torque values noted in this figure indicated that great differences in whipping characteristics as registered by whipping torque result from variations in the mixing operation temperatures. The torque values noted in this figure indicated that differences as great as 400 gm. cm. torque did result from a 1° C. variation in mix operation temperature and that a high mix temperature resulted in less reduction of torque value than a low mix temperature.

Characteristics of Foam

The formula, specific gravity, Brookfield viscosity, maximum torque, duration of maximum torque, time from zero required to attain maximum torque, solids added, concentration of the juice and craterability of the foam are listed in Tables 2 and 3 in the Appendix. The figures and tables given herein were taken from the data in these tables.

Figure 5 was composited from recordings of the torque time curves registered by the recorder attached to the foam producing unit while foaming selected formulations of Myverol 1800 and carrageenan in sauerkraut
Figure 5. Torque-Time Values Obtained by Whipping Various Formulas of Sauerkraut Juice—Myverol 1800 and Carrageenan.

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<th>Myverol %</th>
<th>Carrageenan %</th>
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<td>0.7</td>
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<tr>
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</tr>
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<td>0.1</td>
</tr>
<tr>
<td>0.7</td>
<td>0.3</td>
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Gram centimeters x 10

Time Minutes
juice. The maximum torque, 550 gm. cms., developed the most rapidly of the persistent foams produced; and that among the foams depicted those containing a total of 1 percent additives or more were stable and developed quickly provided that Myverol was not present in excess of carrageenan.

Figure 6 was composited from recordings of the torque time curves registered by the recorder attached to the foam producing unit while foaming selected formulations of Myverol 1800 and carboxymethyl cellulose in sauerkraut juice. The maximum torque, 570 gm. cms., developed the most rapidly of the persistent foams produced; and that foam containing more carboxymethyl cellulose than Myverol were more persistent at higher torque values than foams containing equal parts Myverol and carboxymethyl cellulose or more Myverol than carboxymethyl cellulose.

Figure 7 was composited from recordings of the torque time curves registered by the recorder attached to the foam producing unit while foaming selected formulations of Myverol 1800 and carboxymethyl cellulose
Figure 6. Torque-Time Values Obtained by Whipping Various Formulas of Sauerkraut Juice-Lyocil 1800 and Carboxymethyl Cellulose.

<table>
<thead>
<tr>
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<th>Myv%</th>
<th>Cmc%</th>
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</tr>
<tr>
<td>6</td>
<td>0.4</td>
<td>0.2</td>
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</table>
Figure 7. Torque-Time Values Obtained by Whipping Various Formulas of Sauerkraut Juice-Nyverol 1860 and Carrageenan or Carboxymethyl Cellulose with 10% Sauerkraut Solids Added.
or carrageenan with 1 percent comminuted sauerkraut solids in sauerkraut juice. The torque values obtained indicated that the presence of comminuted sauerkraut solids depressed the torque values of specific formulations by 300 to 400 gm. cms. (See Figures 5 and 6). An increase in Myverol or carboxymethyl cellulose or carrageenan in the formulation overcomes this depression.

Figure 3 was composited from the recordings of the torque time curves registered by the recorder attached to the foam producing unit while foaming a selected formulation of Myverol 1800 and carboxymethyl cellulose or carrageenan in a single strength juice and in a three to one concentrated sauerkraut juice. The use of concentrated juice in carboxymethyl cellulose depressed the torque reading to 350 gm. cms., a reduction of 100 gm. cms. from the value attained by the single strength juice formula. The substitution of concentrated juice for single strength juice had the opposite effect on the torque values obtained when the carrageenan formula was used. This increased the torque value by about 150 gm. cms.
Figure 3. Torque-Time Values Obtained by Whipping Mixes Formulated with 0.3% Hyverol and 1.4% Carrageenan or Carboxymethyl Cellulose in Single Strength and Concentrated Sauerkraut Juice.
The relationship between the Myverol 1000 and the carrageenan content of a sauerkraut juice foam in terms of the specific gravity of the foam, illustrated in Figure 9, indicated that the specific gravity of the foam decreased with increase in Myverol at the Myverol concentrations of 0.2 percent, 0.3 percent, 0.4 percent and 0.5 percent at concentrations of carrageenan of 0.2 percent through 0.8 percent. With the maximum decrease in specific gravity of the foam at carrageenan concentrations in the range of 0.6 percent to 0.7 percent. The data in this figure indicated also that a different relationship existed at concentrations of Myverol at 0.6 percent and 0.7 percent.

The relationships between Myverol and carboxymethyl cellulose in terms of specific gravity (Figure 10) indicated that at concentrations of Myverol 1000 of 0.2 percent, 0.3 percent and 0.4 percent in a sauerkraut juice foam containing carboxymethyl cellulose, the specific gravity decreased with an increase in carboxymethyl cellulose concentration at the carboxymethyl cellulose levels of 0.5 percent to 0.9 percent, 0.2 percent to 0.9 percent and 0.2 percent to 0.3 percent respective-
Figure 9: Specific Gravity of Various Substances
Figure 10. Specific Gravity of Caperkratt Juice Form at Indicated Myverol 1500-Carboxymethyl Cellulose Content.
ly. Also indicated by these data was that at a Myverol concentration of 0.5 percent and 0.6 percent specific gravity increased at carboxymethyl cellulose concentrations of 0.3 percent to 0.7 percent and 0.2 percent to 0.7 percent respectively.

**Viscosity**

A change in the character of the sauerkraut juice foam with time was depicted by graphing Brookfield readings for the various formulas of sauerkraut juice, Myverol and carboxymethyl cellulose at the indicated time intervals (See Figure 11). The values graphed show that a total additive content of 1.2 percent in the carboxymethyl cellulose foams attained a Brookfield reading of 26 centipoise and a total of 0.6 percent addition only 5 centipoise.

As depicted in Figure 12 a change in the character of sauerkraut juice foam with time was noted by graphing the Brookfield readings for the various formulas of sauerkraut juice, Myverol and carrageenan at the indicated time intervals. The values plotted depict generally an increase of Brookfield viscosity in
Figure II. Brookfield viscosity and change in viscosity with time for Lyvreal-Carboxymethyl Cellulose-Sauerkraut Juice Foams.

(® Lyverol, C. R. C.)
Figure 12. Brookfield Viscosity and Change in Viscosity with Time for Several Carrageenan-Carmerkant Juice Forms.
cuntipose with an increase in total additive content.

**Drying**

The two lines illustrated in Figure 13 are composites of four moisture loss trials for each of two formulas. One formula consisted of sauerkraut juice with 0.3 percent Myverol 1800 and 0.7 percent carrageenan, the other consisted of sauerkraut juice with 0.3 percent Myverol 1800 and 0.7 percent carboxymethyl cellulose. An average moisture loss rate of 4.1 gms. per minute was obtained for the formula that contained carboxymethyl cellulose, and an average loss rate of 3.9 gms. per minute for the carrageenan formula.

The effect of the character of the foam due to variation in formula on the rate of moisture loss for the system carrageenan - Myverol 1800 was shown in Figure 14. The moisture loss rate for the combination 0.3 percent Myverol 1800 - 0.7 percent carrageenan was found to be 3.9 gms. per minute. For the formula 0.7 percent Myverol - 0.3 percent carrageenan was found to be 3.6 gms. per minute.
Figure 13. Dehydration Cabinet Load Versus Time in Dehydrator for Pasteurized Sauerkraut Juice.

- Carboxymethyl Cellulose
- Carrageenan

TIME MINUTES
Figure 14. Graph of Dehydration Cabinet Load Versus Time for Foamed Sauerkraut Juice.

- 0.5% Myverol
- 0.7% Carrageenan
- 0.7% Myverol, 0.3% Carrageenan

TIME MINUTES

GRAMS
The data in Figure 15 for three formulations of sauerkraut juice with carboxymethyl cellulose and Myverol indicates moisture loss rates as follows. The formula 0.3 percent Myverol - 0.7 percent carboxymethyl cellulose dehydrated at a rate of 4.1 gms. per minute. The formulation of 0.5 percent Myverol 1800 - 0.5 percent carboxymethyl cellulose lost moisture at the rate of 4.7 gms. per minute and the formula 0.7 percent Myverol - 0.3 percent carboxymethyl cellulose lost moisture at the rate of 3.6 gms. per minute.

The moisture loss rate was charted (see Figure 16) for formulations of sauerkraut juice, Myverol 1800, carrageenan and added sauerkraut solids. The moisture loss rate of the formula 0.6 percent Myverol 1800, 0.7 percent carrageenan in sauerkraut juice with 2 percent coarse solids added was 4 gms. per minute.

The moisture loss rate of the formula 0.5 percent Myverol 1800, 1 percent carrageenan in sauerkraut juice with 1 percent coarse solids was 4.9 gms. per minute. This same formula with fine solids in place of coarse solids had a moisture loss rate of 5.3 gms. per minute.
Figure 15. Graph of Dehydration Cabinet Load Versus Time for Foamed Sauerkraut Juice.

- --- --- 0.2% Myverol, 0.2% CAS
- --- --- 0.5% Myverol, 0.5% CAS
- --- --- 0.7% Myverol, 0.3% CAS
Figure 16. Graph of Dehydration Cabinet Load Versus Time for Foamed Sauerkraut Juice with Added Comminuted Sauerkraut Solids.

- ○ ○ ○ 0.5% dry, 2.7% Carr., 2% Sol.
- ■ ■ ■ 0.5% " , 1% " , 1% Time
- ---- 0.5% " , 1% " , 1% Cuireo
The sauerkraut juice concentrated to 21 percent solids (three to one) was formulated with both Myverol 1800 at 0.3 percent and carrageenan at 1.4 percent and carboxymethyl cellulose at 1.4 percent. When the curves of the moisture loss were recorded (Figure 17) a dehydration rate of 3.3 gms. per minute and 2.9 gms. per minute respectively were calculated.

The effect of the amount of air pumped through the dehydration cabinet was illustrated by the curves found in Figure 18. The formula sauerkraut juice, 0.3 percent Myverol 1800 and 0.7 percent carrageenan was subjected to this variable. With all other conditions standard, the moisture loss rate at an air input rate of 9.5 liters per second was 3.3 gms. per minute, at 11.8 liters per second it was 3.8 gms. per minute, at 12.6 liters per second the rate was 4 gms. per minute.
Figure 17.
Graph of Degradation Cabinet Load Versus Time for Roasted Concentrated Caffeine. 0.5% Caffeine.
Figure 18. Graph of Dehydration Cabinet Load Versus Time for Foamed Sauerkraut Juice at Various Air Velocities.
DISCUSSION

Selection of Additives

During the preliminary consideration of this investigation the reference to the fact that a pure liquid cannot be made to form a bubble (6) together with the knowledge that present foam mat drying systems require a solution containing considerable soluble solids content as substrate for the foam led to the hypothesis that a foam could be made which would resemble the foams now in use. This hypothesis was predicated on the summation by Bikerman (6), that the character of a bubble or of a foam is related to the viscosity and the surface tension of the film surrounding the air particle. Therefore, creation of a system based on sauerkraut juice and simulating the surface tension and viscosity of food products that can be made to produce a stable foam should be possible by using some quantity of additives having the ability to induce alteration of these characteristics of sauerkraut juice to desirable levels.
The major problem anticipated was the effect of relatively high salt and acid content of sauerkraut juice. This was due to the theoretical foam inhibiting qualities of both of these ingredients. This theory was substantiated and expounded upon by Berkman (2) and Jest (34) and subsequently verified in this report (Appendix, Table 2).

A search was instigated for additives which exhibited some resistance to these adverse situations. The results of this search conducted by the methods previously explained were depicted in Figure 2 and Table 1 for those items which exhibited the greatest resistance to the inhibition of the anticipated activity of sauerkraut juice.

The most acceptable foaming agent found was a glycerol monostear of hydrogenated lard, Myverol 1800. Literature references to this product refer to it as a foam stabilizer. In the present work, however, it is considered a foam inducer.

Among the viscosity attenuating materials tested carrageenan exhibited the highest viscosity. Guar
gum was second in its magnitude of effect but the system appeared to develop a precipitate or agglomerate of some fraction, of either the gum or the juice. Carboxymethyl cellulose was next in order of effect, and although its effect was relatively low, it was selected as an additive in preference to guar. In the light of subsequent results it appears that the viscosity registered by the agent tested is not sufficient criteria for the acceptance or rejection of the item. This evaluation does, however, indicate the compatibility of the material with sauerkraut juice.

Preparation of the Mix

Preparation of the mix for the foaming operation was subject to many operational variables such as temperature, heating rate, cooling rate and the intensity of agitation during heating and cooling which affected the suitability of the foam produced for the subsequent cratering and dehydrating operations.

Temperature Effect

The influence of temperature seemed to be the most critical and was the only one documented herein,
Figure 4. The extremely narrow range of the heating end point temperature that would produce a mix that would result in a satisfactory foam that would permit any degree of reproducibility might have been due to the attenuation of Myverol by carrageenan and carboxymethyl cellulose although the diverse nature of these two products made such attenuation difficult to understand.

The effect of heating rate and/or cooling rate and/or duration and/or intensity of agitation were observed usually as interactions of two or more related variables. These variations were usually caused by mechanical, electrical or hydraulic failure, and any such variation could be noted as an aberration from a normal mixing procedure by a difference in the torque time curve recorded by the foaming device. The variation in the torque time values resulted in an observable difference in the results of the cratering operation.

The Foaming Process

The torque-time records of the foaming process added several dimensions to the art of foam pro-
duction not noted in any literature on the subject. For one, it made possible a continuous recording of the progress of foam generation, existence and decay. Interruption of the foam generation process for purposes of sampling or observation resulted in a change in the character of the foam, Figure 19. This recording, indicating system facilitated cessation of the process so that the next step could be carried out as soon as the maximum effect of the additives and aeration had been achieved.

The character of the foam as interpreted by this device related to foam density or specific gravity and to foam viscosity or rigidity. A heavy foam, for example, that had a specific gravity of 0.5 afforded only a small area of contact with the container in which it was being foamed. The area of contact of this type foam with the wires of the whip was relatively very small. This resulted in a low torque reading even though the foam might be almost pudding like in texture. Conversely, a light foam with a specific gravity of 0.2 nearly filled the container and increased the contact.
Figure 19. Effect of Interruption of the Foaming Operation on Torque-Time Values for 0.4% Lyverol-0.7% Carboxymethyl Cellulose Formula.
area greatly. This resulted in a high torque reading.

This effect was further magnified by the tension of the walls of the individual bubbles in the foam which increased as the film of the bubble became thinner as a result of the increased surface area of the original volume of liquid (6 - Chapter 5).

Foam stability was related to the bubble size (4). Bubble stability increased with decrease in size (15). Therefore, the reading in torque related to stability of the foam if the strength of the bubble film was sufficient to prevent coalition of the bubbles. This feature was interpreted by the period of duration of the torque attained.

The values in terms of time - torque for carrageenan and carboxymethyl cellulose formulations through the foam generation and decay cycles are related in Figure 20.

This curve for some formulations was very short, Figure 5, Myverol 0.7 percent carrageenan 0.3 percent was a curve of such a nature.
The foams produced from a number of formulations appeared to have the characteristics necessary for successful cratering and dehydration, but the torque - time curve did not compare favorably with curves for foams which had been successfully cratered and dehydrated. Subsequent evaluation by attempting to process these foams to dryness proved that subjective evaluation was wrong. After the torque - time parameters were established, Figure 21, they could be relied upon without failure to determine the suitability of the foam for subsequent operations.

These parameters, established by superimposing on a single recorder chart all the torque - time recordings of those foams that ultimately resulted in a satisfactory dehydrated product, are represented in Figure 21 by cross hatched area and two lined areas through which all such recordings passed and in which they had a residence time of at least six minutes.

The position of the torque - time curve in the cross hatched area is related to the suitability of the foam for the system used. A curve near the central por-
Figure 21. Standard Torque-Time Chart for Modified Hobart C-4 Mixer Illustrating Area of Torque-Time Relationship for Dehydratable Foam.

- Preferred Area
- Marginally Acceptable Area
tion represents a foam of good quality in regards to craterability, residual moisture content of product and hygroscopicity of product. Foams that developed a curve near the top of the indicated area tended to be unnecessarily stiff while those near the bottom of the area tended to be soft as a foam and more hygroscopic as a powdered product. A foam recording in the lined areas invariably exhibits these adverse characteristics.

**Evaluation of Foam Characteristics**

The review of the literature had led to the belief that determination of foam drainage was a necessary feature of characterizing a foam for dehydration (15,19,21) with the systems examined in this investigation foam drainage at temperatures from room temperature (20° C.) to dehydrating temperatures (80° C.) was not a factor worthy of consideration.

Preliminary work showed that foams, which could be cratered and dehydrated, might or might not drain to a minor extent over a period of several hours.

Specific gravity determinations were made, Figures 9 and 10, Tables 2 and 3. These values were general-
ly in good agreement inversely with the maximum torque value achieved by the particular foam during the foaming process, but could not serve as an index of craterability of the foam. This agreed with the literature concerning foams produced from high solids content substrate (1, 3, 5).

**Viscosity of Foam**

The viscosity of the foam and the change in the viscosity with time, Figures 11 and 12, was determined by the Brookfield Viscosimeter indicated that foams that could be cratered registered a viscosity in the range of 12 to 26 centipoise. The rate of decay, i.e., the change of viscosity with time was generally less for carrageenan stabilized foams than for carboxymethyl cellulose stabilized foams. These values, however, could not be related to the degree of suitability of the foam for processing.

**Craterability of the Foam**

The index of the craterability of the foam, Plate 7, although highly subjective did serve as a valuable guide to the nature of the product in the final condition in which it was presented to the dehydrator. The
index number one represented a condition of the foam which obviously was impossible to dehydrate as a cratered mat with the system available. Index two was representative of a foam that could be dehydrated, but experience showed that such dehydrated products were usually more hygroscopic than products from a foam of index three character, which would dehydrate to a porous stable sheet. An index four foam was considered stiffer than necessary and an index five foam would fracture and frequently blow off of the tray instead of cratering.

It was noted that on occasion a foam observed to be cratering in a condition between index two and three at a given air velocity could be degenerated to an index one by excessively high air velocities while cratering, but that lowering the velocity of the air might permit the foam to crater at an index of three. This phenomenon seemed to relate to a condition that might be described as shock resistance or susceptibility.

The craterability of the foams that indexed at three were foams that always satisfied the requirements of the preferred area of the torque - time area depict-
ed in Figure 21. These foams would always dehydrate to a satisfactory product in the system used.

**Dehydration**

Dehydration of cratered foam was reported to be very rapid (3, 7, 23). Times required to dehydrate foam-ed high solids products were listed as ranging from 9 to 23 minutes residence time on a belt or on trays in different types of dehydrating systems. This speed together with the inherent variables of any dehydrating system made the likelihood of good accuracy in determining dehydration rates without a large investment in highly sophisticated equipment seem rather remote.

In as much as this investigation was not concerned with absolute dehydration rates but only with the relative rates for the various formulas, elimination of the speed factor seemed in order. The dehydration cabinet design permitted making use of the advantages of the crater method of operation by stacking the trays reasonably spaced one above another, the time element involved was increased by a factor of about five. The potential influence of the dehydrator load variation
due to the difference in specific gravity of different products on the trays was negated by operating the de­hydration system at conditions far in excess of the maximum requirements that could be anticipated. Test runs with the load factor as the only variable confirmed that within the load variations possible in practice this factor was negligible.

Product Formulation

Formulas containing a given carboxymethyl cellulose - Myverol ratio typically lost moisture more rapidly than the same formula ratio containing carrageenan. The product dried to equilibrium with a higher residual moisture (Appendix, Tables 2 and 3).

Any formula consisting of a greater quantity of Myverol than carboxymethyl cellulose or carrageenan was hygroscopic. This principle was found to decrease with a decrease in the ratio of Myverol to the other additive. As the ratio passed the one to one point, hygroscopicity decreased and the dehydration equilibrium moisture decreased. A ratio of three to seven for carrageenan and a ratio of four to seven for carboxymethyl cellulose
produced the best drying rates to the lowest residual moisture for products having the lowest additive to raw material ratio for single strength juice.

The addition of sauerkraut solids to the formulations appeared to be worthy of consideration as this produced a product of superior drying characteristics on the basis of dehydration rates and residual moisture. The finely ground solids as an additive resulted in the highest dehydration rate experienced in this investigation. The presence of added solids apparently minimized the usual differences noted between drying rates but not equilibrium moisture of carboxymethyl cellulose and carrageenan formulas. Attempts to use greater quantities of solids were not reproducible due to mechanical limitations of the mixing device.

The use of concentrated juice appeared to be advantageous when used in conjunction with carrageenan. However, the difficulty of concentrating the juice made this aspect of the process seem undesirable.

Implications for Further Work

Due to the tremendous number of possibilities
in formula variation as well as the task involved in establishing operational procedure using the equipment designed and built to initiate the investigation. The formulations were evaluated in increments of 0.1 percent. Because of effect functions, the parameters should next be evaluated in terms of 0.01 percent increments within the parameters established by this investigation.

In light of information obtained on the change of character with time at a single speed and type of foaming device for this foam system, it would seem desirable to evaluate this system at other speeds of this device and with other types of foaming devices.

Optimum dehydration conditions should be established for this product.
SUMMARY AND CONCLUSION

This investigation had as its objective the development of a procedure for the production of dehydrated sauerkraut juice using the principle of foam mat dehydration.

The method developed consisted of defining the parameters for formulating a mix containing Nyverol 1800 and carboxymethyl cellulose or carrageenan. The mix was heated in a blender to 63°C, subjected to an intense shear rate for one minute and rapidly cooled to 27°C.

This mix was then foamed in the bowl of a Hobart C-4 mixer altered to record the torque developed during the foaming process.

This foam was trayed, cratered and dehydrated at 80°C, to produce sauerkraut juice solids containing less than 8 percent moisture.
The principal conclusions drawn from this study were as follows:

1. A process has been developed to utilize a product ordinarily discarded in the manufacture of canned sauerkraut. Uses for the product appear to be multitudinous.

2. At least two additive systems can be used to produce foam mat dried sauerkraut juice solids and this product can be produced with either additive system using either single strength or concentrated juice and comminuted sauerkraut solids can be added to the juice during formulation.

3. A modification of a Hobart C - 4 mixer can be used to produce and simultaneously record the character and progress of the production of a sauerkraut material foam beginning with a properly prepared mix.

4. The device used to record the foam characteristics proved satisfactory for predicting the suitability of the foam for foam mat dehydration in the system used and provided instantaneous information relative to the optimum time of whip at which to proceed to the next operation in the production schedule or to measure characteristics of the foam by other methods.
APPENDIX
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Table 2. Data For Treatments of System epoxyol 1800 - Carrageenan.

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<td>4.73</td>
</tr>
<tr>
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<td>Concentrated Juice</td>
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</tr>
<tr>
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<td>Heat 62°C</td>
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<td>5.50</td>
</tr>
<tr>
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<td>0.233</td>
<td>4.60</td>
</tr>
<tr>
<td>0.4 0.2</td>
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<td>2.20</td>
</tr>
<tr>
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<td>3.20</td>
</tr>
<tr>
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<td>1% Solids</td>
<td>0.240</td>
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</tr>
<tr>
<td>0.5 0.5</td>
<td>1% Solids</td>
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<tr>
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<td>1% Solids</td>
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<tr>
<td>0.6 0.7</td>
<td>1% Solids</td>
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<tr>
<td>0.3 0.7 2% NaCl-2% Lactic Acid-H2O</td>
<td>0.775</td>
<td>0.17</td>
<td>1.7</td>
</tr>
<tr>
<td>0.3 0.7 Distilled Water</td>
<td>0.151</td>
<td>140</td>
<td>22.0</td>
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</table>
BIBLIOGRAPHY


9. Geisman, J. R., Ohio State University, Personal Communication.


