# Effect of Break Temperature on Rheological Properties and Microstructure of Tomato Juices and Pastes

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## ABSTRACT

The rheological properties and microstructure of canned juices and pastes made from four tomato cultivars at three breaking temperatures of 85°, 96° and 107°C were studied. The apparent viscosities of tomato juices and pastes at a constant shear rate vary with cultivars and processing conditions. The hot break process produced a high viscosity product. The microstructure of tomato pastes and juices were related to their rheology. The microstructure of tomato juice and paste also vary with processing conditions.

## INTRODUCTION

DEVELOPMENT of improved tomato cultivars for processing has been one of the major goals of the breeding programs in California. New and better cultivars of processing tomatoes are being sought which will satisfy the growers, the processors, and the consumers.

Flow characteristics of macerated tomato products are extremely important to the handling and processing procedure in preservation of fresh tomatoes. The effect of break temperature on consistency of tomato pastes has been reported by Sherkat and Luh (1976, 1977). Pastes made from M-32 tomatoes at high break temperature (104.4°C) were highest in pectin retention and consistency. Marsh et al. (1980) found that concentrated tomato products require dilution to 12% natural tomato soluble solids (NTSS) before consistency can be determined by the Bostwick consistometer. Rao et al. (1981) studied flow properties of tomato concentrates. The apparent viscosity of the concentrates of several tomato cultivar was found to be proportional to the concentration (% total solids) raised to 2.5 power.

Carbohydrate polymers in tomatoes, especially pectin, cellulose and fibers, have been shown to be related to the texture of tomato fruits and consistency of tomato products. Shomer et al. (1984) explained a mechanism which enables the cell walls to retain an homogenous appearance in tomato juice. Degradation of insoluble pectin by a relatively high concentration of exogeneous pectinase led to swelling of the cell walls and partial dispersion of the microfibrilar system. Cellulase activity led to partial or complete degradation of the microfibrilar system. Luh et al. (1984) studied pectins and fibers in processing tomatoes. Acid-detergent fiber, cellulose, lignin and cutin in tomatoes are important contributors to the consistency of tomato products.

This purpose of this study was to investigate the relationships between rheological properties and the microstructure of tomato juices and pastes made from four cultivars preheated at three break temperatures.

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## MATERIALS & METHODS

### Tomato processing

Fruits from each tomato cultivar were hand-harvested at canning ripeness with four replications. They were supplied by the Department of Vegetable Crops at the Univ. of California, Davis. Tomatoes were brought to the pilot plant in the Dept. of Food Science & Technology within 2 hr after harvest, washed, and sorted. Fifty-five kg tomatoes were used for each replicate. Tomatoes were macerated in a Rietz disintegrator with a 3.18 mm screen at a rate of 4 kg per min. The

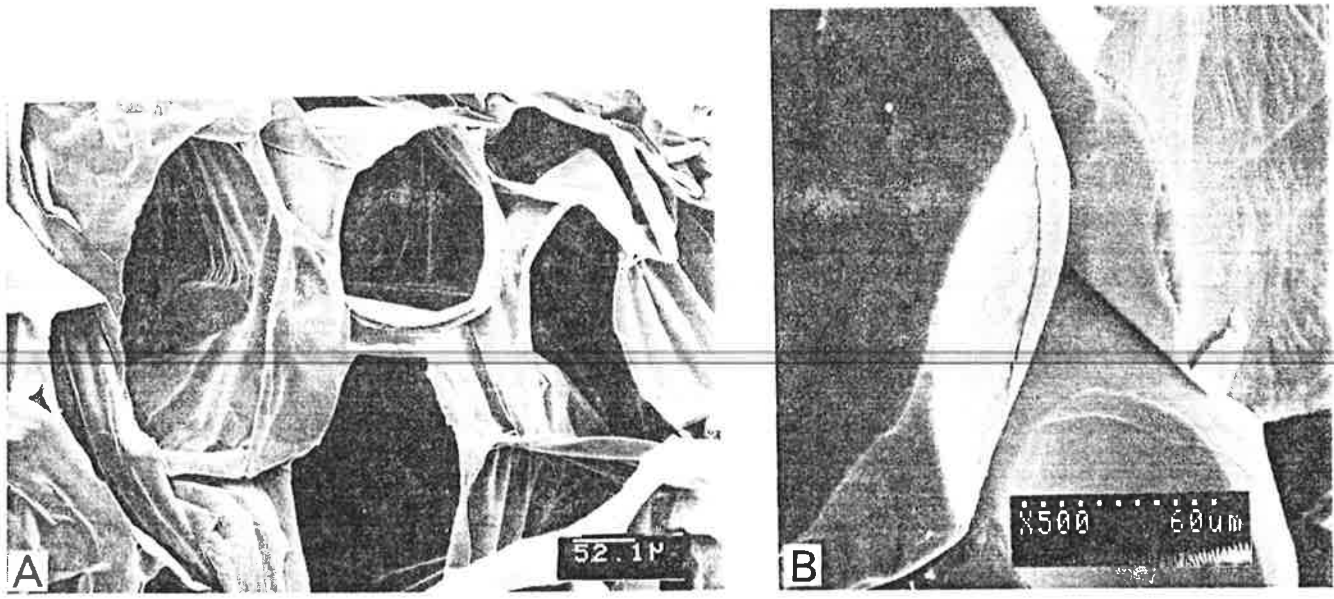

*Fig. 1—(A) Air dried pericarp from fresh Murietta tomatoes. Note empty appearance of cells and coarse folding of cell walls due to shrinkage (192X). (B) Freeze-fractured tomato pericarp from fresh Murietta (500X).*

*Table 1—Power law parameters consistency index (k) and flow index (n) at 25°C for tomato juice processed from four cultivars which were processed at three different break temperatures*

| | Break temperature °C | | | | | |
|---|---|---|---|---|---|---|
| | 85 | | 96 | | 107 | |
| Cultivar | k[a] | n | k | n | k | n |
| E6203 | 72.44 | 0.174 | 83.17 | 0.160 | 147.91 | 0.151 |
| FM785 | 63.09 | 0.188 | 72.44 | 0.194 | 117.48 | 0.149 |
| Murietta | 60.25 | 0.176 | 69.18 | 0.174 | 91.20 | 0.132 |
| H2152 | 41.68 | 0.208 | 72.44 | 0.183 | 134.89 | 0.113 |

[a] The units of k are $10^{-1}N \cdot sec^n/m^2$

*Table 2—Power law parameters consistency index (k) and flow index (n) at 25°C for tomato pastes from four cultivars processed at four different break temperatures*

| | Break temperature °C | | | | | |
|---|---|---|---|---|---|---|
| | 85 | | 96 | | 107 | |
| Cultivar | k[a] | n | k | n | k | n |
| E6203 | 2454 | 0.302 | 4570 | 0.404 | --- | --- |
| FM785 | 1737 | 0.320 | 1862 | 0.332 | 4677 | 0.423 |
| Murietta | 1819 | 0.322 | 2630 | 0.378 | 4570 | 0.400 |
| H2152 | 1548 | 0.314 | 1621 | 0.319 | 5128 | 0.417 |

[a] The units of k are $10^{-1}N \cdot sec^n/m^2$

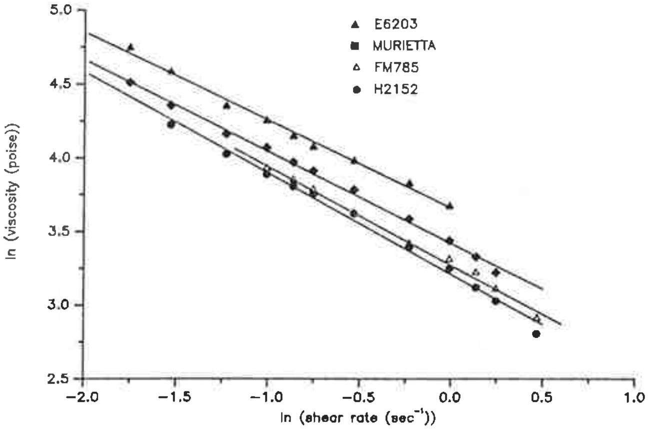

*Fig. 2—Flow curves for the four tomato pastes processed from different cultivars at a break temperature of 96°C.*

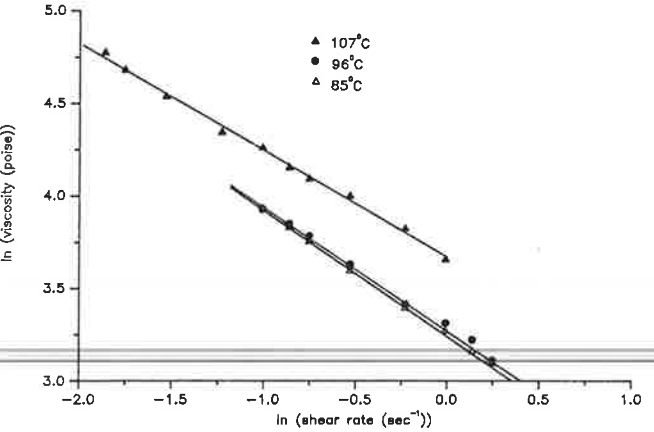

*Fig. 3—Flow curves of tomato paste prepared from FM785 cultivars which were processed at three different break temperatures, 85°, 96°, and 107°C.*

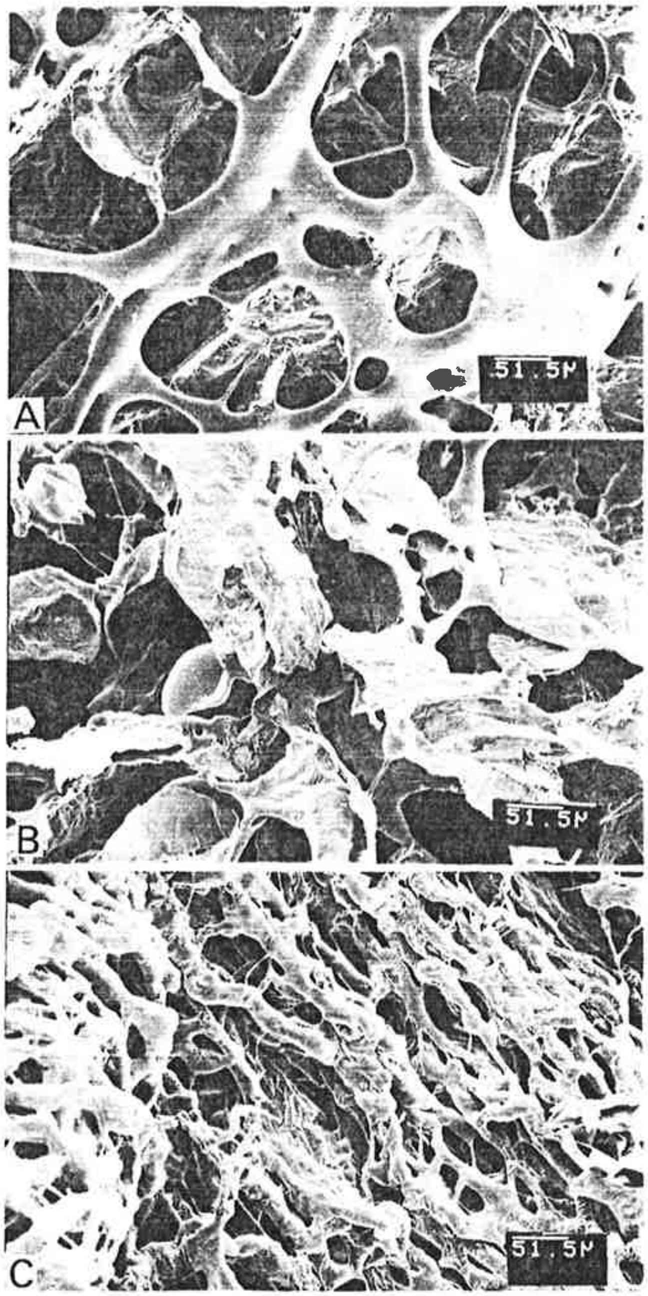

*Fig. 4—Freeze-dried tomato juice prepared from E6203 tomato cultivars processed at different break temperatures; (A) 85°, (B) 96°, and (C) 107°C (194X).*

product was immediately fed into a plate-type heat exchanger at 107°C and held for 45 sec in stainless steel pipes of 2.54 cm diameter. In the break temperature effect studies, the macerates were first heated in the plate heat exchanger to 85°, 96°, and 107°C respectively, and held for 45 sec in the holding section prior to entering the Brown juice extractor.

Skin and seeds were removed in a Brown finisher with a 1.5 mm (0.06 in.) screen. One-half of the juice was filled into #2-½ enameled cans, sealed at 87.8°C in a double seamer, and heat processed at 100°C in a rotary cooker for 10 min. Canned products were cooled in a rotary water-cooler to 38°C in 7 min.

The other half of the tomato pulp was concentrated in a Pfaudler centrifugal swept film vacuum evaporator to pastes of 30° Brix. The paste came out continuously at 45.6°C. The evaporation time was 26–30 min. The steam pressure in the jacket of the Pfaudler evaporator was at 1.54–1.69 kg/cm$^2$ (22–24 psi). The paste was filled into 202 × 306 enameled cans, sealed with steam injection over head space, heat processed in water at 100°C for 30 min and cooled in water.

## Sample preparation for SEM

Three methods of sample preparation were used. Fresh tomato tissue was cut from the pericarp into 2 mm cubes and placed on alu-

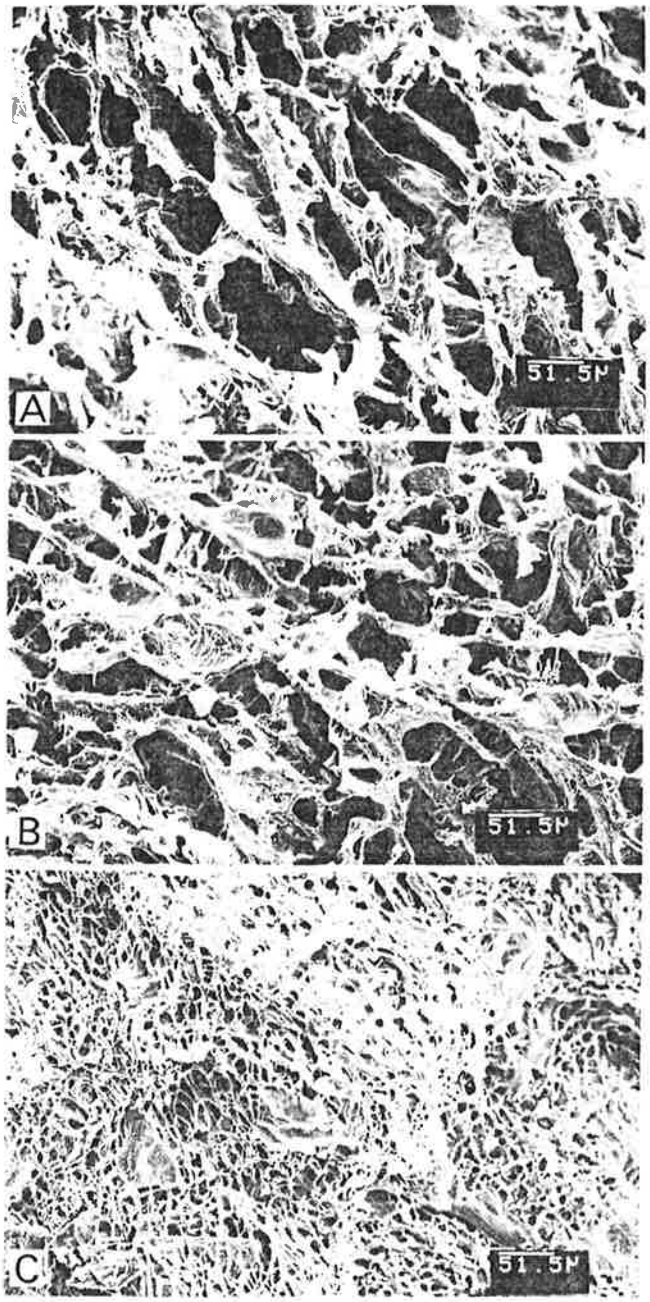

*Fig. 5—Freeze-dried tomato paste prepared from E6203 cultivars processed at different break temperature; (A) 85°, (B) 96°, and (C) 107° (194X).*

minum stubs partially coated with dried copper colloid adhesive. Preparations were placed in a vacuum oven for 30 min at 40°C, and sputtered with about 400 μm of gold. This material was examined on a ISI DS-130 SEM at 10kV (Fig. 1A).

With the second method, samples of tomato pastes and juices were freeze-dried at −50°C under 150 millitorr for 24 hr. The samples were fractured into 2 mm cubes, mounted on aluminum studs, sputtered with gold, and examined on a ISI DS-130 SEM at 10kV.

Quench freezing samples was the third method used. A sample was placed in a special holder with a part of the sample (~1mm) protruding above the holder. A sample was frozen with liquid $N_2$ slush in an Emscope SP 2000 instrument. The protruding part of the frozen sample was fractured with a cooled scalpel at −190°C and then freeze-etched at −88°C for 2 to 6 min. The specimens were sputtered with gold and transferred to a Hitachi S-800 SEM cold stage for observation (Fig. 1B).

### Viscosity determination

A Weissenberg Rheogoniometer Model R-20 was used for viscosity measurements of tomato juices and pastes at 25°C. A cone and plate combination was used for the rheological measurements of tomato juices, and two flat parallel plates (7.5cm diameter) were used for the measurements of tomato pastes.

Sample loading was a very important step. Normally an excess sample volume is placed on the bottom plate or cone. The upper plate is then lowered to an appropriate distance from the bottom plate or cone. When lowering the upper plate, the excess sample volume was extruded from the gap. This procedure works well for standard liquids and semi solid foods such as mayonnaise (Tiu and Boger, 1974; Figoni and Shoemaker, 1983). However, problems were encountered when these tomato juice and paste samples were loaded with excess volumes. Lowering the upper plate did not squeeze out the excess volume of a uniform amount of sample. A partial separation of the serum from the insoluble solids occurred with the tomato juice. Serum flowed from the gap leaving behind a more concentrated and nonrepresentative sample within the gap of the viscometer. When loading the tomato paste all of the excess sample was not squeezed from the gap, but the remaining sample was compacted by closing the gap.

Sample loading of tomato juice was accomplished by minimizing the amount of excess sample volume with a graduate pipette. A plate and a cone with 1° angle were used for loading of tomato juice.

Parallel flat plates with a gap size of 2000 μm were found suitable for tomato paste flow measurements. Normally a cone and plate geometry is preferred for steady flow measurement, since it provides a uniform shear rate at a fixed rotational speed. However, the cone angle must be small (< 30°) (Bird et al. 1960) which requires a small gap size. Loading problems such as sample compacting which dictated the choice of another measurement geometry were encountered with tomato paste. Shear rate is not constant with this geometry in the radii direction within the gap, but the apparent viscosity ($\eta$) of a sample was obtained from the following relationship:

$$\eta = (3T/2\ R^3\dot{\gamma}_{max})\ (1 + 1/3\ d\ln T/d\ln\dot{\gamma}_{max})$$

where T is the torque, R is the radius of the plate, and $\dot{\gamma}_{max}$ is the shear rate. The advantage of the parallel plates as compared to cone and plate is that the gap size is not constrained to a fixed height. This allows the use of large gap distances which worked better with high consistency tomato pastes.

## RESULTS & DISCUSSION

### Rheological behavior of tomato juices and pastes

Rheological study of the tomato juices and pastes showed these materials to be pseudoplastic fluids. The power law equation was fitted to each fluid;

$$\tau = k\dot{\gamma}^n$$

where $\tau$ is the shear stress, k is the consistency index, $\dot{\gamma}$ is the shear rate, and n is the flow index. The k and n values for each material are presented in Tables 1 and 2. Rao et al. (1981) found that the flow index, n, varied over the narrower range of 0.175 to 0.259, of over 70 concentrates made from four tomato cultivars grown in New York State. They found the flow index to be dependent on the cultivar and processing temperature but independent of the concentration of total solids which ranged from 6% to 36%.

Flow indexes for the juices (6% solids) varied between 0.113 and 0.208 and the pastes (25% solids) varied between 0.302 and 0.423 in our study. These flow indexes vary more with percent solids than the values found by Rao et al. (1981). Their study also found that the magnitude of the consistency index (k) increased with an increased total solids of the concentrates. This trend was also found in the present study (Tables 1 and 2). However, the variation of solids content was limited to two values in this study.

### Effect of varietal characteristics

Varietal characteristics had a significant influence on the viscosity of tomato products. Tomato juices made from the four cultivars showed different flow behaviors (Table 1). At any break temperature the juice viscosity was highest in E6203,

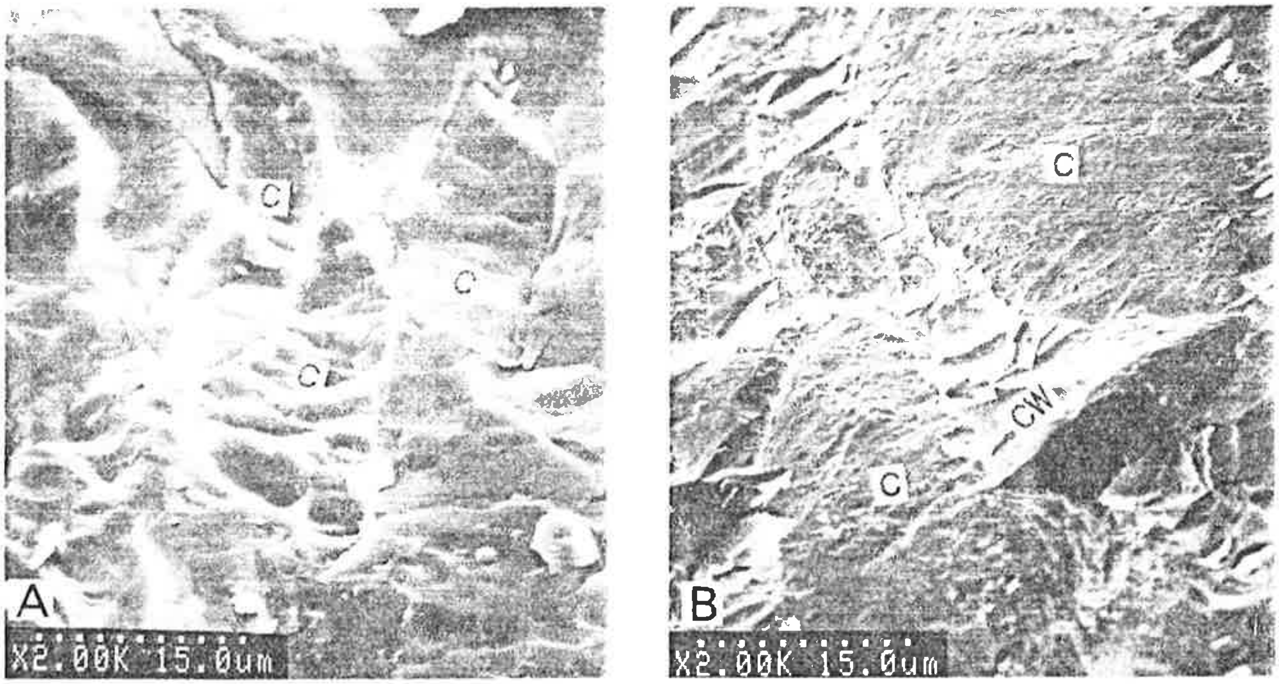

*Fig. 6—Freeze fractured tomato paste processed at a break temperature of 96°C; (A) H2152 cultivars. Note three cells (C) and coarse fracturing of the intracellular ice. (B) Murietta cultivars. Note two cells (C) and cell walls (CW).*

followed by FM785 and lastly Murietta (Table 1). Viscosity data of tomato pastes of the three cultivars (Table 2) showed the same trend as the tomato juices. The effect of tomato cultivars on paste viscosities when the break temperature was 96°C is shown in Fig. 2. A relationship between these flow properties and the structure of the tomato was studied with SEM.

### Effect of break temperature

Break temperature during processing greatly influenced the viscosity of tomato products. Each cultivar displayed similar trends in the canned juices and pastes. The highest break temperature produced products of highest viscosity (Fig. 3). The apparent viscosity of pastes made from FM785 tomatoes was highest at break temperature 107°C and lowest at 85°C. This observation may be explained by the greater degree of inactivation of the pectic enzyme polygalacturonase and pectin esterase (Luh and Daoud, 1971) at higher temperature. Pectin retention was highest at high break temperature. A more concentrated pectin colloidal solution will result in a high viscosity. The high viscosity could also be explained from the microstructure of tomato juices and pastes. When tomato juice from E6203 cultivar was freeze-dried, the soluble solids aggregated as amorphous materials on the collapsed cell wall debris. The juice made at the break temperature of 107°C showed a fine network of debris coated with amorphous deposits which probably consisted of sugars and pectins; in samples processed at lower break temperatures of 85°C and 96°C, the cell wall debris was coarser but also had deposits of amorphous material (Fig. 4). No significant difference was observed in microstructure of tomato juices made with break temperatures of 85°C and 96°C. The same relationship was noted from the small difference in viscosities of tomato juices made at break temperatures of 85°C and 96°C (Table 1). A distinct difference in microstructure and rheological behavior between tomato juices preheated at 96°C and 107°C was observed.

The relationship between the rheology and microstructure of tomato pastes processed at different temperatures was similar to that observed for tomato juices. The highest break temperature (107°C) yielded the most viscous product which was apparently related to a highly disrupted cell structure since a finer structure of freeze-dried tomato paste of E6203 was observed (Fig. 5). Also, this breaking temperature apparently resulted in more leaching of soluble pectin from the cell walls and coated the collapsed cell walls in the freeze-dried material to an amorphous network. More pectin retention resulted in more bound water in the cell wall material, which could explain why it had a high flow resistance. In contrast, the collapsed underlying cell wall material of tomato paste of cultivar E6203 was more evident when preheated at lower temperatures (Fig. 5). The lesser cell disruption in the tomato paste made at lower breaking temperatures was more clearly shown with the freeze-fractured samples. At the lower breaking temperature of 96°C freeze-fractured samples from H2152 and Murietta cultivars were examined at a high magnification of 2000x. They showed evidence of remaining cell structure (Fig. 6A and 6B). At high breaking temperature of 107°C, a freeze-fractured sample from H2152 was examined at a high magnification, but evidence of remaining cell structure could not be seen. Differences were detectable using alternate sample preparation methods on the same sample (compare Fig. 5 and 6). Freeze-fractured samples revealed cell structure in detail. The H2152 cultivar showed a higher apparent viscosity in the juice and paste made at a break temperature of 107°C. It almost approaches that of the E6203 cultivar.

## CONCLUSION

THE EFFECTS of varietal characteristics and breaking temperature on the apparent viscosity of tomato juices and pastes are in agreement with microstructure studies. It suggests that there is a relationship between rheological properties and structure of the processed tomato products. The rheology behavior is also affected by particle size distribution.

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An effort was made to measure viscosity of the product, but problems were encountered with the test.

## DISCUSSION

THE RESULTS from the 74 to 132 hr of recirculation mode testing, after estimating fluxes at common operating conditions (41.4 bar, 40°C) revealed fluxes slightly lower ($\sim$2 Lm$^{-2}$hr$^{-1}$ on average) than the results reported by Merlo et al. (1986). The rejection of NTSS was similar and high (92 to $>$98%).

The results from the 18 hr of single pass mode testing, following the 74–90 hr of recirculation mode testing on each of the two modules tested, showed high fluxes (34–48 Lm$^{-2}$hr$^{-1}$ in stage 2). This testing was performed at temperatures above the manufacturer's recommended upper limit of 80°C. As many tomato processors operate at temperatures higher than 80°C (93–100°C), it was desirable to test the membrane's performance at higher temperatures. Operation of the membrane at temperatures combined with pressures higher than recommended can result in compaction of the membrane which can cause flux decline (Pain, 1983). Testing was performed to ascertain if economical performance could still be obtained. In stage 1 when operating at the temperature of hot break juice ($\sim$93°C) combined with the inlet pressures of 33–37 bar, the flux declined, most likely as a result of membrane compaction. In stage 2 the slightly lower temperatures combined with lower operating pressures may have prevented significant compaction. The membrane rejection was not adversely affected, as NTSS rejection was $>$98%. Organic carbon, sugars, and organic acids did not permeate the membrane to any appreciable extent.

Performance at these levels of flux and rejection was considered by the membrane manufacturer to be economically feasible for preconcentration of tomato juice prior to evaporation (Pain, 1983). Because of the lack of FDA approval of the membrane at the time, longer testing of the membrane in a single pass mode was not possible. Consequently it is not known how the membrane will perform over a longer time. Results thus far are very promising and warrant a further investigation along these lines. Operating at a somewhat lower pressure (as in stage 2) may be advantageous.

The membrane tubes became plugged when operating with high concentrations of feed (9–10% NTSS) and with the flow diversion valves open. Closing these valves prevented a recurrence. For a larger scale commercial unit, the flow characteristics would need to be examined more carefully.

From examination of the permeate, there was very little loss of the product to the permeate. Further investigation should involve sending the concentrate to an evaporator and then comparing product produced with conventionally produced product.

The performance of these membranes was at a level which makes their use economically feasible for preconcentration of tomato juice. Of course, other alternatives must be compared in terms of economics as well as product produced. It appears that this is a viable alternative to be considered. Additional input from testing at high temperatures for a longer period would be useful for this assessment.

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Ms received 6/15/84; revised 9/16/85; accepted 9/22/85.

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Presented at the 44th Annual Meeting of the Institute of Food Technologists, Anaheim, CA, June 10-13, 1984.

The authors express appreciation to the management and personnel of American Home Foods, Vacaville, CA. Thanks also to PCI/The Damrow Co. for loan of equipment and assistance on the project.

This research was supported in part by a grant from the U.S. Department of Energy, Contract No. DE-FC07-81ID12227.

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Ms received 8/12/85; revised 11/2/85; accepted 11/8/85.

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The authors thank professor A.R. Spurr of the Dept. of Vegetable Crops of the Univ. of California, Davis for his technical assistance and advice concerning the SEM micrographs of the tomato juices and pastes.