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SEPARATION, FRACTIONATION, CONCENTRATION,
AND DRYING OF FOOD PRODUCTS

Final Report for the Period March 4, 1987—March 31, 1988

By
C. A. Merlo
W. W. Rose
L. D. Pedersen
P. L. Brewbaker

March 1988

Work Performed Under Contract No. AC07-84ID12553

For
U. S. Department of Energy
Idaho Operations Office
Idaho Falls, Idaho

By
National Food Processors Association
Dublin, California

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Idaho Operations Office, Idaho Falls, ID
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Washington D. C.

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ABSTRACT

This project studied energy efficient processes for separation, fractionation, concentration, drying, and recombination of food products, in order to reduce energy requirements for processing, preservation, and transportation.

The project had three phases. In the laboratory-scale phase, results of which are summarized in this report, tomato puree was separated by three methods: conventional vacuum filtration, centrifugation, and crossflow microfiltration to produce pulp and serum. Three methods of recombination were examined: homogenizing, stomacher blending, and static (in-line) mixing. Satisfactory recombined purees were obtained. In addition, after centrifugation, the pulp was rinsed producing rinsed-pulp, and the rinse water was added to the serum producing rinse/serum. The rinse/serum was concentrated by evaporation. This was recombined with the rinsed-pulp and water producing satisfactory puree.

In the larger-scale phase, results of which are also summarized in this report, puree was separated by decanter centrifuge, the pulp was rinsed producing rinsed-pulp, and the rinse water was added to the serum producing rinse/serum. The rinse/serum was fractionated by ultrafiltration into different molecular weight fractions. Some of the fractions were concentrated by evaporation and were recombined successfully with the rinsed-pulp and water. Some rinsed-pulp was dried by drum dryer producing a low hygroscopy product. In addition, some preliminary work was done with fresh juice.

In the on-site phase, results of which are reported in detail in this report, fresh juice was separated by decanter centrifuge into serum and pulp. The serum was preconcentrated by hyperfiltration prior to further concentration by pilot scale evaporator. The pulp was frozen until after use in recombination with the concentrated serum and water. The recombined purees were potentially acceptable when compared to control made from paste and water. A storage study is continuing of the concentrated serum, control paste, and recombined and control purees.

EXECUTIVE SUMMARY

This study was undertaken to assess the potential for developing more energy efficient technology for processing, containerizing, and transporting of juice products.

Container manufacturing and product transportation consume significant energy in conjunction with food production. Evaporation is presently used to concentrate food products, especially juice products; however, a large fraction of the final product is water, which is packaged and shipped with the food product. For example, tomato paste, which is produced by concentrating tomato juice from 5% total solids to approximately 30% total solids, is approximately 70% water. Technical and economic limitations prevent evaporation from concentrating food products further.

In the laboratory-scale phase of this project, summarized in this report, canned tomato puree was separated by conventional vacuum filtration, centrifugation, and crossflow microfiltration to produce a pulp fraction and a serum fraction. The resulting fractions from each separation were characterized. The pulp and serum fractions were recombined by homogenization, stomacher blending, and static (in-line) mixing; the viscosities of the resulting recombined tomato purees were determined and compared to the viscosity of the original canned puree. In the laboratory-scale study, viscosity was used as the most important quality characteristic of tomato puree. Centrifugation (for separation) followed by homogenization (for recombination) produced a recombined puree with viscosity equivalent to that of the original puree. In subsequent laboratory-scale studies, the pulp fraction was rinsed with water to recover the soluble components of the pulp (producing a rinsed-pulp fraction), and the rinse water was added to the serum fraction (producing a rinse/serum fraction).

The rinse/serum fraction was then concentrated by vacuum evaporation to produce a concentrated-rinse/serum fraction (50% and 21% total solids [TS]). The resulting fractions were characterized. The rinsed-pulp and concentrated-rinse/serum fractions were recombined (with water) by homogenization; satisfactory puree was produced.

In the larger-scale phase of this project, summarized in this report, the following fractionation sequence was investigated. Canned puree was separated by centrifugation and the resulting pulp fraction was rinsed to produce a rinsed-pulp fraction. The rinse water was added to the serum fraction to produce a rinse/serum fraction. The rinse/serum fraction was 1) concentrated by vacuum evaporation to 13% TS, or 2) fractionated by ultrafiltration (with a 100,000 molecular-weight-cutoff membrane) to produce a high-molecular weight (MW) fraction and a low/intermediate-MW fraction. The resulting low/intermediate-MW fraction was then further fractionated by ultrafiltration (with a 2000-MW-cutoff membrane) to produce a low-MW fraction and an intermediate-MW fraction.

The low-MW fraction was fractionated by ion exchange into organic acid and sugar components.

The low/intermediate-MW fraction (pre-ion-exchange) was concentrated by vacuum evaporation to 74% TS.

Recombined puree was produced by homogenizing concentrated rinse/serum (13% TS) with pulp and water, and by homogenizing concentrated low/intermediate-MW fraction, high-MW fraction, and water. The viscosity of these purees was close to the baseline puree; colors were lighter, less red, and yellower.

The larger-scale study also included fractionation/recombination studies using fresh tomato juice. In the fresh juice studies, a puree containing 11% TS was produced by vacuum evaporation to serve as a baseline so that the viscosity measurement commonly used by industry (Bostwick) could be used to assess product quality. The fresh juice was centrifuged to produce a pulp fraction and a serum fraction. The pulp fraction was not rinsed in the fresh juice studies. The serum fraction was concentrated by vacuum evaporation to 13% and 70% TS. Upon static mixing or homogenizing the pulp, concentrated serum (13% TS), and water, a satisfactory recombined puree was produced. Upon homogenizing the pulp, concentrated serum (70% TS), and water, a darker but otherwise satisfactory recombined puree was produced.

Rinsed-pulp was dried successfully on a drum dryer resulting in a low hygroscopy product. Drying of the pulp needs to be examined more thoroughly due to the continued need to have satisfactory methods for storing this fraction.

In the on-site phase of this project, which is described in detail in this report, a decanter centrifuge successfully separated fresh tomato juice into pulp and serum. The serum (5% TS) was concentrated by hyperfiltration to 10% TS, and then by pilot scale evaporator to 41 to 60% TS. The concentrated serum was tested for its ability to support growth of yeast, the most likely spoilage organism for this food product. The yeast had difficulty growing in serum greater than 55 to 60°Brix, indicating the concentrated serum may be self-preserving. A storage study is on-going to determine the quality of the concentrated serum after storage, as well as the quality of the recombined products after storage.

The on-site study also included comparison testing of evaporation of serum versus whole juice. Water was removed at a ~15% faster rate from the serum versus the whole juice, indicating increased productivity in the evaporation process.

Recombined purees were made by homogenizing concentrated serum (41 to 62% TS), frozen pulp, and water. This was compared to a control made by statically-mixing paste and water. The recombined purees generally had acceptable viscosity, syneresis close to the control, and color that was lighter, slightly less red, and more yellow than the control. Thermally processed control and recombined purees were evaluated and the recombined purees were found to have smoother texture and "flatter" or "greener" flavor than the control, but was deemed potentially acceptable. The on-going storage study will evaluate quality of the control and recombined purees after storage.

The laboratory-scale study (Phase I) and the larger-scale study (Phase II) are summarized in this report. Details of these studies are contained in a previous report, W. W. Rose et al, Separation, Fractionation, Concentration and Drying of Food Products, Technology Progress Report for the Period October 1, 1984-March 3, 1987), DOE Report No. DOE/ID/12553-1. This report is available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161. The NTIS order number is DE88006269, November 1987 and the price code for a printed copy is A06.

TABLE OF CONTENTS

	<u>Page</u>
Abstract.....	i
Summary.....	111
List of Figures.....	viii
List of Tables.....	ix
Acknowledgements.....	x
Introduction.....	1
Equipment and Analytical Procedures.....	5
Testing Procedures and Results.....	16
Separation.....	16
Laboratory-Scale Study.....	16
Larger-Scale Study - Centrifugation.....	19
Puree Study.....	19
Fresh Juice Study.....	19
On-Site Study - Centrifugation.....	21
Fractionation.....	21
Larger-Scale Study.....	21
Ultrafiltration.....	21
Ion Exchange.....	24
Concentration.....	26
Laboratory-Scale Study.....	26
Larger-Scale Study.....	26
Rinse/Serum Concentration.....	27
Ultrafilter Permeate Concentration.....	27
Fresh Juice Serum Concentration.....	27
On-Site Study.....	27
Hyperfiltration of Serum.....	27
Evaporation of Serum.....	28
Storability (Microbial Resistance).....	32
Efficiency of Evaporation (Juice vs. Serum).....	35
Pulp Preservation.....	37
Larger-Scale Studies - Drying.....	37
On-Site Study - Freezing.....	39
Recombination.....	42
Laboratory-Scale Study.....	42
Larger-Scale Study.....	51
Puree Study.....	51
Fresh Juice Study.....	51
On-Site Study.....	53
Economic/Energy Analysis	62
Conclusions and Recommendations.....	67
References.....	70
Appendix A - Abbreviations.....	71
Appendix B - Metric to English Conversion Table.....	72

LIST OF FIGURES

<u>No.</u>		<u>Page</u>
1	Separation, fractionation and concentration schematic.....	3
2	Recirculation mode operation.....	6
3	Batch mode operation.....	6
4	Continuous mode operation.....	9
5	Tomato serum pressure scans at 68°C, 5% TS.....	29
6	Tomato serum temperature scans at 4 MPa, 5% TS.....	29
7	Tomato serum concentration scans at 71°C, 4 MPa.....	30
8	Flux versus time for 5% TS tomato serum, 70°C, 4MPa, Module 1.....	30
9	Tomato serum Brix versus water activity (A_w) and % acidity.....	33
10	Tomato Serum Brix versus % acidity.....	33
11	Approximate condensate volume versus time of evaporation for tomato juice and serum at 68°C, 25 to 36 in. Hg vacuum.....	36
12	Hygroscopy - weight gain (%) versus time in tropical room, 82°F, 80% relative humidity.....	40
13	Hygroscopy - weight gain (%) versus time in prairie room, 70°F, 45% relative humidity.....	41
14	Bostwick viscosity (cm) versus stomacher mixing time (min) for unseparated puree (10.8% NTSS).....	48
15	Bostwick viscosity (cm) versus homogenizing time (min) on unseparated puree (10.2% NTSS).....	49
16	Bostwick viscosity (cm) versus homogenizing time (min) on unseparated puree (9.2% NTSS).....	49
17	Bostwick viscosity versus Brix of puree from paste.....	55
18	Color versus Brix of puree from paste.....	55
19	Alternative processes and associated energy usage.....	63

LIST OF TABLES

<u>No.</u>		<u>Page</u>
1	Ultrafiltration Membrane Specifications.....	8
2	Separation Methods.....	17
3	Characterization of Puree and Separated Fractions - Laboratory-Scale Study.....	18
4	Characterization of Puree, Juice, and Fractions - Larger-Scale Study.....	20
5	Characterization of Juice and Fractions - On-Site Study.....	22
6	Characterization of Fractions - Larger-Scale Study.....	23
7	Mass Balance.....	25
8	Evaporation of Serum.....	31
9	Pulp Drying Results.....	38
10	Results of Static Mixer Recombination with Three Separation Techniques - Laboratory-Scale Study.....	44
11	Results of Stomacher Recombination with Two Separation Techniques - Laboratory-Scale Study.....	45
12	Results of Homogenizer Recombination with Three Separation Techniques - Laboratory-Scale Study.....	46
13	Results of Recombinations with Conc. Rinse/Serum and Rinsed-Pulp - Laboratory-Scale Study.....	50
14	Results of Recombinations - Larger-Scale Puree Study...	52
15	Results of Recombinations - Larger-Scale Juice Study...	54
16	Results of First and Second Recombinations - On-Site Study.....	57
17	Results of Third Recombination - On-Site Study.....	59
18	Results of Fourth Recombination (Hot Fill) - On-Site Study.....	59
19	Energy Use by Operation in Alternative Processes.....	64
20	Energy of Combined Processes versus Traditional Process.....	66

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INTRODUCTION

In 1970 the food processing industry used approximately 3.3 quads of energy for all aspects of food processing, including energy for processing the food, manufacturing paper, glass, and metal containers, transporting food products, and manufacturing processing machinery and trucks and trailers for transportation. Of this total, almost half the energy was used for manufacturing metal containers and for transporting food products (Loftness, 1978). Transportation and containerization of the final product are major costs associated with food processing.

With the trend toward fewer and larger processing plants and the increased reprocessing of food products into convenience foods at secondary processing plants, energy use and respective cost for transportation is increasing at a faster rate than is energy use in food processing plants. This is especially true of tomato and fruit juice concentrates which are shipped from initial processing plants to reprocessing plants for production into such products as tomato catsup, single strength fruit juices, or blended fruit juice beverages in consumer size containers. Such products have undergone initial production and preservation processing, and a second manufacturing and preservation operation before distribution to consumers.

In order to reduce the processing and transportation costs, juices are concentrated in plants near the source of the raw product and reconstituted at a production plant closer to the consumer. Currently tomato, peach, apricot, and pear juices can only be concentrated to 30 to 45% total solids. However, a significant amount of water still remains in the concentrated product. Further concentration cannot be obtained due to the level of insoluble pulp which affects pumpability and evaporation. However, by first separating juice into pulp and serum fractions, it may be possible to reduce water content further and still produce high quality concentrates.

If the juice is separated into pulp and serum, each fraction can be processed separately and transported to a distant site for recombination (Fig. 1). The serum can be concentrated to a higher level than is possible with whole juice, thus eliminating additional transport of water. Or, the serum could be fractionated by ultrafiltration into different molecular weight fractions. Ion exchange might be used for further fractionation. Each fraction could be handled separately and differently. Thus, the fractions with more heat-sensitive components could be concentrated by evaporation at lower temperatures; those fractions with less heat-sensitive components could be concentrated at higher temperatures. Higher levels of concentration may be obtained with each fraction, than could be obtained with the whole juice. Sugars and organic acids may be separated from the fractions by ion exchange, and may not need to be transported with the other fractions. Recombination may then use locally available sugar, organic acids, and water.

The pulp may be preserved by canning or aseptically packed. Or it may be dried to further eliminate more water, and reduce energy for transportation and its cost.

After the juice is separated into fractions, concentrated, and transported, the fractions are available to be recombined to produce conventional, and also perhaps new, food products. This new product potential may expand the capability of the food processor, thus making implementation of this approach even more attractive.

This proposed approach may be applicable to the processing of tomato, orange, peach, apricot, pear, apple, and grape juices. Significant energy savings could result in several segments of the juice processing industry due to decreased energy for transportation.

Figure 1 - Separation, fractionation, and concentration schematic.

The overall objective of this project was the development of energy efficient separation, fractionation, concentration, and recombination processes for food products in order to reduce processing, preservation, and transportation energy requirements and their associated costs. While the work was done with tomato juice, the concept may be applied to other juices as well.

EQUIPMENT AND ANALYTICAL PROCEDURES

EQUIPMENT

The following equipment was used for fraction separation in the Laboratory-Scale Study:

Centrifuge - Sorvall RC-5B and SS-3 centrifuges with GSA rotors were used for separation by density. These centrifuge heads, when operated at 12,000 rpm, have a g-force (relative centrifugal force) of approximately $19,000 \pm 4000 \times g$ (gravity), and when operated at 9500 rpm, have a g-force of approximately $12,000 \pm 2700 \times g$.

Conventional Filter - A conventional filter allowed separation by size. This consisted of a milk filter disc, 38 μ m pore size in a Buchner funnel. Vacuum was used to drive the separation.

Microporous Filter - A ceramic microfilter (Norton Co.) also separated by size. Modules with 1.0 μ m and 0.2 μ m pore sizes were used. Each module (2.5 cm x 40 cm) contained eight ceramic tubes (2.8 mm ID) in a shell and tube configuration. The total surface area was 0.3 ft² per module.

Three different pumping units were used with the microporous filter: a Rannie A3 piston pump, a portable pumping unit (CARRE, Inc.) with a centrifugal booster pump and a 3 hp high pressure diaphragm pump, a lab top pumping unit (Norton Co.) employing an external gear pump (Indiana General).

Two modes of operation were used. Recirculation mode (Fig. 2) was run with permeate and concentrate returning to the feed tank. Batch mode (Fig. 3) was run to effect concentration, with concentrate returning to the feed tank and permeate going to a permeate holding tank.

Figure 2 - Recirculation mode operation.

Figure 3 - Batch mode operation.

The following equipment was used for separation in the Larger-Scale Study and On-Site Study:

Decanter Centrifuges - A Westfalia Model CA 220-110 Decanter was used for separating tomato puree in the Larger-Scale Study. This centrifuge has a maximum g-force of ~3500. A similar decanter centrifuge was used for separating tomato juice in the On-Site Study.

The following equipment was used for fractionation in the Larger-Scale Study:

Ultrafilter - A DDS/Niro Lab 20 Module with Rannie A3 piston pump was used. This is a plate and frame type module. Membranes used include:

2000-MW-cutoff value, Type GR90PP (polysulfone)
100,000-MW-cutoff value, Types GR40PP (polysulfone) and PES-100 (polyether sulfone) (See Table 1 for specifications.)

Each membrane had 0.195 ft^2 (0.018 m^2) surface area.

Three modes of operation were used:

Recirculation mode and batch mode were run as described under Microporous Filter in the Laboratory-Scale Study Equipment section (Figs. 2 and 3).

Continuous mode (or feed and bleed) was run initially in batch mode to increase the concentration of the retentate to the level where the permeate SS (soluble solids) equalled the original feed SS. Then batch mode operation was continued, but with feed added periodically to the feed tank in amounts equal to the volume lost to permeate (Fig. 4). This was done to increase the amount of constituents passing through the membrane without diluting the permeate.

TABLE 1. ULTRAFILTRATION MEMBRANE SPECIFICATIONS

Membrane Type	Component Type	Approx. MW-Cutoff Value	pH	Recommended Operation Limits			
				Temperature		Pressure	
				°C	°F	MPa	psi
GR40PP	Polysulfone	100,000	1-13	0-75	32-157	0-1	0-145
PES100	Polyethersulfone	100,000	NA	0-75	32-167	0-0.7	0-100
GR90PP	Polysulfone	2000	1-13	0-75	32-167	0-2	0-290

Figure 4 - Continuous mode operation.

Ion Exchange - Anion exchange resins, IWT SM-73 and IWT A-399b (Illinois Water Treatment Co.), were used for removing organic acids from sugars. The columns used were 2.3x27cm and 1.9x35cm respectively.

Cation exchange resin, IWT C-391b, was used to convert organic acid salts to organic acids. The column used was 1.9 x 35 cm.

The following equipment was used for serum concentration:

Hyperfilter - Two Paterson Candy International, Ltd. B1 R.O. Modules were used with a portable pumping unit (CARRE, Inc.) consisting of a centrifugal booster pump and a 3 hp high pressure diaphragm pump. The modules were 12 ft (3.66m) long with 28 ft² (2.6m²) membrane surface area per module. The modules were connected in series. The membrane in the modules was an aromatic polyamide thin film composite designated as type ZF99.

Rotary evaporator - A Yamato Rotary Evaporator (Model No. RE-51B) and a Buchi/Brinkmann Rotovapor-R were used in connection with vacuum.

Pilot scale evaporators - A single effect Junior Plate Evaporator (APV) was used. A generic single-effect evaporator and a small generic single effect evaporator were also used.

The following equipment was used for pulp drying:

Drum dryer - A twin drum laboratory dryer (Blau-Knox Co., Buflovak Equipment Div., Model ALC4) was used. The dryer has two drums (6 in. diameter, 8 in. long) which are driven by a Graham transmission model 175BR5. The drums are heated internally by saturated steam. The nip setting on the drums was adjusted to vary the film thickness.

The following equipment was used for recombination of fractions:

Homogenizer - A Brinkmann Homogenizer PT-35 (also known as Polytron) with a PT-35/K probe generator which runs at 0-20,000 rpm was used. The homogenizer combines ultrasonic energy with mechanical shearing.

Static Mixer - A static mixer (Komax Systems, Inc.) was used. This inline mixer (1.2cm x 28cm) uses multivaned elements to divide and recombine a flowing process stream. Product flow was driven by a peristaltic pump (Sigmamotor T6S) at 0.5 gpm.

Stomacher - A Stomacher 80 laboratory blender (Dynatech Labs., Inc.) provided mixing by the action of two reciprocating paddles on a Whirl-pak bag. This instrument is commonly used for mixing in the laboratory.

ANALYTICAL PROCEDURES

1. Natural tomato soluble solids (NTSS) - This is defined as the reading obtained on a refractometer at 20°C, expressed in percent sucrose, of the serum from the sample. Samples were analyzed with a Bausch and Lomb 33-45-58 refractometer (Lamb, 1969, 1977). Some samples were analyzed using an AO Hand Refractometer Model 10430. For some testing the term °Brix is used interchangeably with % NTSS, since Brix can be read on the sugar scale (% sucrose) of a refractometer.
2. Gross viscosity - The Bostwick procedure was used (NCA, 1968). In this test a low centimeter (cm) value indicates a high viscosity value.

3. Total Solids (TS) - Total solids were determined by drying at 70°C under vacuum for 4 hours (NCA, 1968). Samples were also analyzed using a microwave drying moisture solids analyzer (CEM Corp.) following the method of Chin et al. (1985).
4. Filtered Total Solids (FTS) - Samples were centrifuged with a Sorvall centrifuge at 10,000 rpm for 20 min. Supernatant was filtered with a Gelman Type A-E glass fiber filter. The filtrate was analyzed for total solids by the vacuum oven method.
5. Soluble Solids (SS) - The soluble solids was calculated from the total solids and filtered total solids determined by the vacuum oven method:

$$\%SS = \frac{\%FTS (100\% - \%TS)}{(100\% - \%FTS)}$$

This equation is derived from the following three equations:

$$\%FTS = \frac{\%SS}{\%SS + \%H_2O}$$

$$\%TS = \frac{\%SS + \%IS}{\%SS + \%IS + \%H_2O}$$

$$100\% = \%SS + \%IS + \%H_2O$$

6. Insoluble solids (IS) - The insoluble solids was calculated from the total solids and soluble solids:

$$\%IS = \%TS - \%SS$$

7. Insoluble Solids to Soluble Solids Ratio (IS/SS) - This is a ratio commonly used in the tomato processing industry to assess the relative amount of insoluble solids to soluble solids. It is calculated:

$$IS/SS = \frac{\%IS}{\%SS}$$

8. Spin Down Solids - Sample (10ml) was placed in 15ml graduated centrifuge tube(s). The tubes were spun in an IEC clinical centrifuge No. L6520 at maximum speed for 3 or 10 min. (Time included acceleration time, but not deceleration time.) The solids that settled was read from the tube in ml and calculated to per cent spin down solids.
9. Syneresis (Serum Separation) - Sample (40 gm) was weighed into a tube (26 mm i.d.) with a 60 mesh screen on the bottom. The tube was suspended over a 50 ml beaker. At time intervals (0.25, 0.5, 1, 2, 3, 4, 5 hrs) fluid that had accumulated in the beaker was weighed. Value reported is the weight of fluid at 0.25 or 1 hr divided by 40 gms x 100. This method was adapted from the method of N. Stoforos (University of California, Davis).
10. Color - A Minolta Chroma Meter CR-100 was used. A beaker (150ml) was filled to the rim with sample. The meter's measuring head was equipped with the glass light projection tube and was immersed ~1cm into the sample. Measurement ($L^*a^*b^*$) was made. L^* is a measure of light/dark, the higher the number the lighter the color. a^* is a measure of red/green, the higher the number, the redder the color. b^* is a measure of yellow/blue, the higher the number the yellower the

color. (The instrument was set to make three measurements and record the mean value.) The measuring head was removed from the sample, cleaned, and dried. The measurement process was performed a total of 10 times, and the overall mean was reported.

11. Titratable Acidity - The electrometric titration method, using 0.02N and 0.1N NaOH to pH 8.1, was used (NCA, 1968). The results were presented as the anhydrous citric acid equivalent.
12. Serum Color - Serum color, as an indication of heat damage, was analyzed. The sample was diluted, filtered, and % transmittance was read on a Bausch and Lomb Spectronic 20 (NCA, 1968).
13. pH - pH meters (IBC Trophy Meter and Yokogawa Model PH51 Pocket pH Meter) were used.
14. Conductivity - A conductivity meter (Yokogawa Model SC51 Pocket Conductivity Meter) was used.
15. Sugars - A Bio-Rad high performance liquid chromatographic (HPLC) system with column heater and refractive index detector was used. An HPX-87C column (Bio-Rad) was used with the HPLC system. Samples were diluted 1:10, mixed thoroughly, centrifuged, and the supernatant filtered through a 0.45 micron filter.
16. Organic Acids - (See Sugars procedure for instrument used.) An HPX-87H column (Bio-Rad) was used. Samples were treated as for sugar analysis, but with an additional clean-up step: an aliquot was passed through a Bond-Elut PSA column, rinsed with methanol and with water, and then eluted with 2N HCl.

17. Pectin - Samples were analyzed in the following manner. Sugars were removed and the samples defatted as per Southgate (1969). Pectin was extracted by pectinase following McCready and McComb (1952). The uronic acids were determined colorimetrically using the method of Blumenkrantz and Asboe-Hansen (1973).
18. Protein - Samples were analyzed using the Kjeldahl method 2.055 - 2.057 (AOAC, 1984).
19. Lipid - Samples were analyzed using the Chloroform-Methanol Extraction method 43.276-43.277 (AOAC, 1984).

TESTING PROCEDURES AND RESULTS

Studies were performed with commercially-prepared tomato puree (8-14% NTSS) or fresh tomato juice. Commercially-prepared tomato puree was used because of its year-round availability and because its viscosity can be easily measured by means of the Bostwick procedure, a viscosity measurement procedure commonly used in the tomato processing industry.

Laboratory-scale, larger-scale, and on-site studies were performed in this project. The laboratory- and larger-scale studies are summarized in this report. Further information on these studies is available in Rose, et al (1987). The on-site studies are described in detail in this report.

SEPARATION

Laboratory-Scale Study

Canned tomato puree was separated into two fractions (pulp and serum) by three methods: centrifugation, conventional vacuum filtration, and crossflow microporous filtration (or microfiltration). Details of the three separation methods and separation obtained are given in Table 2. The fractions obtained by the three methods were characterized and results are given in Table 3. Of the three separation methods studied centrifugation provided the most complete separation on a weight basis, microporous filtration provided the second most complete separation by weight. Microporous filtration provided the most complete separation of pectin (Table 3).

Centrifuging and Rinsing. An additional study was performed with the centrifugation separation step. After centrifuging the

TABLE 2. SEPARATION METHODS

Method	Centrifuge ^a	Conventional ^b Filter	Microporous ^c Filter	Centrifuge ^d and Rinsing
Specifications	30 min 12,000 rpm	30 min 23 in. vacuum	1.0 micron 130psi, 64°C	40 min 9500 rpm
%NTSS Original	10.8	10.8	11.9	9.5
%Separation (by wt.)				
% Mass in Pulp	22	60	60	22
% Mass in Serum	78	40	40	78

^aSee: Equipment-Centrifuge-Sorvall

^bSee: Equipment-Conventional Filter

^cSee: Equipment-Microporous Filter, 5.3 gal/min feed flow rate

^dSee: Equipment-Centrifuge-Sorvall (Water equal to ~1/2 decanted serum volume was added to pulp, mixed (rinsing step) and recentrifuged. This rinsing step was repeated 5 to 6 times until %NTSS was <1%.)

*Natural Tomato Soluble Solids - See Analytical Procedures-1.

TABLE 3. CHARACTERIZATION OF PUREE AND SEPARATED FRACTIONS - LABORATORY-SCALE STUDY

I.D.	NTSS, %	Pro- tein, % w/w	Pectin, % w/w	Lipid, % w/w	Suc- rose, % w/w	Glu- cose, % w/w	Fruc- tose, % w/w	Citric Acid, % w/w	Malic Acid, % w/w	Pyroglu- tamic Acid, % w/w
<u>Puree</u>										
Centrifugation	10.8	1.79	0.75	0.20	<0.1	2.76	3.07	0.80	0.06	0.04
Conv.Filtration										
Microfiltration	11.9	2.00	0.86	0.32	<0.1	3.23	3.55	0.88	0.08	0.02
Centrifugation/Rinsing	9.5	1.66	0.63	NA	<0.1	2.63	2.92	NA	NA	0.17
<u>Serum</u>										
Centrifugation	10.8	1.43	0.60	0.03	<0.1	2.60	3.11	0.92	0.06	0.02
Conv. Filtration	10.8	1.50	0.44	0.06	<0.1	3.11	3.54	0.88	0.06	0.02
Microfiltration	11.6	1.49	<0.1	0.02	<0.1	3.73	4.10	1.04	0.08	0.02
Centrifugation/Rinsing (Rinse/Serum)	5.2	0.66	<0.1	NA	<0.1	0.81	0.91	NA	<0.02	0.01
<u>Pulp</u>										
Centrifugation	NA	2.90	1.17	0.66	<0.1	2.67	3.07	0.88	0.09	0.05
Conv.Filtration	NA	1.93	0.84	0.29	<0.1	2.72	3.16	0.96	0.13	0.08
Microfiltration	NA	2.54	1.39	0.62	<0.1	3.14	3.51	1.00	0.12	0.03
Centrifugation/Rinsing (Rinsed Pulp)	0.8	1.97	1.14	NA	<0.1	<0.1	<0.1	<0.1	<0.02	<0.01

NA means not measured.

puree, the pulp was rinsed producing rinsed-pulp and the rinse water was added to the serum to produce rinse/serum. The rinsing step was designed to remove components from the pulp which might be damaged if the pulp were dried (ie. sugars). Details of the process are given in Table 2. The rinsed-pulp and rinse/serum were characterized (Table 3).

Larger-Scale Study - Centrifugation: Puree Study

Canned tomato puree (320 lb [140 kg] was separated into pulp and serum by decanter centrifuge operating with a feed flow rate of 1 gal/min (3.8L/min) at $\sim 3500 \times g$ with slow scroll speed. Pulp was removed from the centrifuge (except what remained inside, because the decanter was not dismantled) and placed in a vat. Water (47°C) in weight equal to the weight of the serum was added to the pulp and mixed. This mixture was centrifuged as above. The rinsing procedure was repeated. The total weight of water used in rinsing was 480 lb (220 kg). The rinse water was added to the serum and this liquid was called rinse/serum. This separation procedure produced rinsed-pulp which was $\sim 15\%$ of the weight of the original puree weight. The rinsed-pulp and rinse/serum were frozen for later use. The puree and two fractions were characterized (Table 4).

Larger-Scale Study - Centrifugation: Fresh Juice Study

Fresh tomato juice (hot break = 210-200°F [99-93°C]) was obtained from a food processing plant along with pulp ($\sim 17\%$ by weight) and serum ($\sim 82\%$ by weight) produced from a decanter centrifuge operating on fresh tomato juice. The juice and the two fractions were characterized (Table 4). Pulp and serum were held under refrigeration for up to 1 week, while further procedures were performed at which time the pulp was frozen.

TABLE 4. CHARACTERIZATION OF PUREE, JUICE AND FRACTIONS - LARGER-SCALE STUDY

Sample I.D.	% of Total Mass	TS, % w/w	NTSS, % w/w	Pec- tin, % w/w	Pro- tein, % w/w	Fat, % w/w	ORGANIC ACIDS			SUGARS		
							Citric, % w/w	Malic, % w/w	Pyro- glu- tamic, % w/w	Fruc- tose, % w/w	Glu- cose, % w/w	Su- crose, % w/w
Puree	100	13.7	9.1	0.65	1.63	0.26	0.75	0.13	0.25	3.1	3.0	<0.05
Rinsed- Pulp	~15	12.1	0.8	1.47	2.04	0.64	0.14	0.02	0.02	<0.05	<0.05	<0.05
Rinse/ serum	- ¹	~4.0	4.0	0.19	0.65	<0.01	0.34	0.07	0.12	1.25	1.12	<0.05
Juice	100	5.9	5.0	0.32	NA	NA	NA	NA	NA	NA	NA	NA
Pulp	~17	11.2	5.4	1.31	NA	NA	NA	NA	NA	NA	NA	NA
Serum	~82	4.8	4.9	0.18	NA	NA	NA	NA	NA	NA	NA	NA

NA means not measured.

¹The rinse/serum consists of serum from the puree plus water, so % of total puree mass is not calculated.

On-Site Study - Centrifugation

Fresh tomato juice (hot break) was separated by decanter centrifuge into pulp and serum. Several runs were made. Pulp from two runs (Nos. 5 and 6) was frozen in plastic bags for later use. Results of juice, serum, and pulp characterization are given in Table 5. Separation obtained by weight was calculated to be 11-13% pulp and 87-89% serum in Run No. 5 and ~10% pulp and ~90% serum in Run No. 6.

FRACTIONATION

Larger-Scale Study

The rinse/serum produced from separation by centrifugation and rinsing was further fractionated by ultrafiltration and ion exchange into several fractions which were characterized (Table 6).

Ultrafiltration. (100,000-MW cutoff membranes) Two types of 100,000-MW cutoff membranes (GR40PP and PES100) were used to fractionate the rinse/serum fraction into high-MW (retentate) and low/intermediate-MW (permeate) fractions. Several batches were run in batch mode with 34 to 46 kg [9 to 12 gal] of rinse/serum. Runs were made at 25°C, 8L/min flow rate, ~100 psi (0.7 MPa) inlet pressure with 0.108m² membrane area of each membrane type.

About 65 to 74% of the sugar (by NTSS) and 66 to 77% of the acid in the rinse/serum permeated the membranes. The final retentate (high-MW fraction) weight was 17 to 28% of the initial feed weight. This amount was limited mainly by the pressure drop across the membranes and the maximum operating pressure of the PES100 membranes (100 psi, 0.7 MPa). The performances of both membranes were similar in flux and rejection, although the PES100 membranes were on the outlet end of the ultrafiltration module and thus experienced lower pressures for most of the testing, while the GR40PP membranes were on the inlet end and experienced higher pressures.

TABLE 5. CHARACTERIZATION OF JUICE AND FRACTIONS - ON SITE-STUDY

		Spin Down Solids					
Run		%	%	TS,	SS,	IS,	IS/
No.	Date	10 min	3 min	% w/w	% w/w	% w/w	SS
<u>Juice</u>							
1	8-4-87	--	--	6.04	4.86	1.18	0.24
5	9-11-87	--	--	5.79	4.80	0.99	0.20
6	10-7-87	--	--	4.63	3.61	1.02	0.28
<u>Serum</u>							
2	8-6-87	~0.9	~0.75	5.05	4.93	0.11	0.02
3	8-27-87						
	(dilut from 43 Brix)		5.0	4.88	4.75	0.13	0.03
4	9-4-87	~2.0	--	9.89	9.66	0.23	0.02
	(after HF)						
5	9-11-87	2.0-2.5	2.8-3.5	4.96	4.83	0.13	0.03
6	10-7-87	--	1	3.85	3.72	0.12	0.03
7	10-8-87	--	1.8	--	--	--	--
<u>Pulp</u>							
1	8-4-87	--	--	7.95	4.71	3.24	0.69
5	9-11-87	--	--	11.80	4.34	7.46	1.72
	(1st bag)						
5	9-11-87	--	--	10.75	3.91	6.85	1.75
	(2nd bag)						
6	10-7-87	--	--	12.40	3.42	8.99	2.63
	(1st bag)						
6	10-7-87	--	--	12.23	3.45	8.79	2.55
	(2nd bag)						

TABLE 6. CHARACTERIZATION OF FRACTIONS - LARGER-SCALE STUDY

Sample I.D.	TS, % w/w	NTSS, %	Pec- tin, % w/w	Pro- tein, % w/w	Fat, % w/w	ORGANIC ACIDS			SUGARS		
						Citric, % w/w	Malic, % w/w	Pyro- glu- tamic, % w/w	Fruc- tose, % w/w	Glu- cose, % w/w	Su- crose, % w/w
High- MW	5.6	~6	0.93	0.92	0.28	0.43	0.08	0.10	1.43	0.95	0.14
Low/ Int.-MW	3.5	3.5	0.02	0.53	<0.01	0.29	0.08	0.12	1.37	0.89	0.14
Concen. Low/Int.-MW	73.6	76	NA	NA	NA	NA	NA	NA	NA	NA	NA
Intermediate -MW	6.7	~7.2	0.19	1.05	0.04	0.55	0.16	0.14	2.51	1.63	0.07
Low-MW	2.8	3.2	<0.01	0.44	0.05	0.22	0.05	0.09	1.14	0.74	0.07
Sugars	NA	3.1	NA	NA	NA	0.09	0.07	0.04	0.27	<0.05	<0.05
Organic Acids	NA	NA	NA	NA	NA	2.13	0.14	0.01	<0.05	<0.05	<0.05

Refer to Fig. 1 for dereviations of these fractions.

NA means not measured.

Ultrafiltration. (2000-MW cutoff membranes) The low/intermediate-MW fraction was further fractionated by use of a 2000-MW cutoff membrane (GR90PP) into intermediate-MW (retentate) and low-MW (permeate) fractions. Several batches were run in batch and then continuous mode with 11 to 22 kg [3 to 6 gal] of low/intermediate-MW fraction. Runs were made at 23°C, 8L/min flow rate, 290psi (2MPa) inlet pressure with 0.18m² total membrane area. Approximately 78% of the sugar (by NTSS) permeated the membranes. The final retentate weight (intermediate-MW fraction) was ~11% of the initial feed weight.

The mass balance of the separation and ultrafiltration studies is calculated in Table 7. All of the total solids, sugars, and organic acids from the rinse/serum (+2.6%) were accounted for in the high-MW and low/intermediate-MW fractions after the first ultrafiltration step (100,000-MW cutoff). About 95 to 98% of the total solids and sugars, and 87% of the organic acids of the rinse/serum were accounted for in the high-MW, intermediate-MW, and low-MW fractions after the second ultrafiltration step (2000-MW cutoff).

Ion Exchange. The low MW-fraction was available for fractionation by ion exchange into sugars and organic acids. The purpose was to examine whether certain components (possibly sugars and/or organic acids) might be eliminated at the tomato processing plant, thus saving on containerization and transportation costs. These component(s) could then be obtained from local sources and added back at the point of remanufacture.

Separation of Low-MW Fraction.

The feed for this testing was the low-MW fraction (3.2% NTSS, 0.223% anhydrous citric acid, pH ~4.1, conductivity = 3650 us/cm). Resins SM-73 and A-399b were used. Each column had 100ml bed volume.

TABLE 7. MASS BALANCE

Fraction	Weight, gm	TS, % w/w	Sugar, % w/w	Acid, % w/w	TS, gm	Sugar, gm	Acid, gm	Mass Balance		
								TS	Sugar	Acid
Puree	400	10.7	6.1	1.13	42.80	24.4	4.52	(% of Puree)		
Water	600	0	0	0	0	0	0	100	100	100
Rinsed-Pulp	62	12.5	<0.10	0.18	7.75	<0.06	0.11	(% of Puree)		
Rinse/Serum	938	3.9	2.37	0.53	36.58	22.23	4.97	18.1	<0.2	2.4
								85.5	91.1	110.0
SubTotal	1000				44.33	22.29	5.08	(% of Puree)		
(Rinsed-Pulp + Rinse/Serum)								103.6	91.3	112.4
High-MW	203.6	5.6	2.52	0.61	11.40	5.13	1.24	(% of Puree)		
Low/Int-MW	734.4	3.5	2.4	0.49	25.70	17.63	3.60	26.6	21.0	27.4
								60.0	72.3	79.6
SubTotal	1000				44.85	22.82	4.95	(% of Puree)		
(Rinsed-Pulp + High-MW + Low/Int-MW)								104.8	93.5	109.5
SubTotal	938				37.10	22.76	4.84	(% of Rinse/Serum)		
(High-MW + Low/Int-MW)								101.4	102.4	97.4
Int-MW	97.9	6.7	4.21	0.85	6.56	4.12	0.83	(% of Puree)		
Low-MW	636.5	2.8	1.95	0.36	17.82	12.41	2.29	15.3	16.9	18.4
								41.6	50.9	50.7
SubTotal	1000				43.53	21.72	4.47	(% of Puree)		
(Rinsed-Pulp + High-MW + Int-MW + Low-MW)								101.7	89.0	98.9
SubTotal	938				35.78	21.66	4.36	(% of Rinse/Serum)		
(High-MW + Int-MW + Low-MW)								97.8	97.4	87.7
Subtotal	734.4				24.38	16.53	3.12	(% of Low/Int-MW)		
(Int-MW + Low-MW)								94.9	93.8	86.7

Both resins removed organic acids from the low-MW fraction (as measured by titratable acidity). The apparent capacity (measured in gm citric acid removed/bed volume) of the A-399b resin (~6.6) was approximately the same as that of the SM-73 resin (~7.5).

The citric acid from the low-MW fraction was left in salt form on the resin, having been removed by NaOH during column regeneration. These organic acid salts were then converted to organic acids by use of a cation resin.

Conversion of Organic Acid Salts to Acids.

The feeds were the solutions from column regeneration of the anion exchange resins. Resin C-391b was used.

The resin successfully converted the organic acid salts to acids. Because some of the effluent was sent back through the column during the runs, the determination of the resin's apparent capacity (measured in gm citric acid produced/bed volume) was obscured, but was approximated at 2.6 to 3.0.

CONCENTRATION

Laboratory-Scale Study

The rinse/serum produced from centrifuging and pulp rinsing was concentrated at ~54°C to 21, 30, 50, and 70°Brix using a rotary evaporator at ~40°C with vacuum.

Larger-Scale Study

Samples concentrated in this study include rinse/serum, ultrafilter permeates, and fresh juice serum.

Rinse/Serum Concentration. Some rinse/serum (6.5 kg, 14.3 lb) was concentrated by rotary evaporation (2-2.5 hrs) at 45-50°C [113-122°F], 26-27 in. Hg vacuum to 12.8% TS.

Ultrafilter Permeate Concentration. Permeate from the 100,000-MW-cutoff ultrafiltration (low/intermediate-MW fraction) (18 kg, 40 lb.) was concentrated using rotary evaporators (4-8 hrs) at 70°C [158°F], 22 in. Hg vacuum to 74% TS. The unconcentrated permeate was initially light yellow; final concentrate was dark brown.

Fresh Juice Serum Concentration. Fresh juice serum (~76L, ~20 gal) was evaporated in a pilot scale evaporator (APV) at ~70°C (160°F) from 4.9% NTSS to 13% NTSS. Approximately 2.5 gal (9.5 L) was removed. Evaporation of the remaining serum was continued to 20.8% NTSS. This 20.8% NTSS serum was further evaporated to 71.5% NTSS by rotary evaporation at ~70°C [~158°F] and 22 in. Hg vacuum.

This serum was stored at room temperature in a plastic tub for 8 mos. There was no sign of growth of yeasts or molds or other microorganisms.

On-Site Study

In some cases serum was concentrated by hyperfilter prior to further concentration by evaporation.

Hyperfiltration of Serum. The tubular hyperfiltration system was used. Initially, serum was recirculated (20 to 30 gal [78 to 114L]) in one module, changing the serum every 2 hr. After 13 hr, the system was cleaned with detergent and the second module was added in series to the system. Most operation was at 600 psi inlet pressure (4 MPa) and 60 to 70°C (140 to 158°F).

Two sets of pressure, temperature, and concentration scans were run with serum. A pressure scan was run where all operating conditions were held constant, while pressure was varied and flux (permeation rate) was measured. Correspondingly, temperature and concentration were varied in temperature and concentration scans, while other operating conditions were held constant. Results of one set of scans for both modules are shown in Figs. 5, 6 and 7, where flux readings shown are taken after the flux was allowed to equilibrate for 5 to 10 min after setting the operating conditions.

On three days (centrifuge Runs Nos. 4, 5 and 6) the hyperfilter was used to preconcentrate serum for the evaporator.

The hyperfiltration system was run for a total of 33 hr during all the above described testing. Flux readings for the first module operating in recirculation mode for this period were temperature corrected to 70°C (158°F), 4MPa (600 psi), and are shown versus time in Fig. 8.

Evaporation of Serum. Four runs were made on pilot scale evaporators. Three of these runs were made with serum previously concentrated by hyperfilter. Table 8 lists data about the operating conditions of the runs and characteristics of the final concentrates. (Evaporator Runs Nos. 3, 4, 5 and 6 were run on the same days as centrifuge Runs Nos. 3, 4, 5 and 6.) Serum from evaporator Run No. 6 (Table 8) was filled from the evaporator into seven No. 10 cans, sealed, run briefly in a retort to "sterilize", and cooled. All concentrated serums were refrigerated prior to the performance of recombination studies.

A study was begun in which the serum and control paste from evaporator Run No. 6 are being stored for 3 months at 40, 70, and 90°F (4, 21, and 32°C) at which time the serum and control will be evaluated for quality factors.

Figure 5 - Tomato serum pressure scans at 68°C, 5% TS.

Figure 6 - Tomato serum temperature scans at 4 MPa, 5% TS.

Figure 7 - Tomato serum concentration scans at 71°C, 4MPa.

Figure 8 - Flux versus time for 5% TS tomato serum, 70°C, 4MPa, Module 1.

TABLE 8. EVAPORATION OF SERUM

Run No.	°Brix Start Finish	Quant. Start, gal	Initial Product Temp/Vac, °F/in. Hg	Time Evap., hr	Final Product Temp/Vac, °F/in. Hg	Serum Color, %T	Heat Exchanger, Temp/°F	Color (at 40° Brix)		
								L*	a*	b*
3	5/43	35	200/22	6.5	120/30	51.5	NA	28.06	21.27	16.91
4	10/48	90	144/NA	1.2	158/NA	53.5	140/180	27.48	19.07	15.35
5	10/58	25	160/24	4	151/25	50	180/165	NA	NA	NA
6	10/62	70	160/25	5.5	158/17	32	200/180	26.07	17.97	14.98

NA = means not measured.

Some serum from the centrifuge was concentrated in a small single effect evaporator to ~35°Brix at ~155°F, ~25.5 in. Hg vacuum. The 35°Brix serum was further concentrated to 40 to 70°Brix by rotary evaporation at 55 to 70°C [130 to 158°F], 21 to 23 in. Hg vacuum. These concentrates were used in Storability Study No. 1, described in the Storability (Microbial Resistance) section. Some of these concentrates were analyzed for acidity and water activity, indicators of storability potential.

The concentrated serum from evaporator Run No. 3 (Table 8) was further concentrated by rotary evaporation at 30 to 49°C [86 to 120°F], 27 in. Hg vacuum, to 55 to 70°Brix for use in Storability Studies Nos. 2 and 3, described in the Storability (Microbial Resistance) section.

Storability (Microbial Resistance).

Serums of various Brix concentrations were analyzed for water activity and acidity (Figs. 9 and 10). In order to learn more about the serum's storability or microbial resistance, serum of various Brix levels was inoculated with yeast which would be the most likely spoilage organism for this type of food product. Three studies were conducted.

Study No. 1. A loopful of tomato paste highly contaminated with yeast was inoculated below the surface of ~10ml tomato serum at the following °Brix levels: 36.8, 39.6, 47.1, 50, 52.7, 55.8, 57.7, 60, 63.6, 66.7, 68.5, 70.5. The tubes were incubated at ambient temperature.

At 11 days spoilage was noted in the 36.8°Brix sample. At 8 days spoilage was noted in the 39.1, 47.1, 52.7, and 55.8° Brix samples. Spoilage was noted by fermentative odor and bubbling throughout the serum. Microscopic examination revealed damaged, distorted, lysed cells of yeast.

Figure 9 - Tomato serum Brix versus water activity (A_w).

Figure 10 - Tomato serum Brix versus % acidity.

After 66 to 73 days of incubation, all tubes had shown signs of spoilage by evidence of bubbling and/or fermentative odor. Serum from each tube (of °Brix 60, 63.6, 66.7, 68.5, 70.5) was diluted 1:10 and 1:100 and plated for growth of viable yeast on acidified potato dextrose agar. No yeasts were recovered at these dilutions for any of the samples, except for one serum sample at 57.7° Brix (incubated for 66 days) where 665 CFU/ml (colony forming units/ml) of yeasts were recovered.

Study No. 2. Pure yeast culture was produced from the yeast isolated from the contaminated paste used in Study No. 1. A known number of yeast from this culture was used to inoculate tubes of tomato serum at different °Brix.

On day 1, ~24 yeast/tube were inoculated into ~10ml of tomato serum at 55, 60, 66, and 71° Brix. Duplicate tubes for each Brix level were prepared for inoculation on and below the serum surface. The tubes were incubated at ambient temperature.

On day 6 and day 9, no spoilage was detected. On day 16 the yeast cells appeared to be distorted and deformed or were lacking in all tubes upon microscopic examination.

Study No. 3. The same yeast culture and the same tubes of serum used in Study No. 2 above were used, but some conditions were different: the Brix of the samples was slightly higher due to evaporation of the samples used in the previous study, a sample with lower °Brix (43) was added, and a higher yeast population was used.

On day 1, ~24,000 yeasts per tube were inoculated on the surface of tomato serums at 43, 60, 69, 70, and 78° Brix, and below the surface of tomato serums at 43, 59, 66, 71, and 77° Brix. ~10ml of serum/tube was used. The tubes were incubated at ambient temperature.

On day 8, the following results were noted:

°Brix		
<u>Center</u>	<u>Surface</u>	<u>Results</u>
43	43	Faint fermentative odor; some dark yeast cells.
60	59	Some dark and some distored yeast cells.
69	66	Some lysed cells, some distorted yeast cells.
70	71	Some lysed yeast cells.
78	77	Some lysed, darkened yeast cells.

A loopful of serum from each tube was struck onto acidified potato dextrose agar to see if viable yeasts could be recovered. The following results were obtained:

°Brix		°Brix	
<u>Center</u>	<u>Results</u>	<u>Surface</u>	<u>Results</u>
43	Yeast	43	Yeast
60	Slight amt. yeast	59	No growth
69	No growth	66	No growth
70	No growth	71	No growth
78	No growth	77	No growth

From these studies, it appears that yeast had difficulty surviving at ≥ 59 to 60° Brix in a high yeast population, and had difficulty surviving at $\geq 55^\circ$ Brix in a low yeast population.

Efficiency of Evaporation (Juice vs. Serum).

Tomato serum and whole tomato juice were concentrated in a small single effect evaporator under the same operating conditions ($\sim 155^\circ\text{F}$ [68°C] product temperature, 25 to 26 in. Hg vacuum). Rate of water removal for the fluids is shown in Fig. 11.

Figure 11 - Approximate condensate volume versus time of evaporation for tomato juice and serum at 68°C, 25 to 26 in. Hg. vacuum.

Comparison of the rates indicate that the serum water removal rate was ~15% higher than that of whole juice. The serum was able to be concentrated to ~30° Brix in ~70 min, while the system had to be shut down to prevent burn-on when the whole juice reached ~15° Brix in ~45 min.

PULP PRESERVATION

Larger-Scale Study - Drying

Drying of the rinsed-pulp would greatly facilitate its handling, storage, and transportation. To study this, tomato pulp was drum dried and evaluated for hygroscopy.

Seven drying runs were conducted (Table 9). The first run was a preliminary test. In order to obtain a feed consistency which could film on the dryer's surface, a slurry of rinsed-pulp and water was used. In the subsequent four runs, the amount of water added to rinsed-pulp was varied, and dryer settings were also varied. To provide a dried tomato product as a sugar-containing control, puree (9.6% NTSS) and a mixture of tomato puree and tomato paste (18.6% NTSS) were dried in Runs 6 and 7.

Results in Table 9 show that Runs 2, 4 and 5 successfully produced a dried rinsed-pulp which did not experience fungal spoilage (Run No. 4 had 6% moisture content). The dried rinsed-pulp was orange in color, and resembled flakes of bran. Tomato puree (Run No. 6) could not be dried successfully because the sticky product rolled up at the cut-off knives. The puree/paste blend was successfully dried to 4% moisture content and did not experience fungal spoilage; it was red in color.

TABLE 9. PULP DRYING RESULTS

Run No.	Product	Initial Moisture Content, % w/w	DRYER SETTINGS			
			Steam Pressure, psi	Steam Temp., °F	Drying time, sec	Film Thickness, in
1	Prelim. Pulp: Water	89.5	55	302	26.2	0.009
2	Pulp: Water 2.33:1	90.5	55-70	302-316	26.2	0.009
3	Pulp: Water 2.33:1	89.3	65	312	26.2	0.007
4	Pulp: Water 3.51:1	87.6	65-68	312-315	33.7	0.006
5	Pulp: Water 5.00:1	87.7	66-68	313-315	28.1	0.006
6	Puree	89.5	55	302	28.1-33.7	.006-.008
7	Puree/Paste	79.2	50	298	13.7	0.008

Run No.Dryer Results

1	Not dried sufficiently to avoid fungal spoilage
2	Dried well, no spoilage
3	Not dried sufficiently to avoid fungal spoilage
4	Dried well, no spoilage, final moisture content: 6%
5	Dried well, no spoilage
6	Wouldn't dry, very sticky, rolled up at cut-off knives
7	Dried very well, no spoilage, final moisture content: 4%

Hygroscopy of Dried Pulp. Hygroscopy is important because it relates to the storage stability, packaging needs, and handling requirements of dried foods. To study the hygroscopy of the dried rinsed-pulp (Run No. 4, Table 9) and the dried puree/paste (Run No. 7, Table 9), samples were placed in constant humidity rooms, and water uptake (gain in weight) was recorded.

Two constant humidity rooms were used for the tests. The tropical room had 82°F (28°C) dry bulb temperature and 80% relative humidity. The prairie room had 70°F (21°C) dry bulb temperature and 45% relative humidity.

In the hygroscopy test, twelve petri dishes were tared. Five gm samples of each of the dried products were weighed into each of six dishes. Three dishes of each sample were placed in each room. The samples were weighed after 1, 2, 5, and 8 days in the rooms. The results, given as percent gain in weight versus storage time, are shown in Figs. 12 and 13.

This study showed the hygroscopy of rinsed-pulp to be low, especially when compared with dried puree/paste. Samples of puree/paste stored in the Tropical Room absorbed enough water to permit mold growth after 10 days. The difference in hygroscopy can be explained by the difference in sugar content between the two samples, since at low moisture content, sugar has a great water binding capacity.

On-Site Study - Freezing

Freezing was chosen as a way of preserving the pulp for the purposes of this study since the scope of the project was limited, preventing the adequate exploration of other methods of preservation. However, it is realized that this method of storage is probably not economically feasible.

Figure 12 - Hygroscopy - weight gain (%) versus time in tropical room, 82°F, 80% relative humidity.

Figure 13 - Hygroscopy - weight gain (%) versus time in prairie room, 70°F, 45% relative humidity.

The pulp from two centrifuge runs (Run Nos. 5 and 6, Table 5) was frozen in plastic bags. The bags used were the type normally used for frozen processed fruit storage, but approximately one fourth the size. Approximately 3.2 lb. (1.5 kg) were placed in each bag. For Run No. 5 (Table 5), ~25 lb (11 kg) was frozen. For Run No. 6 (Table 5), ~75 lb (34 kg) was frozen. The pulp from Run No. 6 has been used in the storage of fractions study, which will be described in a future report (DOE Report No. DOE/ID/12553-3).

Two bags of pulp from centrifuge Run No. 5 (Table 5) were examined for yeasts and molds. One bag was removed directly from the freezer, thawed, and was tested. The other bag had been thawed and refrigerated for approximately 1 week before testing. Total colony forming units (CFU) were 50 and 55/gm pulp respectively, indicating a low enough level of yeast for the pulp to be acceptable for use.

RECOMBINATION

Laboratory-Scale Study

Immediately after the serum and pulp had been separated by the three methods (centrifugation, conventional vacuum filtration, and microfiltration) they were recombined by three techniques (static mixing, stomacher blending, and homogenizing) to make puree.

Static (In-Line) Mixing. Serum and pulp were placed in a container and pumped through the static mixer. Two passes were made for all testing except when recombining the fractions which had been separated by centrifugation (for which three passes were made).

Results of the recombinations are given in Table 10. Centrifuge-separated or conventional filter-separated fractions experienced slightly decreased viscosity (4.2% and 3.8%, respectively) upon recombination. Microporous filter-separated fractions experienced slightly increased viscosity (3.2%) upon recombination.

Stomacher Blending. Serum and pulp were placed in Whirl-pak bags and then in a protective bag and placed in the stomacher compartment. When recombining the centrifuge-separated serum and pulp, the stomacher was run for 2 min; with the conventional filter-separated fractions, the stomacher was run and samples tested after 0.5, 1, 3, and 5 min. Testing with the stomacher on un-separated puree showed viscosity deterioration with its use. Hence, the stomacher was not used to recombine the microporous filter-separated fractions.

Results of the recombinations are given in Table 11. Centrifuge-separated fractions experienced a loss in viscosity (26.5% to 10.9%); conventional filter-separated fractions experienced no significant change in viscosity upon recombination.

Homogenization. The homogenizer was used for recombining by placing serum and pulp (~300 gms total) into a 400 ml beaker and homogenizing for 0.5 to 7 min.

Results of the recombinations are given in Table 12. After separation by all three methods, homogenization for 5 min or longer resulted in viscosity gain (8.9% to 33.0%); homogenization for 3 min resulted in a viscosity gain for all (8.9 to 16.8%) but the centrifuge-separated fractions (5.6% loss). Homogenization for 0.5 min of the centrifuge-separated fractions resulted in a viscosity loss (14.8 to 22.5%).

Evaluation of Recombination Methods. Studies were undertaken to examine the effect of two recombination methods, stomacher blending and homogenization, upon the viscosity of un-separated puree.

TABLE 10. RESULTS OF STATIC MIXER RECOMBINATION WITH THREE SEPARATION TECHNIQUES - LABORATORY-SCALE STUDY

	Centrifuge		Conventional Filter		Microporous Filter	
	NTSS, %	Bostwick, cm	NTSS, %	Bostwick, cm	NTSS, %	Bostwick, cm
Original Puree	9.2	5.28	10.8	4.75	9.2	5.27
Recombined Puree	9.2	5.5	10.8	4.93	9.15	5.1

TABLE 11. RESULTS OF STOMACHER RECOMBINATION WITH TWO SEPARATION TECHNIQUES - LABORATORY-SCALE STUDY

	Centrifuge				Conventional Filter	
	NTSS, %	Bostwick, cm	NTSS, %	Bostwick, cm	NTSS, %	Bostwick, cm
Original Puree	12.9	4.15	8.9	5.5	10.8	4.95
Recombined Puree at:	12.9		8.9		10.8	
0.5 min		—		—		4.97
1 min		—		—		4.82
2 min		5.25		6.1		—
3 min		—		—		5.2
5 min		—		—		5.2

TABLE 12. RESULTS OF HOMOGENIZER RECOMBINATION WITH THREE SEPARATION TECHNIQUES - LABORATORY-SCALE STUDY

	Centrifuge				Conventional Filter		Microporous Filter	
	NTSS, %	Bostwick, cm			NTSS, %	Bostwick, cm	NTSS, %	Bostwick, cm
Original Puree	9.0, 8.8, 9.8, 10.2	5.03, 5.4, 5.0, 4.85			9.6	5.25	9.2, 9.2	5.27, 5.27
Recombined Puree	9.0, 8.8, 9.8, 10.2				9.6		9.15, NA	
at: 0.5 min		6.16, 6.2*, 6.0*, —				—		— —
3 min		— — — 5.1				1.4		4.8 4.57
5 min		— — — 4.4				—		— —
7 min		— — — 3.9				3.5		4.75 4.37

*Recombined puree heated to 82°C for 35 min, before Bostwick measurement.

NA means not measured.

Stomacher blending.

The effect of stomaching time on puree viscosity was examined. Puree of 10.8% NTSS was used. Bostwick was measured initially and after 1, 2, 4 and 8 min of stomaching time. Viscosity decreased with stomacher mixing time (Fig. 14).

Homogenization.

The effect of homogenization time on puree viscosity was examined in two tests. In the first test puree of 10.2% NTSS was used. Bostwick was measured initially and at 1, 3, 5 and 7 min. The viscosity decreased at 1 and 3 min and then increased above the initial value at 5 and 7 min (Fig. 15).

In the second test, puree of 9.2% NTSS was used. Bostwick was measured initially and after 3, 5 and 7 min of homogenization. The viscosity increased at 3 min but showed no further increase with longer homogenization time (Fig. 16).

Recombination of Concentrated Rinse/Serum and Rinsed-Pulp.

Concentrated rinse/serum and frozen thawed rinsed-pulp were recombined by homogenization to make puree. Two sets of original puree and recombined purees were made, Set No. 1 and Set No. 2. Results of the recombinations are shown in Table 13.

Recombined purees Nos. 2-1 and 2-2 (Table 13) were refrigerated three days and then Bostwick measurements were made; they were respectively 5.65 and 5.3 cm. These results indicate that the viscosity of the original purees was adequately recovered in recombined purees Nos. 2-1 (after refrigeration), 2-2, 1-2, and 1-3 (Table 13).

Figure 14 - Bostwick viscosity (cm) versus stomacher mixing time (min) for unseparated puree (10.8% NTSS).

Figure 15 - Bostwick viscosity (cm) versus homogenizing time (min) on unseparated puree (10.2% NTSS).

Figure 16 - Bostwick viscosity (cm) versus homogenizing time (min) on unseparated puree (9.2% NTSS).

TABLE 13. RESULTS OF RECOMBINATIONS WITH CONC. RINSE/SERUM AND RINSED-PULP - LABORATORY-SCALE STUDY

Sample I.D.	NTSS, %	TS, % w/w	Homog., min	Conc. Rinse/ Serum, °Brix	Pulp, % w/w	Conc. Rinse/ Serum, % w/w	Bostwick, cm
Original Puree/1	9.5	10.77	—	—	—	—	5.5
Recombined Puree/1-1	9.3	—	3	50	21.5	17.4	5.8
Recombined Puree/1-2	9.7	10.91	3	50	21.5	18.8	5.6
Recombined Puree/1-3	9.6	11.0	7	50	21.5	18.8	5.35
Original Puree/2	9.1	10.81	—	—	—	—	5.45
Recombined Puree/2-1	9.1	10.84	7	21	23.7	40.6	6.33
Recombined Puree/2-2	9.2	10.96	7	21	23.7	40.6	5.5

Larger-Scale Study: Puree Study

Rinsed-pulp, high-MW, and concentrated low/intermediate-MW fractions were recombined by homogenizing 7 min. Results of three trials are shown in Table 14. The recombined purees had slightly higher solids than the original canned puree; the color was generally lighter, less red/purple, and more yellow; viscosity (Bostwick) was acceptable; syneresis was better.

Rinsed-pulp and concentrated rinse/serum (12.8% NTSS) were recombined by homogenizing 7 min. The results of two trials are given in Table 14. The recombined purees had slightly higher solids than the original canned puree; the color was lighter, less red/purple, and more yellow; viscosity was acceptable; syneresis was better.

Larger-Scale Study: Fresh Juice Study

Concentrated serum (13% TS and 70% TS), pulp, and water were recombined in this study.

Recombination with Low Level Solids (13% TS) Serum. The objective was to recombine serum (13% TS) with pulp and water in order to assess the effect of separation and recombination upon quality of the recombined product.

Pulp, 13% TS serum, and water were combined to make puree, homogenizing for 7 min. Control puree was made by evaporating fresh juice at 158°F (70°C) 22 in. Hg vacuum. Results are given in Table 15. The results indicate that separation by centrifuge, and recombination by homogenizer did not adversely affect viscosity (Bostwick), color, or syneresis. Recombination by static mixer did not appear to adversely affect color or syneresis, and the Bostwick viscosity was almost fully recovered (7% low).

TABLE 14. RESULTS OF RECOMBINATIONS - LARGER-SCALE PUREE STUDY

Sample I.D.	TS, % w/w	SS, % w/w	IS, % w/w	Bost- wick, cm.	Color			Syner- esis 1 hr, % w/w
					L*	a*	b*	
Original Puree	10.65	8.56	2.08	5.35	31.62	21.90	19.44	5.93
Recombined Puree from Rinsed-Pulp, High MW, and Conc. Low/Int. MW Fraction								
Trial 1	10.76	8.05	2.71	5.68	35.07	20.22	24.40	6.64
2	10.83	8.52	2.32	4.5	35.09	19.52	24.55	2.84
3	10.92	8.66	2.26	5.33	34.91	19.35	24.25	2.35
Recombined Puree from Rinsed-Pulp and Concentrated Rinse/Serum								
Trial 1	10.87	8.57	2.30	5.45	35.69	19.45	25.15	3.2
2	10.85	8.60	2.25	4.8	35.92	19.42	25.46	NA

NA means not measured.

Recombination with High Level Solids (70% TS) Serum. The objective was to recombine serum (70% TS) with pulp and water in order to assess the effect of serum concentration plus separation and recombination upon quality of the recombined product.

Trial 1 - Pulp, 70% TS serum, and water were combined to make puree, homogenizing for 7 min. This recombination procedure was repeated using the static mixer (2 passes). Results are in Table 15.

Trial 2 - The recombination by homogenization was repeated with different ratios of the three components to try to better duplicate the solids of the baseline puree. Results are in Table 15.

The results indicate that separation by centrifuge, concentration of serum to a high level, and recombination by homogenization gave a puree with adequate viscosity, less serum separation, and slightly darker color. The total and insoluble solids content of the recombined product was critical to its viscosity. Since the static mixed recombination was not repeated, it is difficult to draw firm conclusions about its quality.

On-Site Study

Since it is not always possible to exactly duplicate the solids of the control puree when making the recombined purees, a brief study was made to see how the viscosity and color vary with varying solids levels. Tomato paste was diluted to four solids levels. In order to quickly approximate the solids levels, the °Brix, or natural tomato soluble solids, was used as an indication of the concentration of the solids. The four purees (9-12° Brix) were then analyzed for color and viscosity (Bostwick).

Results are shown in Figures 17 and 18. The slopes of both curves are very linear from 9 to 11° Brix and almost linear from 9 to 12° Brix. Using linear regression, one can calculate that

TABLE 15. RESULTS OF RECOMBINATIONS - LARGER-SCALE JUICE STUDY

Sample I.D.	TS, % w/w	SS, % w/w	IS, % w/w	IS/ SS	NTSS, %	Bost- wick, cm	Color			Syner- esis 1 hr, % w/w
							L*	a*	b*	
							(Std. deviation)			
Baseline Puree	10.59	8.59	2.00	0.233	9.1	5.3	32.20	21.29 (0.10)	19.39 0.26	13.7 0.11)
Recombined Puree from Low Level Solids Serum										
Homog. Puree	10.58	8.68	1.90	0.219	9.2	5.3	32.24	22.19 (0.14)	19.62 0.16	11.2F 0.12)
Stat. Mix Puree	10.60	8.63	1.97	0.229	9.2	5.67	32.06	22.09 (0.13)	19.22 0.17	11.5F 0.17)
Recombined Puree from High Level Solids Serum										
Homog. Puree										
Trial 1	10.43	8.71	1.73	0.198	9.2	6.0	31.91	20.97 (0.21)	19.57 0.16	6.0sF 0.18)
Trial 2	10.87	8.72	2.15	0.247	9.2	4.86	31.04	21.22 (0.11)	19.13 0.14	5.7 0.12)
Stat. Mix Puree										
Trial 1	10.34	8.51	1.83	0.215	9.2	6.45	30.69	20.54 (0.18)	18.60 0.18	11.5sF 0.16)

F = Possibly fermenting

sF = Possibly slightly fermenting

Figure 17 - Bostwick viscosity versus Brix of puree from paste.

Figure 18 - Color versus Brix of puree from paste.

if the Brix varies by $\pm 0.1^\circ$ Brix around 9.0 and 10.0° Brix, the Bostwick will vary by $\sim \pm 2\%$ and a^* (redness) will vary by $\sim \pm 0.1$ unit; if the Brix varies by $\pm 0.2^\circ$ Brix around 9.0 and 10.0° Brix, the Bostwick will vary by $\sim \pm 4\%$ and a^* will vary by $\sim \pm 0.19$ unit. It appears then, that if the Brix or solids of the recombined are within this range ($\pm 0.2\%$ solids) of the control, it is acceptable to make comparisons.

Several recombinations were made using frozen pulp and concentrated serum from the runs on the pilot scale evaporators.

First Recombination. The first set of recombinations were made with serum and pulp from centrifuge and evaporator Runs No. 5 (Tables 5 and 8). The control puree was made from canned paste obtained on that day from the plant's paste production line. Two reconstituted control purees were made from paste, one by stomacher (3 min), and one by two passes through the static mixer. The second control was also homogenized 7 min after static mixing and viscosity was retested. Three recombined purees were made. Using the amount of soluble and insoluble solids in serum and pulp, calculations were made to determine the amount of each fraction to add to make recombined puree to duplicate the solids in the control puree. These amounts were combined and homogenized 7 min.

Results (Table 16) indicate that the solids of the recombined puree were a little higher than the solids of the control puree. The recombined Bostwick was lower than the statically mixed control (23 to 26%) and the homogenized control (15 to 19%) indicating better viscosity; the syneresis was lower (better) (3.8 units). The recombined puree was lighter ($\bar{x} = 0.72 L^*$ unit), less red ($\bar{x} = 2.00$ units), and about the same in yellow hue as the control purees.

TABLE 16. RESULTS OF FIRST AND SECOND RECOMBINATIONS - ON-SITE STUDY

Sample I.D.	TS, % w/w	SS, % w/w	Solids		Bostwick, cm	Color			Syneresis 0.25hr, % w/w
			IS, % w/w	IS/ SS		L*	a*	b*	
(Std. deviation)									
RECONSTITUTED CONTROL PUREES									
Trial 1 Stomacher	10.23	8.52	1.71	0.20	—	31.34 (0.25)	21.25 0.19	19.57 0.19)	—
Trial 2 Stat/Mix	10.22	8.48	1.74	0.20	8.6	31.28 (0.11)	21.00 0.09	19.46 0.06)	4.7
Trial 2 Homog.	"	"	"	"	7.8	"	"	"	—
RECOMBINED PUREES									
First Recombination									
Trial 1	10.36	8.61	1.75	0.20	6.6	32.18 (0.17)	19.43 0.16	19.38 0.16)	—
Trial 2	10.52	8.68	1.83	0.21	6.33	31.88 (0.17)	19.05 0.15	19.31 0.10)	0.93
Trial 3	10.41	8.62	1.78	0.21	—	32.02 (0.08)	18.87 0.06	19.57 0.09)	—
Second Recombination									
Trial 1	10.50	8.71	1.80	0.21	5.6	33.07 (0.04)	20.65 0.09	20.36 0.04)	0.16
Trial 2	10.38	8.60	1.79	0.21	6.23	32.68 (0.07)	20.79 0.13	20.16 0.05)	—
Trial 3	10.40	8.64	1.76	0.20	5.77	33.27 (0.18)	20.91 0.12	20.73 0.11)	—

Second Recombination. A second set of recombinations was made with serum from evaporator Run No. 3 (Table 8) and pulp from centrifuge Run No. 5 (Table 5) and compared with the above control purees to see if the serum from evaporator Run No. 3 would give a better color. Using similar calculations, amounts of fractions were determined and homogenized 7 min.

Results (Table 16) indicate that the solids of the recombined purees were slightly higher than the control puree solids. Comparison of viscosity showed the recombined purees had better viscosity than the statically mixed control puree (28 to 35%) and the homogenized control puree (20 to 28%). The recombined puree had lower syneresis (4.5 units) than the statically mixed control puree. The second set of recombined purees were more red ($\bar{x}$ = 1.66 a* units) than the first set of recombined purees, but were slightly less red than the control purees ($\bar{x}$ = 0.34 a* unit). The second set of recombined purees were also lighter ($\bar{x}$ = 0.98 L* unit) and more yellow ($\bar{x}$ = 1.00 b* unit) than the first set of recombined purees, and lighter ($\bar{x}$ = 1.70 L* unit) and more yellow ($\bar{x}$ = 0.90 b* unit) than the control purees.

Third Recombination. A third set of recombinations was made with serum and pulp from centrifuge and evaporator Runs No. 6 (Tables 5 and 8). The control puree was made from paste pulled on that day from the plant's evaporator into nine No. 10 cans, sealed, "cooked" briefly in pilot plant retort, and cooled. One reconstituted control puree was made with the static mixer (2 passes). Using calculations similar to the above to determine the amount of each fraction to add, one recombined puree was made and homogenized 7 min.

Results (Table 17) indicate that the recombined puree solids were slightly lower than the control puree solids. Comparison of viscosity, color, and syneresis showed the recombined puree had slightly lower (5.3%) viscosity than the control puree; recombined color was lighter (1.43 L* unit), slightly less red (0.51

TABLE 17. RESULTS OF THIRD RECOMBINATION - ON-SITE STUDY

Sample I.D.	Solids				Bostwick, cm	Color			Syneresis 0.25hr, % w/w
	TS, % w/w	SS, % w/w	IS, % w/w	IS/ SS		L* (Std. deviation)	a* (Std. deviation)	b* (Std. deviation)	
Control Puree	10.27	8.17	2.09	0.256	6.2	31.38 (0.12)	19.58 0.09	19.82 0.20)	1.98
Recombined Puree	10.17	8.13	2.04	0.251	6.53	32.81 (0.05)	19.07 0.10	20.92 0.16)	2.98

TABLE 18. RESULTS OF FOURTH RECOMBINATION (HOT FILL) - ON-SITE STUDY

Sample I.D.	Solids				Bostwick, cm	Color			Syneresis 0.25hr, % w/w
	TS, % w/w	SS, % w/w	IS, % w/w	IS/ SS		L* (Std. deviation)	a* (Std. deviation)	b* (Std. deviation)	
Control Puree	10.76	9.04	1.72	0.190	7.56	31.27 (0.06)	20.56 0.05	19.30 0.09)	3.1
Recombined Puree	10.61	8.85	1.77	0.200	6.75	32.85 (0.10)	20.05 0.10	19.88 0.15)	3.9

a* unit), and yellower (1.1 b* unit); syneresis was slightly higher (1.0 unit).

Fourth Recombination. A fourth recombination was made with serum from evaporator Run No. 3 (Table 8) and pulp from centrifuge Run No. 5 (Table 5) and the products were thermally processed. This consisted of filling eight #303 cans with product which had been heated to ~190°F, 88°C. They were held for 5 min before cooling. This procedure is called a hot fill. Control puree was made from the paste obtained from the plant's paste production line on the same day centrifuge and evaporator Runs No. 5 were made. The control puree was thermally processed in the same manner as the recombined puree. This set of recombined puree and control puree was thus made from the same fractions and control paste used in making the second set of recombinations. However, the purees in this set were thermally processed, while those made in the second set were not.

Results (Table 18) indicate that the solids of the recombined puree were close to the solids of the control puree, but total and soluble solids were a little low, and insoluble solids were a little high. The recombined puree viscosity was somewhat higher (10.7%) than the control puree; recombined puree color was lighter (1.58 units), slightly less red (0.51 unit), and slightly more yellow (0.58 unit) than the control puree color; recombined puree syneresis was slightly higher (0.8 unit) than control puree syneresis.

Comparing the cooked versus uncooked products, in both recombined and control purees, the total and soluble solids were higher in the cooked (due to the evaporation in the cooking process), but the insoluble solids were lower in the cooked. (It is not known why the insoluble solids were lower; cans of paste used in each set of reconstitutions may have varied slightly.) Comparing the cooked versus uncooked products, the viscosity of the control

puree improved (12%) with cooking (or due to the slightly higher solids) while the viscosity of the recombined puree was lower with cooking (15%), but was still better than the control puree (10.7%). With cooking the color of the control and recombined purees were slightly darker (0.04 and 0.16 unit respectively), less red (0.56 and 0.73 unit), and less yellow (0.21 and 0.54 unit). With cooking, syneresis of the control puree decreased (1.6 unit) while syneresis of the recombined puree increased (3.7 units).

Members of the industry advisory committee tasted the unlabeled cooked control and recombined purees. The recombined puree tasted "flatter" or "greener" or "less cooked" than the control puree which may have been due to the fact that the pulp had not been cooked other than in the hot break process. The recombined puree texture appeared smoother. The committee generally felt that the product could still be potentially acceptable.

ECONOMIC/ENERGY ANALYSIS

The objective of this analysis is to compare energy usage and its associated costs for producing, containerizing, storing, and shipping tomato juice and/or other fruit and vegetable concentrates using technology more efficient than currently used technology.

Figure 18 shows alternative processes for producing and distributing tomato juice concentrates. These figures are based on the annual processing by the entire tomato paste processing industry of 6 million tons of tomato juice. Only the operations which differ from the traditional process are shown. Operations common to all alternatives such as cleaning, sorting, hot breaking, pulping, etc. are omitted. The first process (I) is the traditional method of processing tomato juice into tomato paste. The other four processes produce fractions of tomato juice; the second (II) and third (III) processes handle the serum separately; the fourth (IV) and fifth (V) processes handle the pulp separately. All five processes lead to products which can be shipped to a recombination center close to the actual site of consumption as is currently done with tomato paste.

Recombination of the product from Process I is a reconstitution process where water is added to obtain the desired product solids and viscosity. Recombination of the products from Processes II-V require recombination of serum and pulp plus reconstitution with water to obtain the desired product characteristics. The product could be a traditional tomato product. Or the serum and pulp fractions could be used to open up new avenues for product development. When reconstituting with product from Process III, the sugar component would not have been transported, thus reducing transportation costs; sugar from a local source would be used, offsetting some of the savings.

Table 19 shows the breakdown of energy, and its cost, needed for

Figure 18. Alternative processes and associated energy usage for annual tomato juice processing.

TABLE 19. ANNUAL ENERGY USE AND COST BY OPERATION IN ALTERNATIVE PROCESSES

Process Operation	I		II		III		IV		V	
	10 ¹² Btu/yr	10 ⁶ \$/yr	10 ¹² Btu/yr	10 ⁶ \$/yr	10 ¹² Btu/yr	10 ⁶ \$/yr	10 ¹² Btu/yr	10 ⁶ \$/yr	10 ¹² Btu/yr	10 ⁶ \$/yr
Centrifugation	—	—	0.01	<.01	0.01	<0.01	—	—	—	—
Ultrafiltration	—	—	—	—	0.1	0.5	—	—	—	—
Ion Exchange	—	—	—	—	0.01	<0.01	—	—	—	—
Hyperfiltration	—	—	0.19	1.0	0.28	1.55	—	—	—	—
Evaporation	7.84	34.5	3.70	16.2	1.76	7.76	—	—	—	—
Drying	—	—	—	—	—	—	—	—	1.59	7.0
Containerization	1.48	59.4	0.42	20.8	0.22	8.6	0.81	32.4	~0	~0
Shipping	<u>3.43</u>	<u>75.7</u>	<u>1.20</u>	<u>26.6</u>	<u>0.49</u>	<u>10.9</u>	<u>1.87</u>	<u>41.3</u>	<u>0.22</u>	<u>4.8</u>
Total	12.75	169.6	5.52	64.6	2.87	29.3	2.68	73.7	1.81	11.8

each operation in the five processes plus the total energy and dollar cost. Again, only the operations which differ from the traditional process have been itemized, as those operations common to each would bear the same cost.

Energy usage for ultrafiltration was figured using 15 Btu/lb of permeate removed. Hyperfiltration energy usage was calculated based on 35 Btu/lb of water removed. Evaporation energy usage was figured using 800 Btu/lb of water removed. Drying energy usage was calculated from 1500 Btu/lb of water removed. Containerization by drums energy usage was based on 6.75×10^5 Btu needed to manufacture one drum. Shipping energy usage was based on 50% traveling by rail at 1000 Btu/ton/mile and 50% traveling by truck at 2121 Btu/ton/mile.

Implementation of Process II has the advantage of using a currently used or existing developed technology; centrifugation for separation is known to the food industry. The concentration of serum by evaporation is also a currently used technology. The preconcentration of the serum by hyperfiltration is a relatively new technology. A major obstacle for its implementation has been the high level of suspended matter in a juice stream; prior separation will eliminate this obstacle, thus making the technology more trouble free and cost effective for industry's use. The high concentration level of the serum should lead to a self-preserving product which can be handled by existing storage and transportation systems that have been developed for corn syrup, molasses, etc.

Implementation of Process III would probably need additional research to optimize the process whose technical feasibility has been demonstrated in the Larger-Scale Study. The techniques for practical plant applications would need to be optimized including scale-up operation of the ultrafiltration and ion exchange steps.

The advantage of Process V over Process IV lies in the savings from the reduction in energy used in containerization and shipping of the dried pulp versus undried pulp. The work done in the Larger-Scale Study showed the technical feasibility of drying of the pulp. Further study of drying has not been possible so far within the scope of this project. However, it is recommended that drying of the pulp and its recombination with serum should be studied further. The drying process is another existing developed technology known to the food industry, which gives another advantage to its implementation, should studies be successful.

By combining Processes II and V, 5.4×10^{12} Btu and 93.2×10^6 dollars can potentially be saved over the traditional process, a 42.5% savings in energy and 55.0% savings in dollars (Table 20).

This would increase the energy savings by 6.8% and the dollar savings by 36.5% over the combination of Processes II and IV (35.7% energy savings and 18.5% dollar savings over the traditional process), in return for a relatively small amount of research. For this reason further investigation of the pulp drying process is advisable.

TABLE 20. ANNUAL ENERGY USE AND COST OF COMBINED PROCESSES VERSUS TRADITIONAL PROCESS

Processes	10^{12} Btu/yr Total	10^{12} Btu/yr Saved	Percent Saved Btu	10^6 \$/yr Total	10^6 \$/yr Saved	Percent Saved \$
I	12.75	--	--	169.6	--	--
II + IV	8.20	4.55	35.7	138.3	31.3	18.5
II + V	7.33	5.42	42.5	76.4	93.2	55.0
III + IV	5.55	7.20	56.5	103.0	66.6	39.3
III + V	4.68	8.07	63.3	41.1	128.5	75.8

CONCLUSIONS AND RECOMMENDATIONS

Separation studies have shown that the greatest separation by weight was obtained by centrifugation. The clearest serum with the least color and pectin was obtained with microfiltration. Rinsing of the pulp and repeating the centrifugation step successfully lowered the sugar and organic acid content of the rinsed-pulp, also producing a rinse/serum fraction. Fresh tomato juice was successfully separated by centrifuge into pulp (~11% by weight) and serum (~89% by weight).

In fractionation studies, two-stage ultrafiltration was shown to be able to successfully fractionate rinse/serum into high-, intermediate- and low-MW fractions. Further study of the flux and rejection under actual plant operating conditions is recommended. Ion exchange successfully produced sugar and organic acid fractions from the low-MW fraction. Further work is needed to demonstrate the possibility of recombining using the sugar and/or organic acid fractions.

Concentration studies demonstrated that rinse/serum could be successfully concentrated by evaporation to 13, 30, 50, and 70 °Brix. The low/intermediate-MW fraction was successfully concentrated by evaporation to 74% total solids (TS). Fresh juice serum was successfully evaporated to 13% and 70% TS. In addition, fresh juice serum was also successfully concentrated by hyperfiltration to 10% TS, and then by pilot scale evaporator to 41 to 60% TS. This concentrated serum was tested for the possibility of yeast growth, yeast being the most likely spoilage organism for this food product. Results showed that yeast had difficulty growing at °Brix levels above 55 to 60, indicating that the concentrated serum may be self-preserving. A storage study is on-going to determine the quality of the concentrated serum and control paste after storage as well as the quality of the recombined product after storage. Small scale comparison

testing of evaporating serum versus whole juice indicated that water was removed ~15% faster from the serum than from the whole juice, indicating an energy savings in the evaporation process.

In pulp preservation studies, rinsed-pulp was dried successfully resulting in a low hygroscopy product. The drying of pulp needs to be examined further due to the larger than expected quantity of pulp produced by centrifugation (~13% of juice by weight). The reason for studying pulp drying is to find a way to reduce the quantity of pulp for shipping in order to improve the energy balance of the process. Recombination with the dried pulp would also need to be studied.

In examining the methods for recombination, it was found that the stomacher blending led to a decrease in viscosity; homogenization for 5 to 7 minutes increased viscosity. When homogenizing serum and pulp made by any of the three separation methods using canned puree, viscosity was restored or increased above the control puree (canned puree). The static mixer worked well in restoring viscosity when recombining the microporous filter-separated serum and pulp. When recombining concentrated rinse/serum (13% TS) and rinsed-pulp, or when recombining high-MW (5.6% TS), concentrated low/intermediate-MW (74% TS), and rinsed-pulp, the purees obtained by homogenizing had satisfactory viscosity, but were lighter, less red, and more yellow in color than the control puree (canned puree). Fresh juice fractions of serum (13% TS) and pulp were successfully recombined by homogenization to obtain viscosity, color, and syneresis at least as good as the control (fresh juice evaporated to puree). When more highly concentrated fresh juice serum (70% TS) was homogenized with pulp and water, the puree had comparable viscosity, darker color, and satisfactory syneresis when compared to the same control. In the on-site studies, recombined puree made by homogenizing concentrated fresh juice serum (41 to 62% TS), frozen pulp, and water were compared

to control puree made of paste and water statically-mixed. The recombined purees generally had acceptable viscosity, syneresis that was usually close to the control, and color that was lighter, slightly less red, and more yellow than the control. Sensory evaluation of thermally processed control and recombined purees revealed that the recombined was smoother in texture and "flatter" or "greener" in flavor, but potentially acceptable. At the end of the storage of the serum and paste, control and recombined purees will be made for a storage study to assess their quality after storage.

The overall results of this study indicate that the process of separating tomato juice into serum and pulp, concentrating the serum to a self-preserving solids level, and recombining by homogenization produces a product which is potentially acceptable by the food industry. On-going storage studies will give more information on the products' quality. The hyperfiltration and evaporation processes will, of course, need to be optimized for the tomato serum by industry participants. Studies should be undertaken to examine drying of the pulp to reduce its volume for shipment. Preparing recombined products with the dried pulp should be included in this study. If this were successful, the whole process would become more attractive.

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APPENDIX A

ABBREVIATIONS

Btu	British thermal unit
°C	degree Celsius
cm	centimeter
cP	centipoise
°F	degree Fahrenheit
ft	foot
gal	gallon
gal/ft ² day	gallon per square foot per day
gal/min	gallon per minute
gm	gram
h	hour
hr	hour
hp	horsepower
in	inch
J	joule
K	kelvin
kg	kilogram
kJ	kilojoule
L	liter
lb	pound
L/m ² hr	liter per square meter per hour
L/min	liter per min
m	meter
mPa	milliPascal
MPa	megaPascal
psi	pound per square inch
rpm	revolutions per minute
s	second
w	watt

APPENDIX B

METRIC TO ENGLISH CONVERSION TABLE

<u>To Convert From</u>	<u>To</u>	<u>Multiply By</u>
L/m ² hr	gal/ft ² day	5.891×10^{-1}
bar	psi	1.45×10^1
mPa	psi	1.45×10^{-7}
MPa	psi	1.45×10^7
L	gal	2.642×10^{-1}
L/min	gal/min	2.642×10^{-1}
cm	in	3.937×10^{-1}
m	in	3.937×10^1
m	ft	3.2808
cm ²	in ²	1.55×10^{-1}
m ²	ft ²	1.0764×10^1
m ³	ft ³	3.5313×10^1
m ³	gal	2.642×10^2
gm	lb	2.2046×10^{-3}
kg	lb	2.2046
kg	t	1.023×10^{-3}
w	hp	1.3405×10^{-3}
J	kwh	2.7778×10^{-7}
kJ	Btu	9.478×10^{-1}

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SEPARATION, FRACTIONATION, CONCENTRATION, AND DRYING OF FOOD PRODUCTS

DOE