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Energetics of Home Dehydration; The Effect on Product Cost and Quality

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ENERGETICS OF HOME DEHYDRATION; THE EFFECT ON PRODUCT COST AND QUALITY

by

Crystal Ann Willis

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Nutrition and Food Sciences

Approved:

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ABSTRACT

Energetics of Home Dehydration;
The Effect on Product Cost and Quality

by

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Utah State University, 1980

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Department: Nutrition and Food Science

The purpose of this study was two-fold: (1) to compare different home dehydrators and determine if the operation and design of the home dehydrators affected the color, cost, nutrient content, acceptability or flavor of the resulting products and (2) to determine the effect of physical parameters on product color, nutrient content, acceptability and flavor. The physical parameters that were measured during the dehydration process were temperature, relative humidity, and mass flow rate of air. Two products, Daucus carota var sativa (carrot) and juice of Lycopersicon sp. (tomato), were dried in each of six dehydrators (treatments). A sensory panel was used to determine the color, acceptability and flavor differences in dehydrated carrots and tomato juice from the different treatments. Carotene and ascorbic acid content were determined in the carrots and tomato juice, respectively. The total cost of dehydration was calculated by summing the fresh produce cost, energy costs, equipment depreciation and cost of labor.

The design and operation of the five dehydrators designated for home use had significantly different effects on the cost, color, flavor, and acceptability of both carrots and tomato juice. Ascorbic acid content in dehydrated tomato juice produced from the six dehydrators differed significantly, but, the carotene content of dehydrated carrots did not differ statistically between treatments.

(134 pages)

INTRODUCTION

Energetics is defined as a branch of engineering science dealing with energy transfer and transformation. In food dehydration the parameters influencing energetics include air flow rates, humidity levels, and temperature variation. Salunkhe, Do, and Bolin (1973) stated that nutrient retention and quality of dehydrated food is dependent upon the nature of the food, the care of the food, dehydration time and the parameters aforementioned.

Literature is available concerning flavor (Clan and Cavaletto, 1978) nutrient content, (Bender, 1966; Moyer, 1943; Stevens, 1943; Harris and Karmas, 1975; Labuza, 1972; Calloway, 1962) and color of dehydrated products (Lee, 1967; Boskovic, 1979; Nury, 1967; Shah and Edwards, 1977). Work has also been conducted on commercial process optimization with reference to mass flow rate of air, relative humidity and temperature variations (Fleming and Poole, 1969). Very little information is available, however, regarding the relationship of these parameters to product quality.

At present, a large segment of the Utah population dehydrates fruits and vegetables during the harvest season. The <u>USU Annual Extension Report</u> (USU Extension, 1977) estimated one out of every four Utah homes has a home dehydrator. As evidence of the increased popularity of dehydration in the home, sixty-three thousand of the bulletins entitled <u>Home Drying of Fruits and Vegetables</u> were distributed during the three year period of 1974-1977 to residents of Utah as well as other areas. One distributor of home dehydrators reported that in 1977 his company alone sold several thousand dehydrators (Shalenburger, 1978).

Extension agents in Logan and Salt Lake City, Utah reported that several hundred people request information concerning the cost and quality of dehydrators and home dehydrated food each year. Consumer responses to publications, classes and workshops throughout the state indicate that homemakers are interested in learning the best methods of dehydration in order to obtain a high quality product at a lower cost. Despite the current interest in home dehydration, very little information is available concerning the comparitive drying efficiency, cost and quality of food preserved using equipment designed for home use.

There are a variety of home dehydrators available to the consumer. They vary in initial cost, load capacity, mass flow rates of air, dehydration temperature etc. Comparative physical parameters between commercial and home dehydrators can be correlated to differences in product cost and quality.

The aim of this study is to compare the energetics of six dehydrators (one commercial pilot plant dehydrator and five home dehydrators) correlate energy usage and transformations with nutrient retention, color stability and flavor differences in the dehydrated product and develop models from these correlations. These models may be useful in developing recommendations to improve quality in home dehydrated foods. These recommendations may assist consumers in making informed purchases based on cost and efficiency. They may also provide guidelines for manufacturers to improve the design and efficiency of home dehydrators.

REVIEW OF THE LITERATURE

Historical Background of Drying and Dehydration

Preservation by drying of fruits and vegetables dates back to pre-Biblical times. As early as five thousand years ago, the Chinese and Hindus used sun and wind for drying fruits, vegetables and herbs (Salunkhe, Do, and Bolin, 1973). The Peruvian Incas of two thousand years ago utilized the warm dry days and cold dry nights to make "chuno", a potato product made by repeated freezing, thawing, and juice extraction. As was done in ancient times, the juice extraction today is still accomplished using the pressure of bare human feet (Willis, 1977).

Prescott and Proctor (1937) reported that in the United States food drying originated with the Indians who used sun, wind and fire to dry fish. Up until the late 1870's both home processed and commercially prepared dried fruits and vegetables were sun dried. Farmers of the late 19th and early 20th centuries utilized the drying process to preserve fruits until better marketing opportunities were available (Gould, 1907). Home drying also became more popular. At the turn of the century strings of drying apples could be seen in the windows of farm houses in central New York. Publications were available to instruct U.S. homemakers in the proper methods of drying fruits and vegetables (USDA, 1917).

The early drying processes provided a method of preservation in the absence of adequate refrigeration. Drying was confined to areas of favorable climatic conditions. Unexpected rains sometimes leached out the sugar, and other soluble materials and made the product more susceptible to fungal contamination and growth. Cold weather lengthened the drying time required. Since the product was exposed to the sun and air, it was quite vulnerable to contamination by insects, insect larvae and microorganisms. Dehydration, a process of water removal, utilizing a heat source, was generally faster, more sanitary, more uniform, and more reliable than sun drying. Dehydration probably originated in France and was developed by Masson and Challet. The first public record of dehydration was published in the 18th century. Vegetables were treated with hot water prior to hot air dehydration (Prescott and Proctor, 1937).

In the U.S., mechanical evaporation of apples and peaches began in the late 19th and early 20th century (Beattie and Gould, 1917 and Gould, 1907). Eisen, another early promotor of dehydration, merely heated a room with a stove and laid out the cut food product on wooden racks (Prescott and Proctor, 1937).

Dehydration became more sophisticated as time went on. Breamer (1925) invented one of the early electrical dehydrators in this century. According to his patent, the machine contained removable trays for holding the raw product, a heat source which regulated air temperature and a humidity sensor which increased the fan speed when the relative humidity was too high. Each removable perforated tray was enclosed within a slanted compartment. Breamer claimed that dehydration was uniform and rapid because the air entered each compartment separately, and was not allowed to diffuse to another compartment. A patent was also granted to Judelson (1925) for a dehydrator with many of the same properties. However, humidity control was dependent on natural diffusion through the baffles. In 1928, Whorf received a patent for a dehydrator which maintained constant air temperature, humidity and a higher degree of product uniformity than did the stove heated rooms and the earlier evaporators.

In spite of these advances in commercial dehydrators, it was not possible to purchase an electric dehydrator for home use prior to the early 1970's (Bills and Bills, 1978). Many homemakers were forced to rely on the sun, an oven, or a stove top dehydrator. Stove top dehydrators were used in combination with coal or wood type burning stoves and had several disadvantages such as poor temperature control, production of off-flavors and poor colors due to smoke and soot (Prescott and Proctor, 1937). Recently a wide variety of home dehydrators varying in size, cost, construction materials, temperature and fan regulators have become available to consumers. The manufacturers of these dehydrators often make claims concerning quality and nutrient retention in the final product.

Three main types of convective atmospheric dehydrators have been used commercially. Kiln driers consist of a two story building with a burner on the bottom floor and an upper drying room. This process depends on natural diffusion of heated air through the slits in the floor and later through the exhaust. Cabinet or tray dehydrators are another kind of batch dehydrator. Warm dry air is forced over removable trays of food and exhausted as moist air. A heater is often present within the drier to hasten the dehydration process. Many of these dehydrators have temperature, humidity and air flow controls. The most common type of dehydrator in present day use, however, is the continuous hot air drier. In this system food trays or belts through a tunnel which provides the appropriate conditions for dehydration. This system generally offers more control since temperature, air flow, and relative humidity are regulated according to the specific product. Some systems may employ two or more stages with different air flow, temperature and relative humidity schemes for different stages during product dehydration (Karel, 1975).

Home dehydrators differ greatly from commercial dehydrators. In general, home dehydrators are smaller, lack temperature humidity and air flow controls, and do not provide the homogenous conditions that commercial dehydrators provide. Since all these physical parameters affect product cost, quality and nutrient retention, the data and information present in the literature cannot entirely be applied to home dehydration.

Drying Rate Behavior

Dehydration of most foods is characterized by two phases, a constant-rate period and a falling-rate period. Harper (1976), and Heldman (1977), reported that in a critical-rate period the food exists at a relatively high moisture content and ambient temperature is well above product temperature. During the constant-rate period dehydration moisture evaporating from food absorbed heat energy to overcome the latent heat of vaporization. The absorption of this heat energy lowers ambient temperature and causes the product temperature to remain low in comparison with air temperature. The constant-rate period had a greater dependency on external variables such as ambient temperature, relative humidity and air flow than the falling-rate period.

The second general stage was the falling-rate period (Harper, 1976 and Heldman, 1977). It was characterized by an intermediate to low moisture condition in the food, a drop in ambient relative humidity and increased product temperature. In contrast to the constant-rate period the drying rate in the falling-rate period was reduced due to the small difference between air pressure and product vapor pressures, and internal factors such as pore size, product temperature and diffusion pressure.

Effect of Dehydration Parameters on Product Quality and Nutrient Retention

Processing foods partially removes and alters many of the nutrients in them. Since nutrients are essential for life it is desirable where possible to minimize their destruction. Dehydrated fruits and vegetables contribute mainly carbohydrates, vitamins and minerals. Of the vitamins found in dehydrated foods, two of the most heat sensitive are ascorbic acid and beta-carotene.

Factors affecting degradation of ascorbic acid during dehydration are complex. Labuza (1972) reported that a 10C increase in temperature results in a two-fifteen-fold rate increase in ascorbic acid degradation. Lowering air temperature during dehydration, however, does not necessarily aid in additional retention because it increases the time food is exposed to dehydration temperatures.

In a study reported by Harris and Von Loesecke (1960) ascorbic acid retention in riced potatoed was compared for two different dehydration schemes (a high and a low temperature scheme). Each scheme was divided into two stages. Exit temperatures for the two schemes were different in the first stage but identicle in the second. Relative humidity was the same for both dehydration schemes. The higher temperature scheme (93.3 to 76.6C) resulted in significantly greater ascorbic acid retention than the lower temperature scheme (93.3 to 54.4C). Ascorbic acid retention was observed to be inversely proportional to dehydration time in the first period of dehydration when the moisture content is high. This was mainly due to two factors: (1) the activation energy for ascorbic acid degredation is lower at higher moisture potentials (Labuza, 1972) (2) despite high air temperatures, product temperature was low at this stage due to the cooling effect of evaporation. In the same study a comparison between wooden and metal drying slats revealed an advantage in the use of metal drying slats. A faster dehydration rate and better ascorbic acid retention resulted primarily due to increased heat transfer from the metal slats to the riced potatoes.

Harris and Loesecke (1960) reviewed early literature and found losses of ascorbic acid during dehydration to range from 10 to 50 percent. Shelley (1978) reported losses ranging from about 15 percent in untreated apples to 85 percent in untreated bananas using a home model electric dehydrator. In Shelly's study he compared several home dehydration methods. Beta-carotene and ascorbic acid retention were comparable or greater in the higher temperature method of electrical home dehydration than in the three solar methods he used. He concluded that longer dehydration times and additional exposure to light increased degradation of these vitamins.

Bluestein and Labuza (1975) stated that any process which increases drying rate without increasing the product temperature would aid in ascorbic acid retention. These processes included decreasing the size of the product piece, and anything which would lower relative humidity such as drying the air or increasing the air flow.

Bluestein and Labuza (1975) hypothesized that at least two deteriorative mechanisms for beta-carotene exist. The first is a free-radical oxidation mechanism of low activation energy which occurs most rapidly at very high and very low moisture potentials but slowly at low moisture potentials. The second is a direct thermal reaction. Calloway (1962) indicated that beta-carotene retention is generally higher for dehydrated carrots than for canned carrots although the dehydration process time is longer. Higher temperatures in conjunction with the constant high moisture potential, probably account for lower beta-carotene in the canning process.

Good retention of beta-carotene can be expected if foods are blanched prior to dehydration. Calloway (1962) reported a 70-100 percent retention of beta-carotene in blanched dehydrated foods. He also indicated that beta-carotene data from early literature were low because blanching was not practiced. This probably accounts for the low retention reported by Stevens (1943). In carrots and sweet potatoes he indicated a 40-75 percent retention. Shelley (1978) reported up to 100 percent retention of beta-carotene in various home dehyrated products.

Processing practices likely to retain higher quantities of beta-carotene include decreasing the time spent in the high moisture stage by using a moderately high temperature for that stage and decreasing relative humidity. Beta-carotene is less stable in the presense of air than in other gases (Bender, 1966; Stevens, 1943). Increasing air flow may increase oxidative degredation by increasing product exposure to oxygen.

Physical parameters such as mass flow rate of air, relative humidity and temperature affect product texture, color and flavor in addition to nutrient content. Kramer and El-Kattan (1953) found that intensity of red color in processed tomato juice increased with time as the temperature surpassed 60C. Boskovic (1979) outlined the fate of lycopene in dehydrated tomato systems. All-trans-lycopene (ATL) was the most common form in which lycopene was isolated from natural systems. Boskovic reported that up to 20 percent of ATL can be changed during foam mat dehydration at 50C to the cis-isomers. Further degradation to smaller molecules may take place during the dehydration process. Cis-lycopenes have somewhat less color and may revert to ATL or may oxidize resulting in a faded product with off-flavors described as "hay flavors". The conversion of ATL to the cis-isomers was not detected in spray dried or freeze dried tomato juice (Wong and Bohart, 1957). Boskovic hypothesized that this was due to uniform heat, quick dehydration, and low temperature in the case of freeze dehydration.

In tomatoes about 95 percent of the flesh pigment is lycopene and 5 percent orange beta-carotene. These pigments are almost entirely responsible for juice color (Francis and Clydesdale, 1975). Likewise, carotenoids are largely responsible for carrot color. Beta-carotene, alpha-carotene and xanthophyll comprise 90 percent of the total carotenoids in carrots while gamma-carotene and all-trans-lycopene constitute most of the remaining pigment (Goodwin, 1952; Francis and Clydesdale, 1975). These polyunsaturated hydrocarbons may oxidize or polymerize during dehydration. This causes them to reflect different wavelengths thus changing the product color (Francis and Clydesdale, 1975 and Tannenbaum, 1976).

Nonenzymatic browning also plays a role in food color as well as flavor. This process takes place faster at higher temperatures and near a water activity of 0.7. The chemical changes involved with nonenzymatic browning are manifested as a change in color and often a change in flavor. These changes have been studied by Boskovic (1979), Barnell, Gooding and Wager(1955); Tannenbaum (1976). Tannenbaum indicated that dehydration incites other degradative processes which alter flavor, color, and acceptability, such as oxidation of lipids, disruption of cell membranes and other cellular structures. He further states that the most perfect indicator that we have of the chemical and biochemical changes in processing is the quality of the final product.

MATERIALS AND METHODS

Evaluation and Comparison of Dehydrators

Selection

Six dehydrators, including a pilot plant size dehydrator, were selected for use in this study on the basis of cost, size some unique feature or claims made by the manufacturer. The dehydrators were assigned random letters to insure that no implication of brand name was made. For comparitive purposes a pilot plant dehydrator with humidity and temperature control was included in this study (Proctor and Schwartz, Philadelphia, PA). The pilot plant model simulated very closely a commercial batch type dehydrator. Tray surface area was measured in square meters and the volume of each dehydrator was measured in cubic meters using a meter stick. Load capacity was calculated as the maximum number of 60 x 15mm petri dishes that could be placed in a single layer on the dehydration trays when all the trays were used.

Sampling Locations

In preliminary trials, samples dried at different rates depending on their position within each dehydrator. In dehydrators A and B, the fan and coil were located in the back of the cabinet, so the samples located in the front dried more slowly than those situated in the back. The rate of dehydration in dehydrators A and B was also faster in the bottom trays than in the top trays. For this reason, dehydrators A and B were divided into four sampling sections top front, top back, bottom front and bottom back. Dehydrator C had a small cylindrical fan which pulled air through perforations on the side of the cabinet and forced it over the heating coil. Both the fan and the coil were compartmentalized under the dehydration cabinet. In order to pass over the dehydrating food, heated air from the compartment was required to move upward in the hollow walls through baffles and across the food. It was also observed that an anemometer placed above the shelves in dehydrator C, gave a reading much lower than the reading observed on the exit port. It was easier for heated air to move upward in the hollow walls, through baffles and out the exit port than to move across the food. Dehydrator C was divided into the same sampling sections as A and B. Food samples from different sections in dehydrator D dried at comparable rates in preliminary trials. Dehydrator D was divided into two sampling sections top and bottom due to reasons which will be discussed later. The heating coil in dehydrator E, (the smallest dehydrator) was located in the bottom of the cabinet. Each of the four drawers in dehydrator E was designated as a seperate sampling section according to their distance from the heating coil.

Hereafter sampling sections one-four refer to top front, top back, and bottom back, respectively, for dehydrators A, B and C. Sampling sections one and two refer to top and bottom, respectively, for dehydrator D, and sampling section one means center trays for the pilot plant dehydrator. Sampling sections one-four refer to drawers one-four, respectively, where four is the drawer closest to the coil.

Physical measurements of air temperature in different areas of each cabinet were used to reinforce the sampling design described previously. Each dehydrator was evaluated for variations in internal cabinet temperatures by operating the empty dehydrator for 10 minutes and recording the temperature in different parts of the cabinet. Temperature was measured using four copper-constantan thermocouples attached to a Speedomax recorder (Leeds and Northrup, North Wales PA 63148).

Mass Flow Rates of Air

Exit mass flow rate of air was determined in each home dehydrator using the following equation

$$M = \rho \nu A$$

where M is equal to the mass flow rate of air, ρ is equal to the density of air (using the temperature at midpoint in dehydration) ν is equal to the velocity over the entire cross sectional area, and A is equal to the cross sectional area. Velocity of exit air was measured in each home dehydrator by covering the entire dehydrator with a 0.15 mm thick polyethylene bag and allowing air to enter through a single orifice and permitting it to escape only through an anemometer (Kauffel and Eisen). The mass flow rate of air in the operating pilot plant dehydrator was determined by placing a metal cone over the exit port to funnel the air into a circular opening the same size as the anemometer. The mean of three velocity readings for each dehydrator was used for calculations of mass flow rate of air.

Measurement of Temperature and Relative Humidity

A copper-constantan thermocouple attached to a Speedomax recorder (Leeds and Northrup, North Wales, PA 63148) was placed at the exit port of each dehydrator to measure air temperature during the entire dehydration process. A thermometer equipped with a wet stocking was situated on a portion of the exit of each dehydrator to measure wet bulb temperature. Measurements of wet bulb temperature were monitored throughout the dehydration period. The thermometer was shielded from the coolness of outside air by a paper cup taped to the exit port (Figure 1). The stocking on the wet bulb thermometer was maintained in a moist condition. Normally wet bulb temperature is measured by grasping the pivoting handle of a sling psychrometer and rotating the wet and dry bulb thermometer rapidly several times before taking a reading. Since the wet bulb thermometer in this experiment was by necessity intact, it was allowed to come to equilibrium. A computer program employing the calculations explained by Batty (1979) and Van Wylen (1963) was used to calculate relative humidity from wet and dry bulb temperatures (Appendix A). Temperature and relative humidity data for three runs were fit to a polynomial equation as a function of time (Ryan, Joiner and Barbara, 1976).

Energy Calculations

Total energy consumption for each home dehydrator was measured using the following equation:

$$\text{Total kW.hr} = \text{kW fan} \times \text{hr fan only} + (\text{kW fan} + \text{kW coil}) \times \text{hr (fan + coil)}$$

where total kW.hr is equal to the total energy consumed during dehydration, kW fan is equal to the kilowatts consumed by the fan alone without the coil and kW fan + kW coil is equal to the kilowatts used by the the fan and the coil together. All the dehydrators except dehydrator E contained thermostats. A watt and volt meter (Simpson,

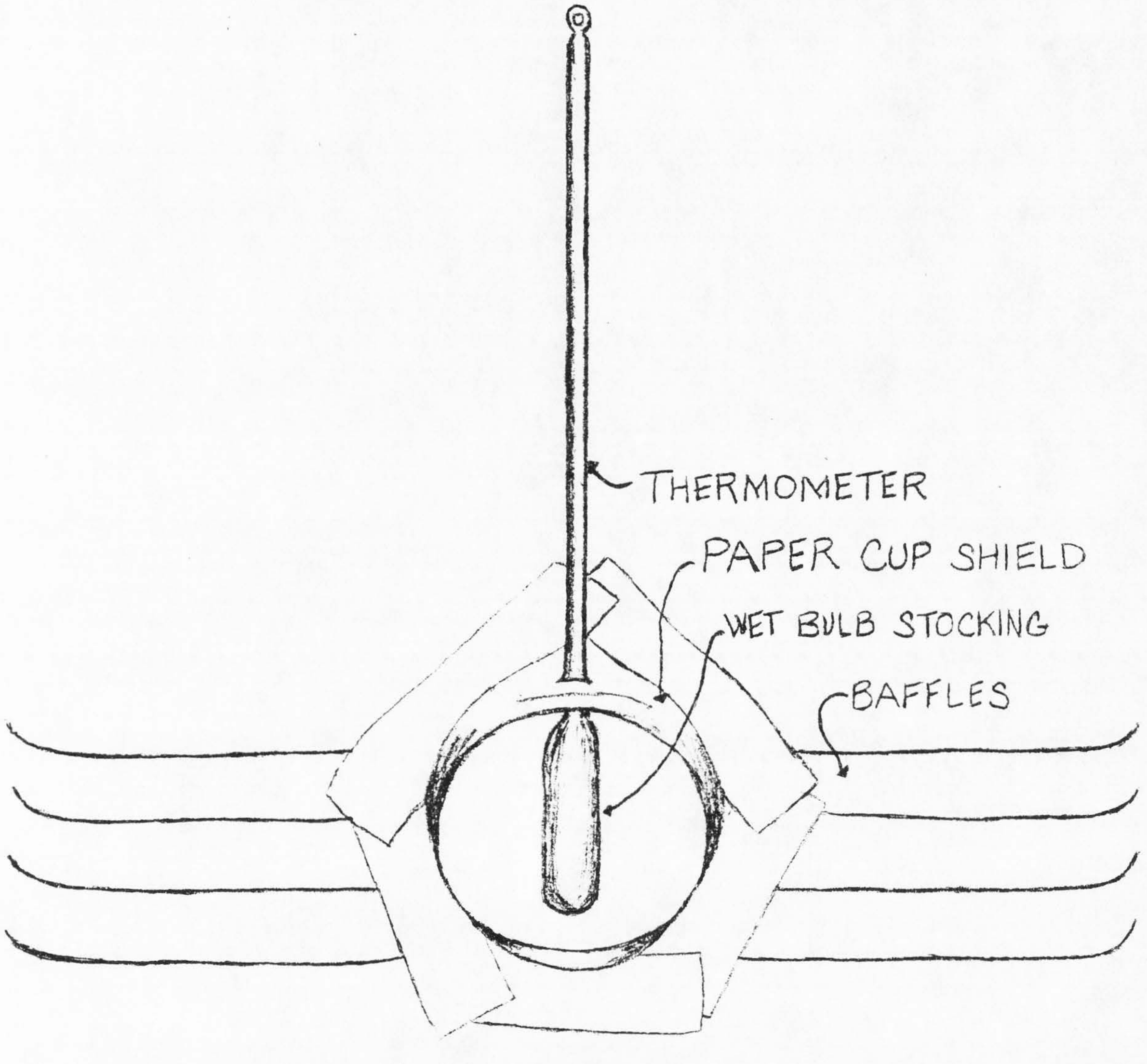

Figure 1. Cut-away section of wet bulb thermometer apparatus.

Chicago, IL 60644) was used to monitor the power requirements, when the thermostat switched on the heating element and when the thermostat switched the heating element off. When the coil was switched off, the power requirements for the fans were determined. The time that the fan only was on was determined by using continuous temperature recordings (obtained in the manner described in the preceeding section) and measuring the time that the temperature rose above the temperature required to switch on the coil.

Calculation of energy consumption in the pilot plant dehydrator included the kilowatt hours to run the electric fan, kilowatts hours used in an electric air compressor, kilowatt hours of steam heat required to warm inlet air and kilowatt hours lost through the walls of the dehydrator (Appendix B).

Calculation of Product Cost

Total dry product cost was determined using the cost of the raw produce, adding to this the energy costs (assuming 5.3 cents per kilowatt hour) (Utah Power and Light Co., 1980), incorporating the cost of paying minimum wages ($2.90, July, 1979) for prepartion and adding the machine usage cost. Machine depreciation was calculated by assuming a 2500 hour usage life on each of the home dehydrators. The cost of the dehydrator was divided by 2500 and multiplied by the number of hours required to dehydrate one batch. Machine depreciation of the pilot plant dehydrator was calculated by assuming 10 percent depreciation per annum.

Preparation and Dehydration of Carrots
(Daucus Carota var Sativa)

Carrots were selected for dehydration because of the year-round availability, the facility with which they are ground and the relatively high content on beta-carotene. Approximately 15 kg of top-quality carrots were selected from a local wholesale dealer. The carrots were then washed and finely ground, using a grinder (Hobart, Troy, NY) after removal or the stem and tip ends. Steam blanching of the ground carrots was accomplished by placing a 4-6 cm layer of freshly ground carrots in a large perforated metal basket and placing the filled perforated basket in a steam jacketed kettle (Groen Mfg. Co., Chicago 39, IL) over boiling water. The lid was closed and the temperature of the carrots was monitored by a vat thermometer (Taylor Creamliner, Rochester, NY). The product was brought up to 88C removed and placed in a 15 gallon stainless steel container. The container was then immersed in ice water for approximately 30 minutes then placed in a 6C cooler for 12 hours. After 12 hours, the entire batch was mixed thoroughly for about 10 minutes. A fresh sample for nutrient, color and moisture analysis was then taken and placed in an air impermeable, heat sealable, flexible bag (Daisy Products, Kansas City, MO). The bag was stored at 6C in darkness to minimize exposure of carrots to heat, light and air. Fresh samples such as these were taken throughtout the loading process. Plastic petri dishes (60 x 15mm) filled with carrots, were placed in each dehydrator until each cabinet contained the maximum number of petri dishes possible. The average weight of 52 measurements of ground carrots in petri dishes was 21.0 g, with a standard deviation of 2.19. Two trays of the pilot plant dehydyrator were filled to provide enough product for color, flavor and nutrient analysis. Each dehydrator was filled to capacity to collect energy consumption data. Temperature settings for the dehydrators followed manufacturers recommendations. When all of the product was dry (below 7 percent moisture) each dehydrator was turned off, the time recorded, and the dehydrator was unloaded. The dehydrated product was placed in an air impermeable, heat sealable bag (Daisy Products, Kansas City, MO) and stored at -20C for not more than 48 hours before being ground with a Grindall grinder (Ram Products, Inc., Provo, UT). Particle size was standardized to pass through a No. 40 US standard sieve. This sample was assayed for moisture, carotene and objective color. The proceedure described above was repeated three times on three different lots of carrots (Figure 2).

Dehydrated Carrot Analyses

Carotene Determination

Duplicate 2g subsamples of each sample from each treatment were collected and quantitatively assayed for carotene using method 43.018-43.023, (Association of Analytical Chemists, 1975) which seperated xanthophylls from carotenes. A randomized block design analysis of variance was used for statistical analysis of the carotene data (Hurst, 1979).

Moisture Analysis

Where possible, triplicate subsamples of about 5g were taken for moisture determinations using method 22.012-22.013 (Association of

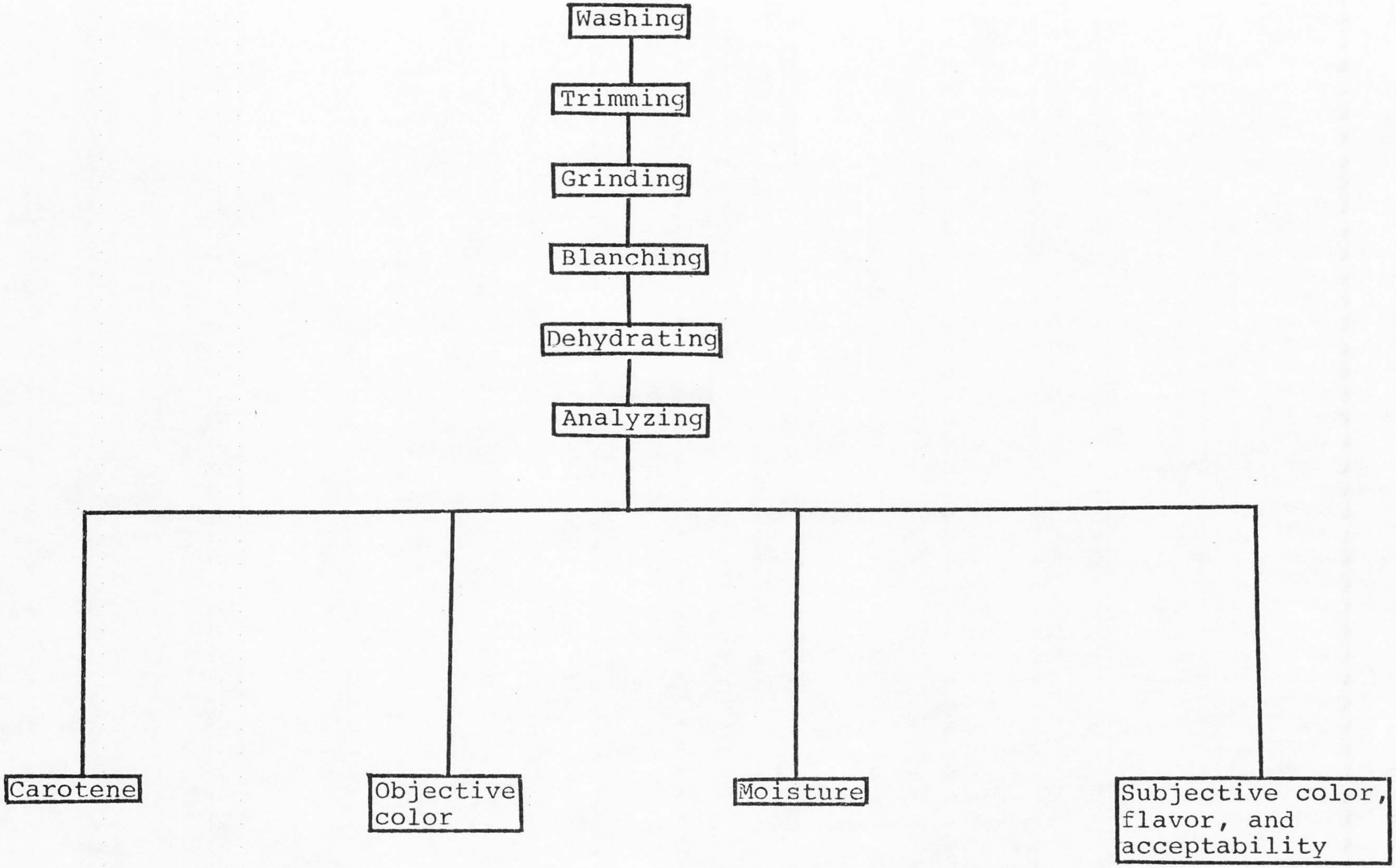

Figure 2. Flow sheet for carrot dehydration and product analysis.

Analytical Chemists, 1975). In a some cases sample was limited to duplicates.

Objective Color Measurement

Duplicate 4.5g portions of the ground sample were rehydrated with 50ml of 20C distilled water and stirred until evenly rehydrated (approximately one minute). The Hunter "L", "a", "b", and CIE "Y" values were then measured on a Hunter Lab Color Meter (Hunterlab, Fairfax, VA) standardized using an L=46.2, a=32.9, b=26.8, Y=21.3, X=24.3 and z=4.1 color standard (Pomeranz and Meloan, 1971). The Hunter "L" value is an indication of lightness and darkness, a positive "a" value indicates redness, and the possitive "b" value indicates yellowness. The CIE "Y" value is also a measure of lightness and darkness and is equivalent to $(L/10)^2$. The Hunter Color Meter data were analyzed with an analysis of variance for a randomized block design (Hurst, 1979).

Sensory Evaluation

The quantity of water required to rehydrate the dehydrated carrot sample for sensory testing was calculated from the average moisture content of the sample and the moisture of the fresh carrots. The dry carrot samples from each of the six dehydrators were added to boiling water. The carrots and water were boiled for 15 minutes and kept warm (approximately 80C) in a steam tray until they were presented to the panel of 41 judges. A nine point hedonic scoring test was used to assess typical carrot flavor, color and over-all acceptability (Amerine, Pangborn, and Roessler, 1965). An analysis of variance and LSD test for a completely randomized design were used to determine the significant difference between the color, flavor and acceptability of product from the six treatments (Ott, 1977; Hurst, 1979).

Preparation and Dehydration of Tomato Juice (Lycopersicon esculentum)

The procedures for dehydrating tomato juice were very similar to those used in the preparation and dehydration of carrots. Tomatoes were chosen because they are readily availabile, the facility with which juice is extracted, and the relatively high content of ascorbic acid. Ten kg of tomatoes were selected from a local wholesale dealer. The fresh tomatoes were washed and the blossom end removed. The tomatoes were partially blanched for one minute above boiling water in a steam jacketed kettle (Groen Mfg Co., Chicago 39, IL) at approximately 98C to facilitate juicing with a Victoria Strainer (Vitantonio Mfg., Willoughby, OH). The resulting juice was stirred and heated in a steam jacked kettle till a vat thermometer (Taylor Creamliner, Rochester, NY) read 82.2C, then mixed until homogenous, then emptied into a 15 gallon container and cooled by placing the container in ice water prior to refrigeration at 6C where it remained until dehydration. Ten ml of tomato juice was delivered to each petri dish. The loading, unloading, packaging and storing operations were identical to the proceedures used in the carrot experiment (Figure 3).

Dehydrated Tomato Juice Analyses

Ascorbic Acid Determination

Not more than 48 hours following dehydration, triplicate fresh and dried samples were assayed for ascorbic acid. The assay utilized

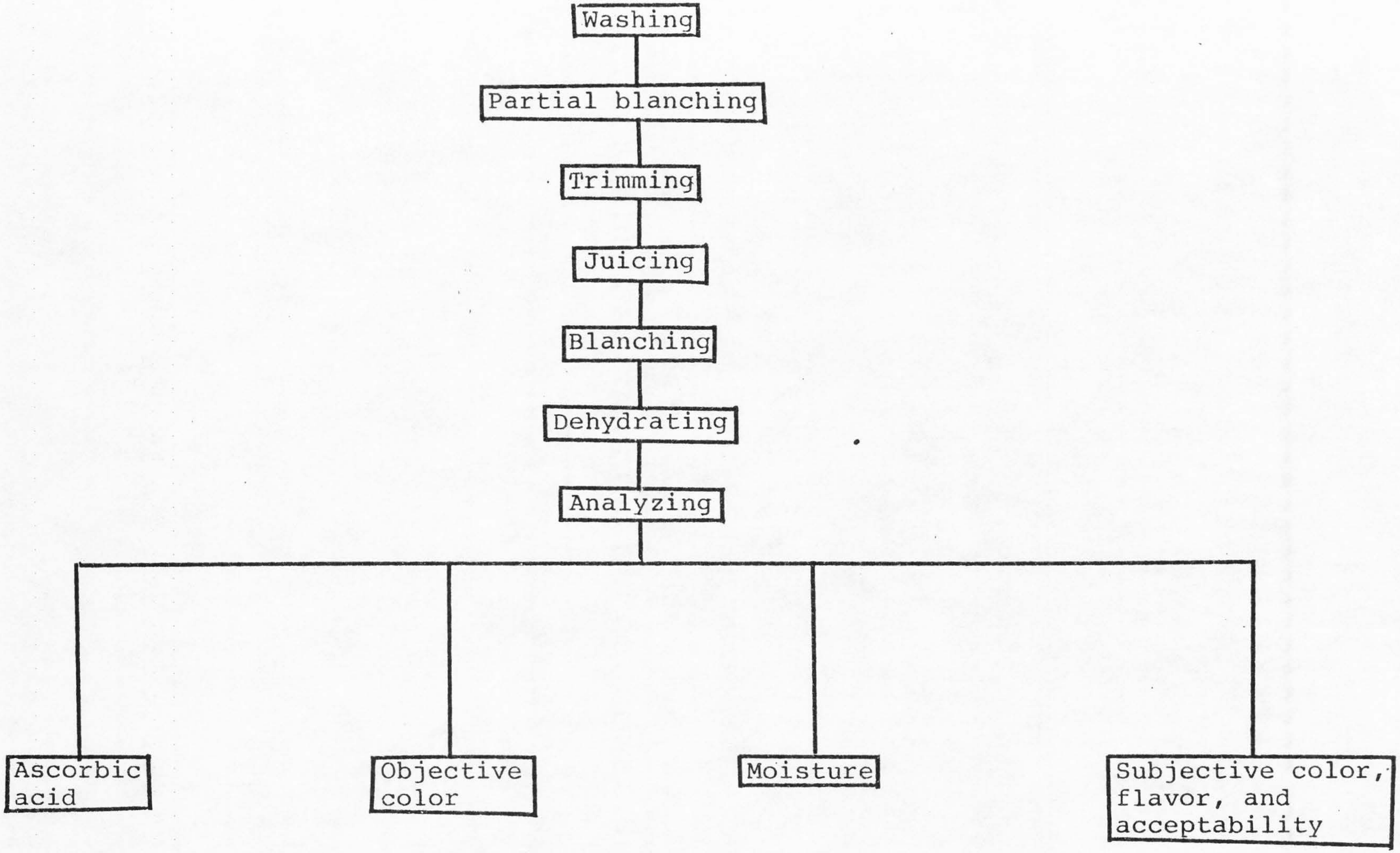

Figure 3. Flow sheet for tomato juice dehydration and product.

Ruck's method (1963) with two modifications. A Spectronic 21 spectrophotometer (Bausch and Lomb, Rochester, NY) set at 520 nm (Owen and Iggo, 1956) was used instead of a Klett-Summerson colorimeter and a number 540 filter) for measuring ascorbic acid concentration. An extracting solution prepared according to method 43.052 (Association of Analytical Chemists, 1975) was used in place of the Ruck extracting solution because Ruck's oxalic acid extracting solution foamed more with the tomato juice in blending than the method described by the AOAC. Both solutions gave comparable results.

Moisture Analysis

Where possible triplicate subsamples of about 5g were taken for moisture determinations using method 22.012-11.013 (Assocation of Analytical Chemists, 1975). In a some cases sample replication was limited to duplicates.

Objective Color Measurements

Dried tomato samples were rehydrated to fresh moisture content by blending them with distilled water at 20C in a high speed blender (Sorvall inc., Newton, CT) for one minute. Duplicate color readings on the Hunter Color Meter followed the format described for carrots except that the instrument was calibrated to an L=25.9, a=27.4, b=13.1, Y=6.7, X=10.5, Z=2.1 standard color disk. The statistical analysis employed a randomized block analysis with subsampling and an LSD test (Ott; 1977, Hurst, 1979).

Sensory Evaluation

Samples of dehydrated tomato juice were taken the same way as dehydrated carrot samples were taken. The samples were rehydrated to fresh moisture content and served to 59 judges. Typical tomato flavor and color and overall acceptability were quantified and the results statistically analyzed following the same format as the carrots.

Statistical Analyses of Dehydration Variables

Simple linear regressions were prepared correlating the data from each dehydrator to produce a two dimensional correlation matrix. The regressions involved the factors that consumers most frequently asked about. The following are the list of variables used:

> Cost/kg of dehydrated tomato juice, cost/kg dehydrated carrots, total kW.hr for tomato juice dehydration, total kW.hr for carrot dehydration, mass flow rate of air, initial cost of dehydrator, color score for rehydrated tomato juice, color score for rehydrated carrots, flavor score for dehydrated tomato juice, flavor score for dehydrated carrots, acceptability score for rehydrated tomato juice, acceptability score for rehydrated carrots, square meters of surface area of trays, volume of cabinet in cubic meters and maximum temperature difference between different portions of the dehydrator.

All of the quality factors such as color, nutrient retention and flavor were modeled statistically using a step by step multiple regression (Nie, Hull, Jenkins, Steinbrenner, and Bent, 1975). The dependent and independent variables used were as follows:

Independent variables: Total time of dehydration (TOTIME), mass flow rate of air (AIRFLOW), temperature at dehydration time = 1 hr (INTEMP), final dehydration temperature (FINTEMP), slope of the dehydration temperature curve (TEMPSLOP), exit relative humidity of dehydration at time = 1 hr (RHIN), exit final relative humidity of dehydration (FINRH), the slope of the curve of relative humidity (RHS), Natural log of RHIN (RHLN), reciprocal of RHIN (RHI), and reciprocal of TOTIME (RECT).

Dependent variables: Color score as determined by taste panel judges (COLORS), flavor as determined by taste panel judges (FLAVOR), acceptability as determined by taste panel judges (ACCEP), concentration of carotene in dehydrated carrots on a dry weight basis (NUTR), concentration of ascorbic acid in dehydrated tomato juice, on a dry weight basis (NUTR), Hunter L value (C1), Hunter a value (C2), Hunter b value (C3) and CIE Y value (C4).

Individual correlations were used to make multiple models of the dependent variables. In this study a fair model was judged to be one that explained 40-50 percent of the variability, a good model 65 percent and anything above 85 percent was considered excellent (White, 1980).

RESULTS

The increase of home dehydration in Utah has prompted many unanswered questions from consumers. Consumers interested in dehydrating foods at home often request information from Utah State University extention personnel concerning selection and efficiency of home dehydrators. Those who have purchased home dehydrators are concerned with the nutrient value, flavor and cost of the product. Physical parameters such as temperature, relative humidity and mass flow rate of air greatly influence the efficiency of operation and the nutrient value, flavor and cost of the finished product. The effect of these parameters on the efficency of dehydration and the product is not in the current scientific literature. In addition, sufficient information regarding selection of home dehydrators, product cost and quality is not available to consumers.

Evaluation and Comparison of Dehydrators

Selection

Selection of dehydrators was based on claims made by the manufacturer, cost, size, or some unique feature in the design (Table 1). Some significant differences were found in the surface area and volume of the six dehydrations cabinets (Table 2). When the initial cost of the dehydrators was correlated with mass flow rate of air, square meters of tray surface area and cubic meters of volume, using the linear regression equation, high positive correlation (r= 0.907, 0.906, 0.907, respectively) was revealed between these parameters (Table 3).

Table 1. Characteristics of five home dehydrators and a pilot plant dehydrator

Dehydrator	Price	Manufacturer Claims	Unique Features
A (unassembled)	$ 99.00	Preserves nutrients better than home canning.	highest mass air flow rate of all tested
B (unassembled)	119.00	Preserves most of nutrients, color and flavor. Economical product, no need to rotate shelves.	
B	129.00		
C	150.00	Theraputic value of dehydrated foods in control of hypogycemia conditions. Best nutrient retention at 63C. Product is nutritious.	fan and coil in separate compartment under dehydration cabinet
D	109.00		timer, temperature control
E	25.99	Unnecessary to slice thinly or separate pieces. Table leftovers can be dehydrated; finest on the market. Economical product.	no fan, no thermostat
F	6395.00		control of temperature, relative humidity and mass air flow rate

Table 2. Size and capacity of five home dehydrators and a pilot plant dehydrator

Dehydrator	Volume (m^3)	Surface Area (m^2)	sq ft	load capacity (number of petri dishes)
A	0.086	0.92	10	180
B	0.069	1.28	14	250
C	0.112	1.51	16	288
D	0.076	1.29	14	306
E	0.040	0.34	4	48
F	4.159	6.86	74	1008

Table 3. Correlation matrix for cost and quality factors resulting from the dehydration of ground carrots and tomato juice

	$/KgT	$/KgC	kW.hrT	kW.hrC	AIRFLO	COST	CLRC	FLVRC	ACEPC	CLRT	FLVRT	ACEPT	MSQR	MCUBE
$/KgC	-0.042													
kW.hrT	0.199	0.155												
kW.hrC	-0.075	0.917	0.369											
AIRFLO	-0.546	-0.584	0.048	-0.325										
COST	-0.661	-0.409	0.016	-0.116	0.907									
CLRC	0.275	-0.034	-0.253	-0.264	-0.658	-0.500								
FLVRC	0.671	-.337	-0.013	0.319	-0.359	-0.499	-0.309							
ACEPC	-0.001	-0.377	-0.013	-0.241	0.644	0.334	-0.828	0.408						
CLRT	-0.231	-0.815	-0.180	-0.899	0.427	0.222	0.189	-0.596	0.167					
FLVRT	-0.254	-0.841	-0.196	-0.906	0.468	0.281	0.182	-0.621	0.167	0.997				
ACEPT	-0.277	-0.900	-0.243	-0.917	0.568	0.404	0.118	-0.610	0.229	0.970	0.985			
MSQR	-0.639	-0.525	-0.039	-0.255	0.906	0.988	-0.395	-0.571	0.298	0.346	0.407	0.526		
MCUBE	-0.665	-0.404	0.019	-0.111	0.907	1.000	-0.501	-0.500	0.332	0.220	0.279	0.401	0.987	
TDELT	0.060	0.944	0.147	0.954	-0.506	-0.281	-0.105	0.451	-0.310	-0.956	-0.963	-0.971	-0.406	-0.278

Note: $/KgT = cost/kg dehydrated tomato juice, $/KgC = cost/kg dehydrated carrots, kW.hrT = total kW/hr used/kg dehydrated tomato juice, kW.hrC = total kW.hr used/kg dehydrated carrots, AIRFLO = mass flow rate of air, COST = initial cost of dehydrator, CLRC = subjective color score for rehydrated carrots, FLVRC = flavor score for rehydrated carrots, ACEPC = acceptability score for carrots, CLRT = subjective color score for rehydrated tomato juice, FLVRT = flavor score for rehydrated tomato juice, ACEPT = acceptability score for rehydrated tomato juice, MSQR = m^2 of tray surface, MCUBE = dehydration cabinet volumn in m^3, TDELT = maximum temperature difference within the cabinet.

Sampling Locations

The difference in drying rates between sections within each dehydrator was explained in part by the differences in internal cabinet temperatures after 10 minutes of operation with each cabinet empty (Table 4). The greatest difference in internal cabinet temperature for dehydrator D was noted between the top and bottom sections (Table 4), therefore, it was divided into sections top and bottom. The pilot plant dehydrator differed less than 2C throughout, and no difference could be measured on the shelves on which food was dehydrated.

Table 4. Internal cabinet temperature after operating 10 minutes without a load

	Section			
Dehydrator	Top front	Top back	Bottom front	Bottom back
A	49.0	52.0	50.5	53.5
B	50.0	54.4	50.8	53.2
C	54.5	58.5	56.2	61.8
D	55.4	55.2	54.5	54.0
E*	34.0	38.0	43.5	75.8
F	61.5	62.5	61.2	63.1

*Data for dehydrator E are for drawers 1-4, where drawer 4 is the drawer closest to the heat source, and drawer 1 is furthest away.

Temperature differences within dehydrators ranged from 1.6-41.8C after 10 minutes of operation with the cabinet empty. The design of the dehydrator appeared to affect the temperature differences greatly. In dehydrators with low mass flow rates such as C and E, the temperature differences were greater than any other dehydrator used in this study. Dehydrator F exhibited the highest mass flow rate of air and had one of the smallest temperature differences (1.6C) between sections within dehydrators. Internal maximum temperature difference was very highly correlated (r= 0.954 and 0.944 respectively) with the total kW.hr used to dry the carrots and with the dehydrated carrots and dehydrated carrot cost (Table 3). Internal maximum temperature difference also exhibited a high negative correlation (r= 0.956, -0.963 and -0.971 respectively) with the color flavor and acceptability scores of rehydrated tomato juice (Table 3).

Mass Flow Rates of Air

The average mass flow rate of air for dehydrators A-F was 0.856, 0.571, 0.126, 0.667, 0.126, and 2.019 kg air/min respectively. The highest mass flow rates were measured in the pilot plant dehydrator. The lowest readings were exhibited by dehydrator (E) with no fan, and dehydrator (C) with a compartmentalized fan. Mass flow rates of air showed a negative correlation (r= -0.776, -0.907) with the total time to dehydrate the carrots and the tomato juice, so that as mass flow rates increased dehydration time decreased (Tables 5 and 6). There was a slight negative relationship (r= -0.546) between airflow and cost of dehydrated tomato juice. Approximately the relationship was shown between dehydrated carrot cost and airflow (Table 3). Mass flow rates correlated very highly (r= 0.907) with initial cost of the dehydrator (Table 3).

Measurement of Temperature and Relative Humidity

Polynomial fits of exit air temperatures were near mirror images of polynomial fits of relative humidity for all dehydrators except D (Figures 4-15, Appendix D).

High correlations were found between many of the dependent variables with the temperature and relative humidity parameters. INTEMP had a greater diminishing effect on TOTIME, for both carrots and tomato juice than any other parameter accept AIRFLOW (Tables 5 and 6). A high positive correlation was shown between INTEMP and sensory qualities of rehydrated tomato juice (r= 0.820, 0.825, 0.846, respectively, for color, acceptability and flavor). Relative humidity parameters also affected the sensory scores of rehydrated tomato juice (Table 6) FINRH appeared to have the greatest effect, RHIN had a smaller effect while RHS affected the scores very little. FINTEMP and TEMPSLOP correlated possitively with sensory scores but were not as important as INTEMP in the model for sensory scores of rehydrated tomato juice. Low correlations were found when sensory scores were compared to temperature and relative humidity parameters during carrot dehydration (Table 5).

Energy Calculations

Energy consumption during dehydration varied between dehydrators and within replications (Tables 7 and 8). Dehydrator C, the largest home dehydrator consumed more energy than the other home dehydrators during dehydration. The smallest home dehydrator (E) consumed less total energy than any of the dehydrators.

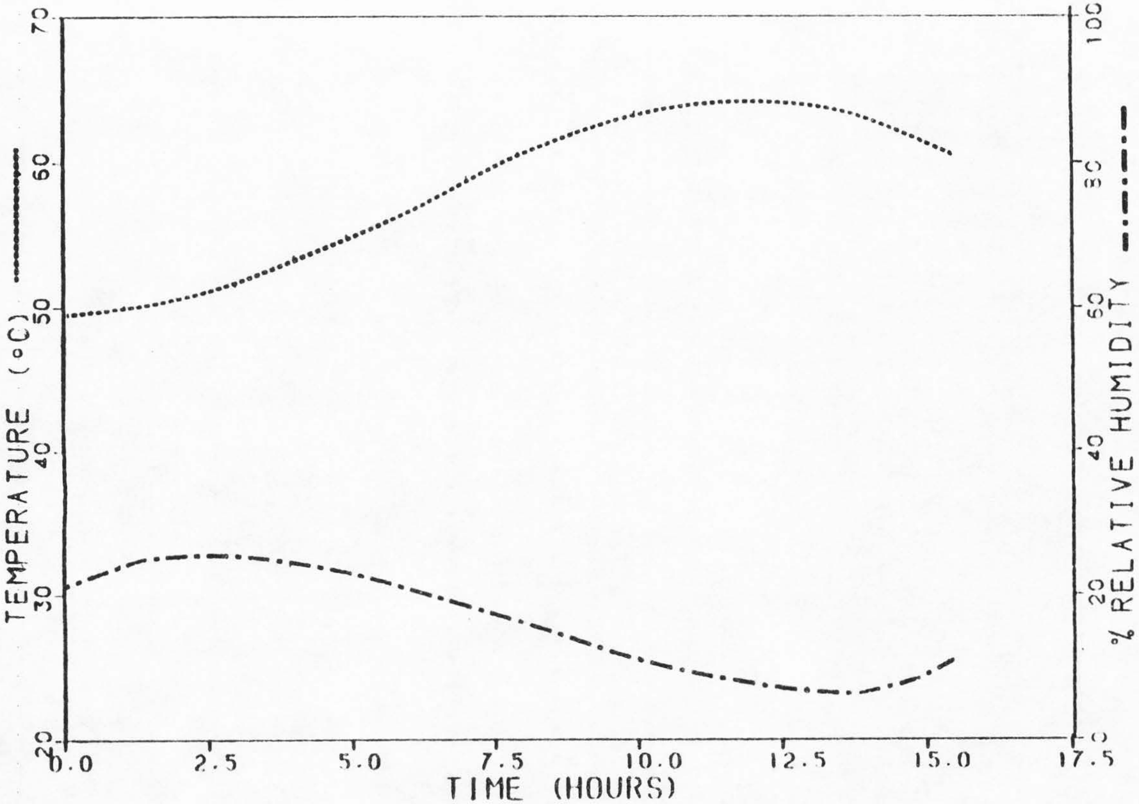

Figure 4. Polonomial fit for temperature and relative humidity in dehydrator A (ground carrots).

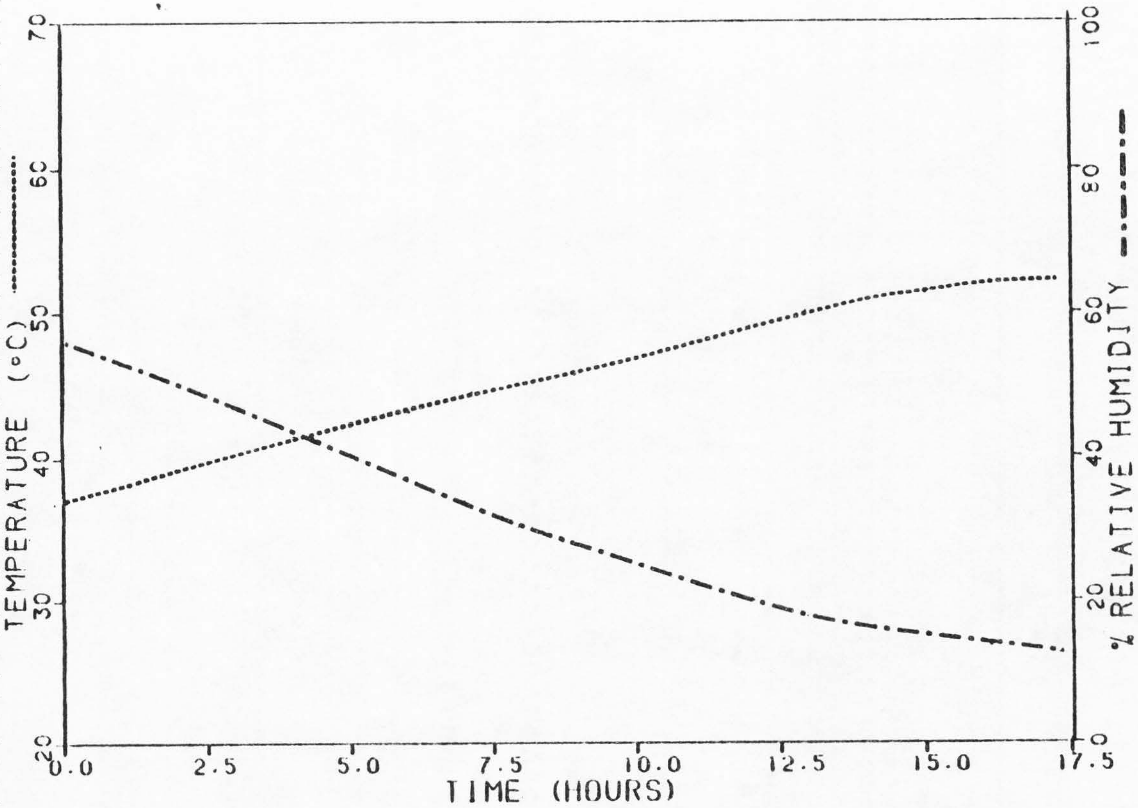

Figure 5. Polonomial fit for temperature and relative humidity in dehydrator B (ground carrots).

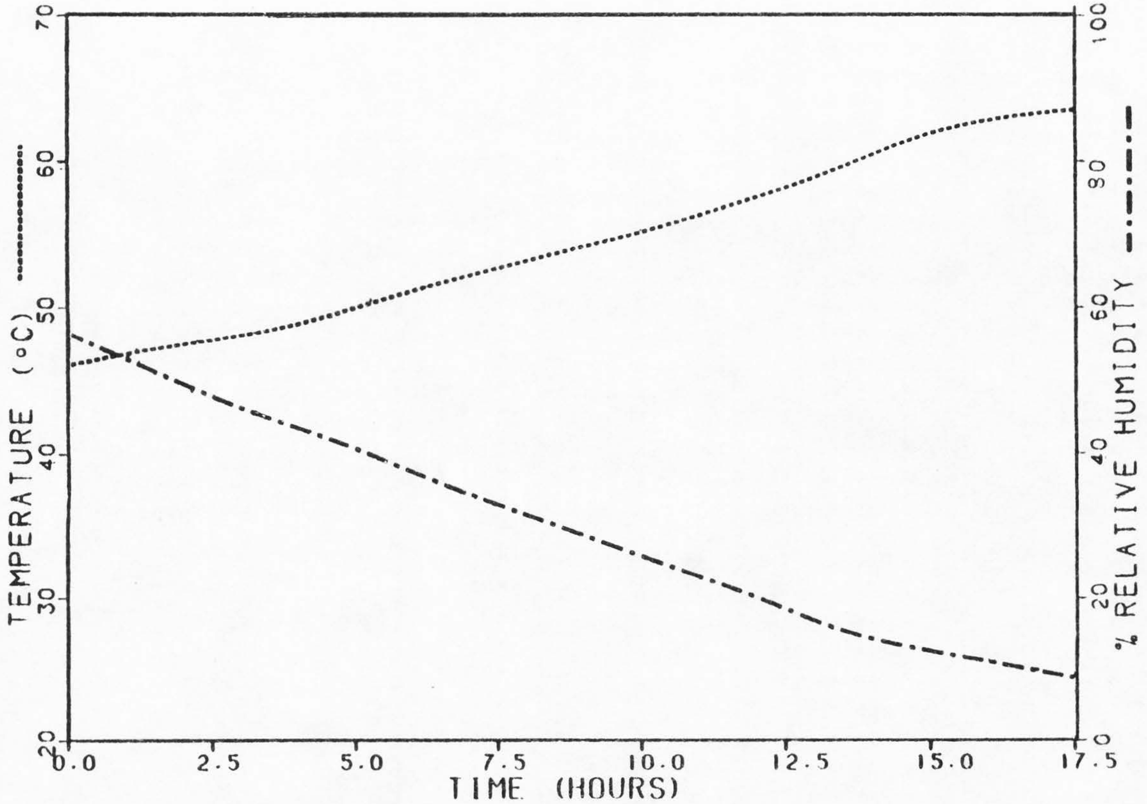

Figure 6. Polonomial fit for temperature and relative humidity in dehydrator C (ground carrots).

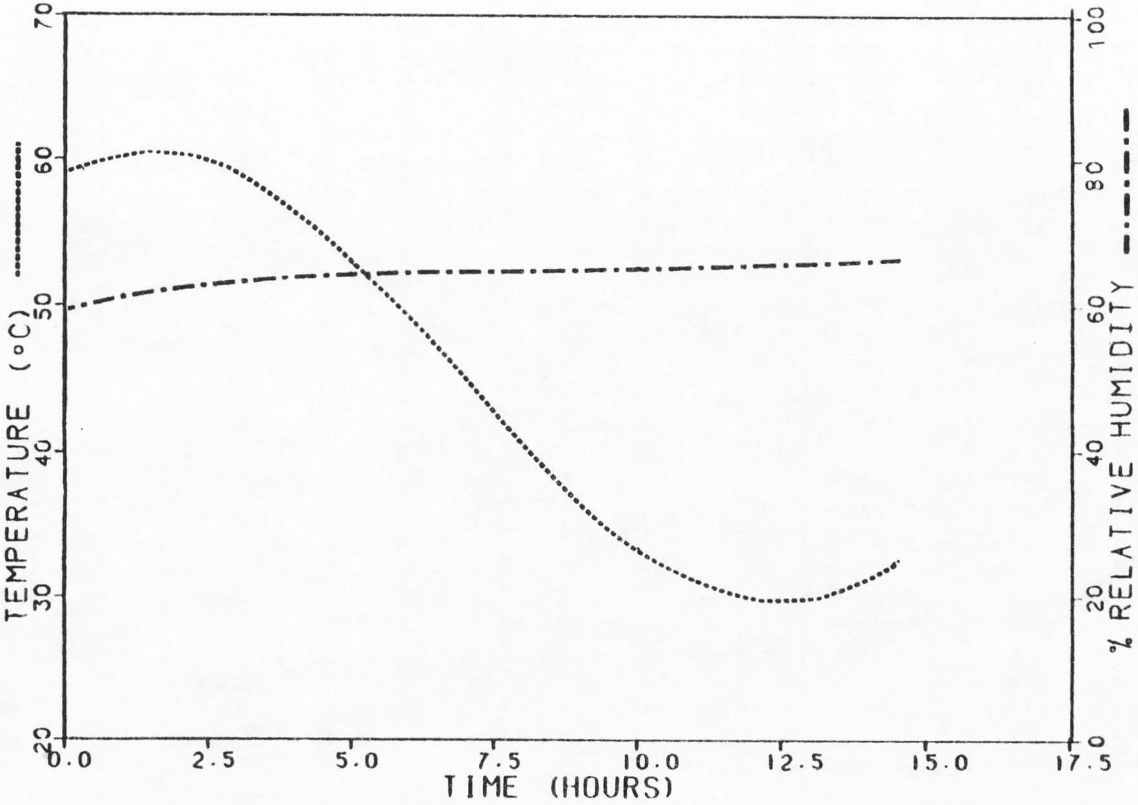

Figure 7. Polonomial fit for temperature and relative humidity in dehydrator D (ground carrots).

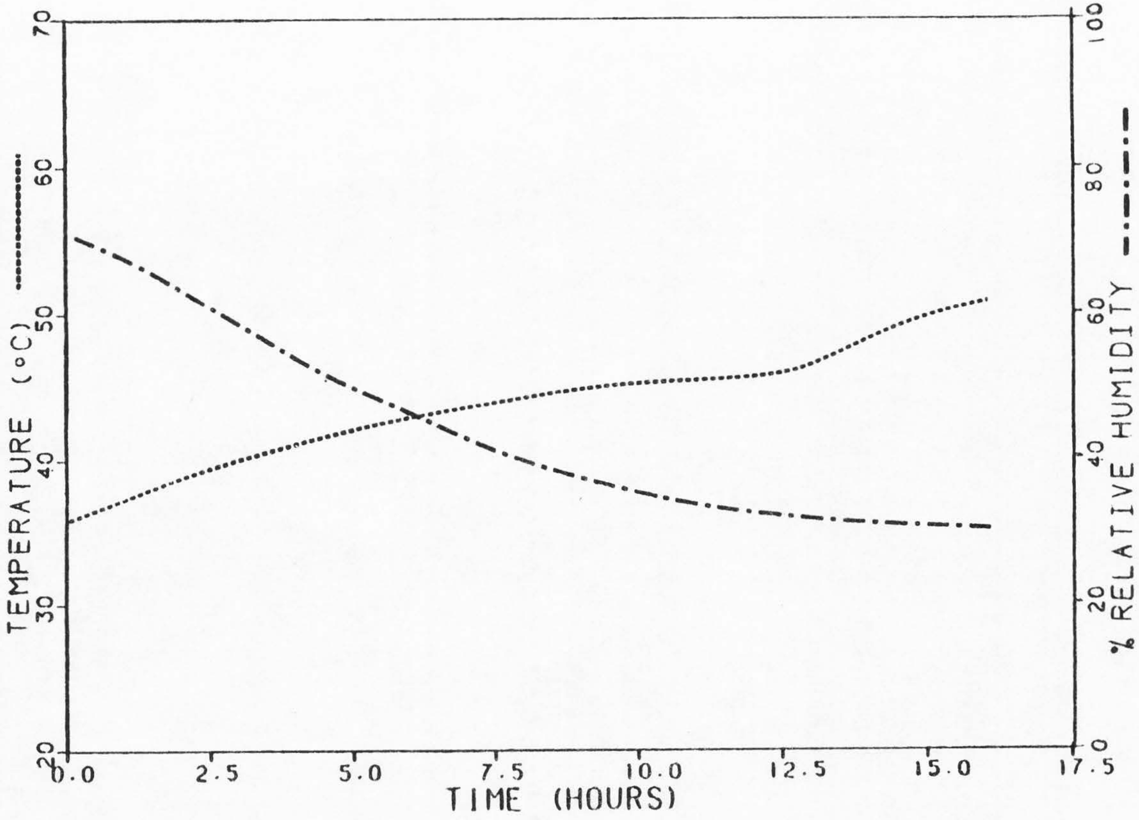

Figure 8. Polonomial fit for temperature and relative humidity in dehydrator E (ground carrots).

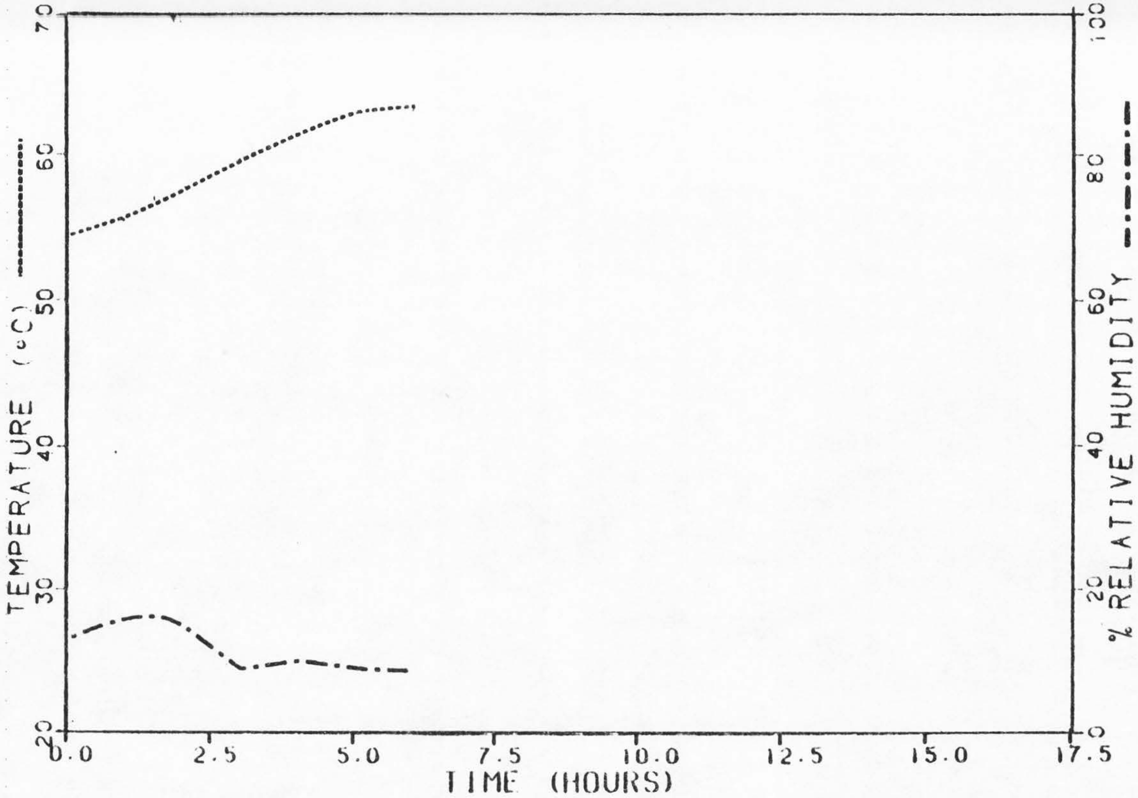

Figure 9. Polonomial fit for temperature and relative humidity in dehydrator F (ground carrots).

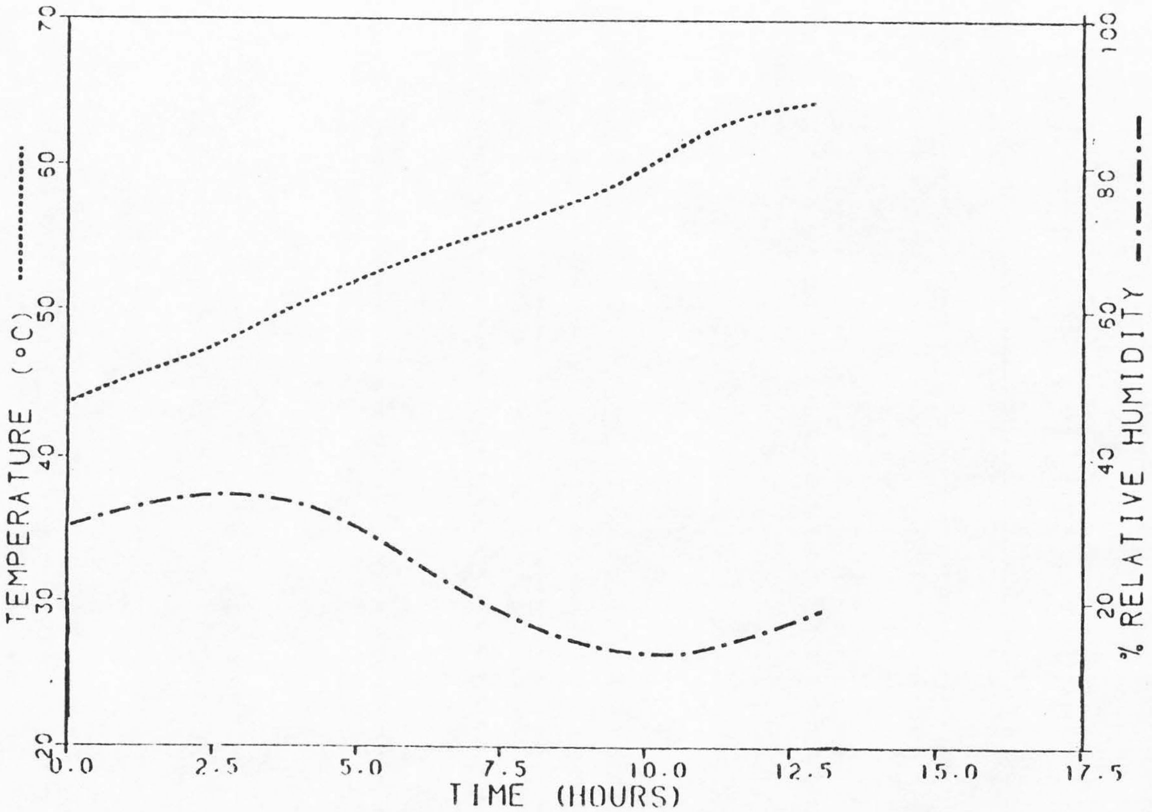

Figure 10. Polonomial fit for temperature and relative humidity in dehydrator A (tomato juice).

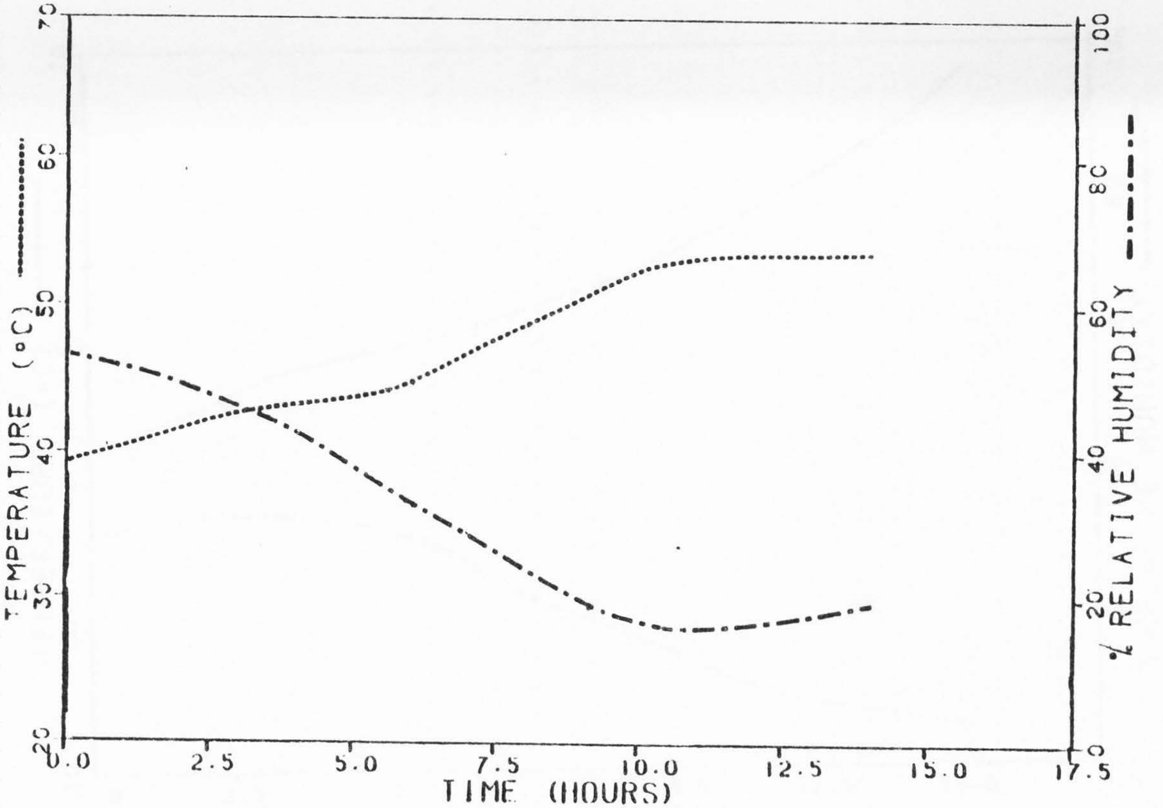

Figure 11. Polonomical fit for temperature and relative humidity in dehydrator B (tomato juice).

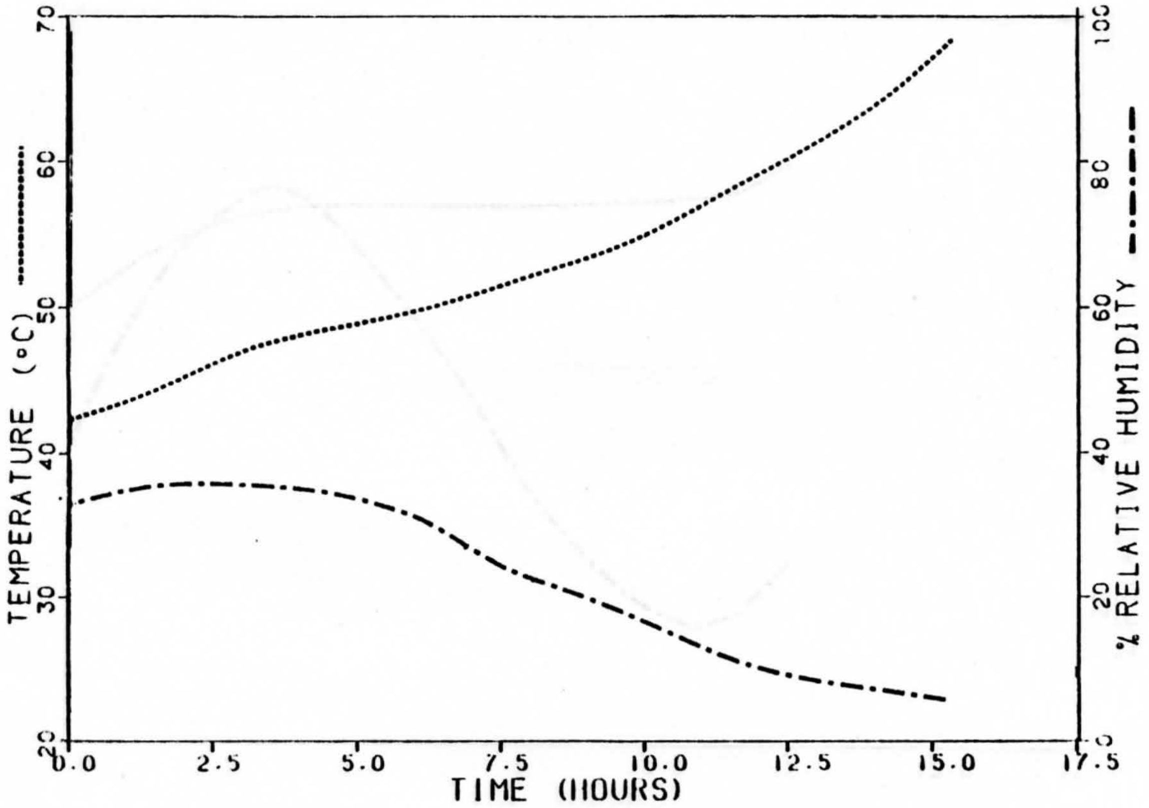

Figure 12. Polonomical fit for temperature and relative humidity in dehydrator C (tomato juice).

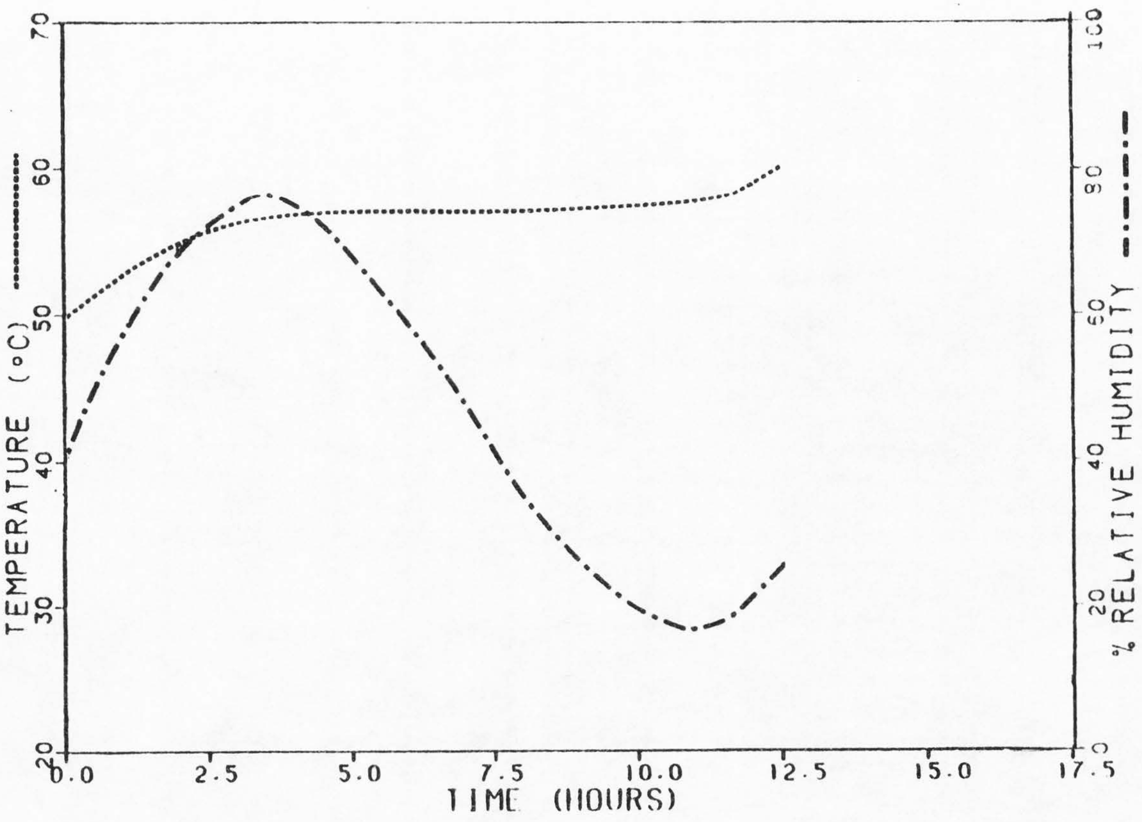

Figure 13. Polonomical fit for temperature and relative humidity in dehydrator D (tomato juice).

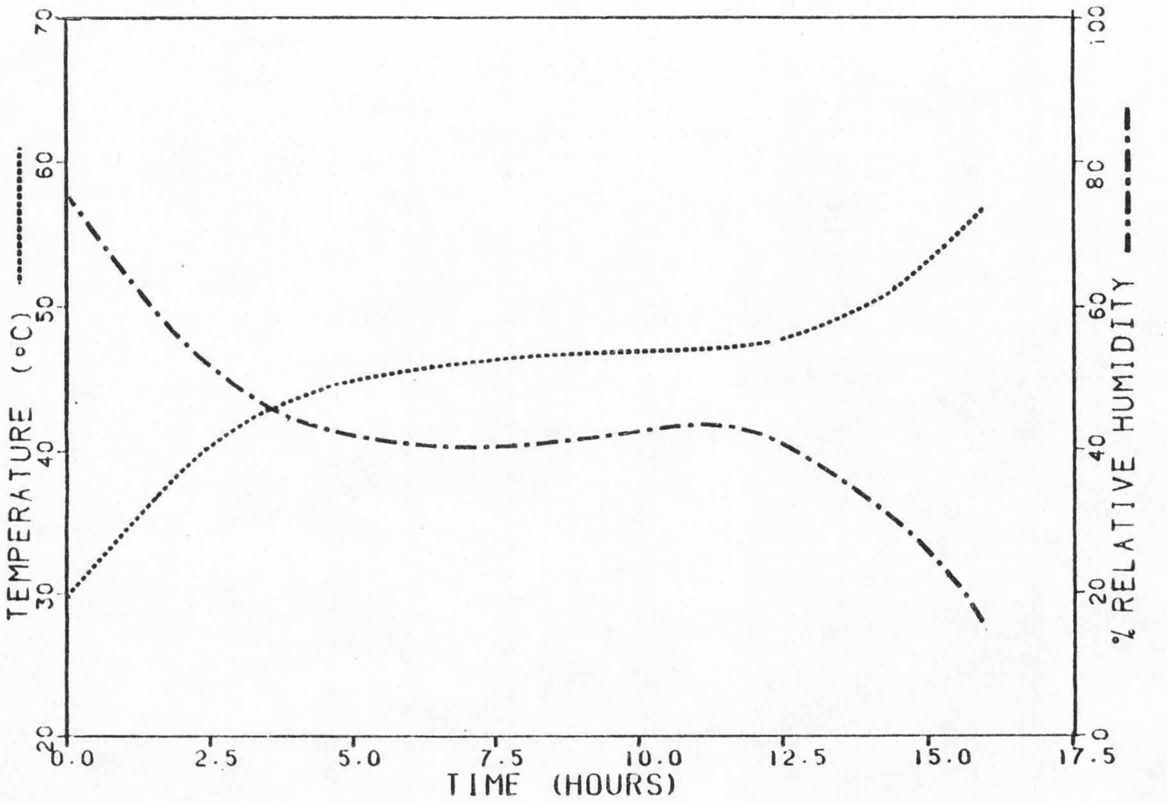

Figure 14. Polonomical fit for temperature and relative humidity in dehydrator E (tomato juice).

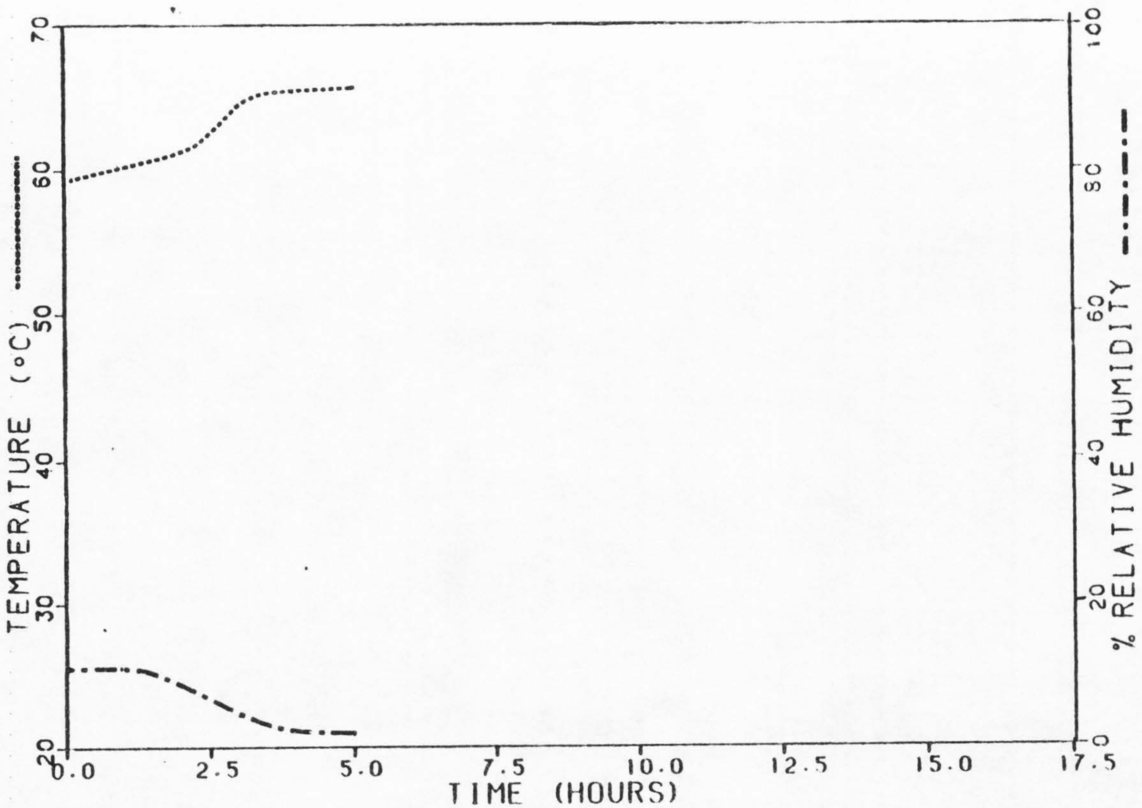

Figure 15. Polonomical fit for temperature and relative humidity in dehydrator F (tomato juice).

Table 5. Correlation matrix for various dependent and independent variables resulting from the dehydration of carrots

	TOTIME	AIRFLOW	COLORS	ACCEP	FLAVOR	NUTR	C1	C2	C3	C4	INTEMP	FINTEMP	TEMPSLOP	RHIN	FINHR	RHS	RHLN	RHI
TOTIME																		
AIRFLOW	-0.776																	
COLORS	0.645	-0.583																
ACCEP	0.023	0.294	-0.255															
FLAVOR	-0.503	0.337	-0.923	0.118														
NUTR	-0.045	-0.020	-0.065	0.112	0.053													
C1	-0.160	-0.010	0.007	-0.006	-0.037	0.219												
C2	-0.394	0.147	-0.037	-0.086	-0.034	0.231	0.489											
C3	-0.162	0.129	0.033	0.041	0.155	0.263	0.813	0.472										
C4	-0.171	0.003	0.004	-0.009	0.001	0.198	0.930	0.417	0.747									
INTEMP	-0.677	0.602	-0.174	-0.168	0.056	0.093	0.180	0.385	0.276	0.243								
FINTEMP	-0.246	0.317	0.209	-0.174	-0.450	0.144	0.206	0.242	0.406	0.194	0.692							
TEMPSLOP	-0.165	0.277	0.061	-0.113	-0.313	0.108	0.170	0.342	0.244	0.073	0.317	0.636						
RHIN	0.278	-0.426	0.113	-0.274	0.234	-0.109	-0.163	-0.259	-0.400	-0.108	-0.355	-0.670	-0.624					
FINRH	0.087	-0.326	-0.202	-0.119	0.481	-0.146	-0.297	-0.162	-0.411	-0.235	-0.373	-0.823	-0.583	0.604				
RHS	-0.044	0.072	-0.159	0.323	-0.071	0.134	0.027	0.132	0.239	-0.016	0.029	0.278	0.400	-0.789	-0.153			
RHLN	0.456	-0.600	0.224	-0.223	0.135	-0.065	-0.140	-0.257	-0.381	-0.089	-0.484	-0.694	-0.620	0.969	0.598	-0.685		
RHI	-0.615	0.747	-0.328	0.175	-0.019	0.014	0.094	0.213	0.320	0.054	0.565	0.643	0.667	-0.869	-0.524	0.551	-0.963	
RECT	-0.913	0.834	-0.487	0.006	0.290	-0.039	0.016	0.220	0.062	0.019	0.612	0.306	0.286	-0.361	-0.167	0.095	-0.545	0.722

NOTE: TOTIME=Total dehydration time, COLORS=Subjective color, ACCEP=Acceptability, NUTR=Carotene content, C1=Hunter L, C2=Hunter A, C3=Hunter 6, C4=CIE Y, INTEMP=Temperature at time=1 hour, FINTEMP=Final temperature, TEMPSLOP=Temperature curve slope, RHIN=Exit relative humidity at time =1 hour, FINRH=Final exit relative humidity, RHS=Relative humidity curve slope, RHLN=Log E of RHIN, RHI=1/RHIN, RECT=1/TOTIME

Table 6. Correlation matrix for various dependent and independent variables resulting from the dehydration of tomato juice

	TOTIME	AIRFLOW	COLORS	ACCEP	FLAVOR	NUTR	C1	C2	C3	C4	INTEMP	FINTEMP	TEMPSLOP	RHIN	FINRH
TOTIME															
AIRFLOW	-0.907														
COLORS	-0.293	0.440													
ACCEP	-0.333	0.456	0.977												
FLAVOR	-0.336	0.465	0.995	0.989											
NUTR	-0.186	0.264	-0.237	-0.184	-0.216										
C1	-0.248	0.468	0.564	0.561	0.563	-0.068									
C2	-0.361	0.592	0.574	0.574	0.572	-0.066	0.923								
C3	-0.201	0.391	0.504	0.507	0.506	-0.070	0.952	0.875							
C4	-0.269	0.501	0.572	0.567	0.571	-0.032	0.992	0.918	0.917						
INTEMP	-0.649	0.639	0.820	0.825	0.846	-0.102	0.442	0.427	0.401	0.448					
FINTEMP	-0.304	0.338	0.725	0.745	0.756	-0.106	0.306	0.280	0.346	0.304	0.717				
TEMPSLOP	-0.166	0.260	0.427	0.456	0.440	0.012	0.242	0.281	0.291	0.244	0.309	0.637			
RHIN	0.323	-0.459	-0.504	-0.554	-0.536	-0.232	-0.462	-0.388	-0.471	-0.464	-0.515	-0.765	-0.709		
FINRH	0.282	-0.382	-0.757	-0.820	-0.790	-0.041	-0.547	-0.487	-0.533	-0.547	-0.649	-0.777	-0.626	0.788	
RHS	-0.070	0.044	-0.114	-0.118	-0.107	0.137	-0.098	-0.146	-0.022	-0.088	-0.007	0.272	0.552	-0.486	-0.049

NOTE: TOTIME=Total dehydration time, COLORS=Subjective color, ACCEP=Acceptability, NUTR=Ascorbic acid content, C1=Hunter L, C2=Hunter a, C3=Hunter b, C4=CIE y, INTEMP=Temperature at time=1 hour, FINTEMP=Final temperature, TEMPSLOP=Temperature curve slope, RHIN=Exit relative humidity at time=1 hour, FINRH=Final exit relative humidity, RHS=Relative humidity curve slope

Table 7. Dehydration time and energy consumption for carrot dehydration

Dehydrator	Rep	Total Time	kW.hr
A	1	15.50	7.962
	2	10.50	4.322
	3	12.17	4.837
B	1	13.33	3.640
	2	14.00	3.734
	3	11.17	4.551
C	1	15.00	6.999
	2	16.00	6.765
	3	17.33	8.700
D	1	14.50	3.876
	2	11.00	3.257
	3	14.50	3.876
E	1	13.75	1.375
	2	15.00	1.500
	3	16.00	1.600

Table 8. Dehydration time and energy consumption for tomato juice dehydration

Dehydrator	Rep	Total Time	kW.hr
A	1	13.33	6.467
	2	14.00	6.467
	3	11.17	5.758
B	1	13.33	3.309
	2	14.00	3.020
	3	13.58	3.329
C	1	15.00	6.479
	2	15.25	7.163
	3	15.17	6.573
D	1	11.85	3.186
	2	12.50	3.130
	3	11.17	3.029
E	1	14.58	1.458
	2	14.00	1.400
	3	15.00	1.500

Calculation of Product Cost

Differences in dehydrated product cost were due mostly to load capacity and energy costs (Table 9 and 10). Energy costs ranged from 2.6-8.5 percent of the total cost of the dried product. Even though dehydrator E consumed less total energy than the other models, the cost per kg dry product and the total cost per kg dry product were among the highest for the six treatments.

Dehydrated Carrot Analyses

Carotene Analysis

No significant differences ($p < 0.01$) in carotene content were indicated in an analysis of variance between treatments (Table 11). Average carotene content was not found to differ significantly from carotene content of fresh blanched samples (Figure 16). A model for carotene content composed of FINRH, RHS, RHLN and TOTIME explained only 11.2 percent of the variability and could only be accepted at $p < 0.117$. This model was thus rejected.

Moisture Analysis

After averaging subsamples within treatments, final moisture measurements ranged from 1.409 to 7.208 percent, the experimental mean was 3.465 percent and the standard deviation for treatment means was 1.068 percent (Appendix E).

Table 9. Comparative costs of ground carrots dehydrated in dehydrators A-F

Dehydrator	Energy Cost/kg Dry Product	Total Cost/kg Dry*
A	$0.67	$10.44
B	0.33	6.92
C	0.56	10.50
D	0.25	9.61
E	1.60	18.80
F	0.13	7.03

* One kg dry carrots reconstitutes to 8.38kg

Table 10. Comparative costs of tomato juice dehydrated in dehydrators A-F

Dehydrator	Energy Cost/kg Dry Product	Total Cost/kg Dry*
A	$2.67	$26.75
B	1.75	33.67
C	2.00	25.00
D	0.90	22.14
E	2.00	25.00
F	0.21	18.10

* One kg dry tomato juice reconstitutes to 14.77 kg

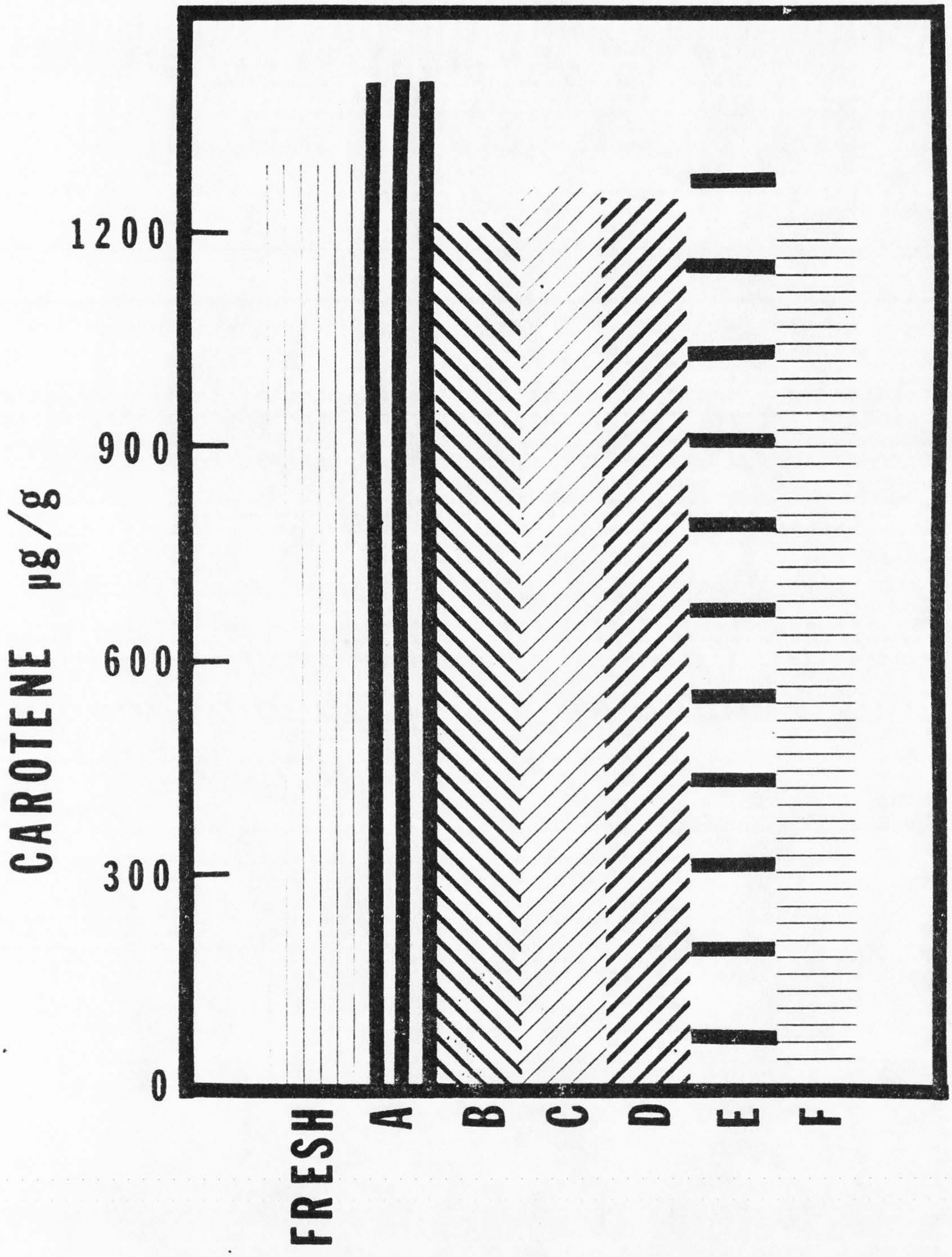

Figure 16. Average carotene content of ground carrots dehydrated in dehydrators A-F, compared with blanched carrots.

Table 11. Mean carotene content in carrots dehydrated in dehydrators A-F

	Carotene μg/g carrots (dry weight basis)					
Section	Dehydrator					
	A	B	C	D	E	F
1	1834	1316	1437	1272	1284	1248
2	1179	1376	1274	1338	1274	
3	1354	1355	1360		1457	
4	1284	1204	1259		1330	

Objective Color Measurements

Lightness or reflectance was significantly different ($p < 0.05$) between treatments as measured by CIE "Y" (Table 12). No differences between treatments were detected with an analysis of variance for "L", "a", and "b" values. Multiple regression models were poor to fair for these parameters (Tables 13-16).

Sensory Evaluation

Typical carrot color, carrot flavor intensity and overall acceptability for treatments were all significantly different. Order of sample presentation had an insignificant effect. Table 17 contains the treatment means, experimental standard deviations and LSD values of sensory scores at $p < 0.05$. A great deal of the variability in sensory scores could be accounted for by physical parameters (Tables 17-20).

Table 12. Mean Hunter L, a, b and CIE Y values for dehydrated ground carrots

Dehydrator	Section	L	a	b	Y
A	1	28.4	18.1	21.0	12.4
	2	34.6	17.4	21.8	12.1
	3	35.4	18.5	21.9	12.5
	4	35.0	18.1	21.3	12.8
B	1	35.1	18.0	20.6	12.4
	2	35.5	17.9	20.9	12.6
	3	35.4	18.2	21.0	12.5
	4	35.0	17.5	20.8	12.3
C	1	35.1	14.6	21.0	10.5
	2	35.0	18.2	21.0	12.0
	3	35.3	18.1	21.0	12.5
	4	35.8	16.9	21.3	12.3
D	1	35.1	17.6	20.7	12.4
	2	34.6	17.6	20.4	12.0
E	1	33.5	18.0	20.2	11.2
	2	31.3	16.5	19.3	9.8
	3	33.4	18.2	20.2	11.3
	4	34.7	17.7	20.8	12.0
F	1	34.8	18.1	21.9	12.2
Fresh Blanched Sample		37.8	20.5	20.9	14.3
Fresh Blanched Sample		37.6	18.2	20.9	14.2
Fresh Blanched Sample		37.7	18.2	20.9	14.0
Fresh Blanched Sample		38.1	18.2	21.0	14.2
LSD at p=0.05					2.1

Table 13. Model for Hunter L values in rehydrated carrots

Independent Variable	R Square	R Square Change
FINRH	0.08823	0.08823
TOTIME	0.10649	0.01826
AIRFLOW	0.23709	0.13061
FINTEMP	0.28487	0.04777
INTEMP	0.33430	0.04943
RHI	0.40569	0.07139

Y = 1.882 - 0.262 FINRH - 0.196 TOTIME -5.042 AIRFLOW - 0.578 FINTEMP + 0.305 INTEMP + 98.889 RHI
standard error of estimate = 1.313

p for model $< 1.4 \times 10^{-4}$

Table 14. Model for Hunter a values in rehydrated carrots

Independent	R Square	R Square Change
TOTIME	0.15521	0.15521
TEMPSLOP	0.23428	0.07907
AIRFLOW	0.34211	0.10783
INTEMP	0.35645	0.01434
FINTEMP	0.37760	0.02115
FINRH	0.45439	0.07680
RHIN	0.52844	0.07040

Y = 33.096 - 0.196 TOTIME + 1.077 TEMPSLOP - 2.599 AIRFLOW + 0.217 INTEMP - 0.343 FINTEMP - 0.102 FINRH - 2.76 RHIN
standard error measurement = 0.819

p for model $< 10-^{3}$

Table 15. Model for Hunter b values in rehydrated carrots

Independent Variable	R Square	R Square Change
FINRH	0.16852	0.16852
RHIN	0.20472	0.03620

$Y = 21.023 - 0.021\ \mathrm{FINRH} - 0.010\ \mathrm{RHIN}$
standard error of estimate = 0.699

p for model $< 2.1 \times 10^{-3}$

Table 16. Model for CIE Y value in rehydrated carrots

Independent	R Square	R Square Change
INTEMP	0.05907	0.05907
AIRFLOW	0.09149	0.03242
FINRH	0.12470	0.03320
FINTEMP	0.24325	0.11855
RHI	0.32779	0.08454

$Y = 26.577 + 275\ \mathrm{INTEMP} - 3.124\ \mathrm{AIRFLOW} - 0.168\ \mathrm{FINRH} - 0.428\ \mathrm{FINTEMP} + 69.809\ \mathrm{RHI}$
standard error of estimate = 0.973

p for model $< 10^{-3}$

Table 17. Sensory scores for cooked rehydrated carrots dehydrated in dehydrators A-F

Dehydrator	Typical Carrot Color	Carrot Flavor	Acceptability
A	5.2^{ab}	5.9^{bc}	5.6^{b}
B	5.5^{c}	6.9^{d}	5.5^{b}
C	6.0^{d}	4.4^{a}	4.0^{a}
D	5.5^{c}	5.7^{b}	5.4^{b}
E	5.3^{b}	6.7^{cd}	4.9^{b}
F	5.1^{a}	4.7^{a}	5.6^{b}
standard deviation	0.03	0.05	0.04
LSD at $p < 0.05$	0.17	0.85	0.76
$p <$	7.1×10^{-3}	5.0×10^{-2}	10^{-8}

Means with no common letters following them are significantly different at $p < 0.05$

Table 18. Model for subjective color scores in cooked rehydrated carrots

Indpendent Variable	R Square	R Square Change
TOTIME	0.41574	0.41574
FINTEMP	0.55953	0.14380
RHS	0.61936	0.05982
AIRFLOW	0.66469	0.04533

$Y = 3.012 + 0.049\ \mathrm{TOTIME} + 0.028\ \mathrm{FINTEMP} - 0.049\ \mathrm{RHS} - 0.232\ \mathrm{AIRFLOW}$

standard error of estimate = 0.187

p for model $< 10^{-8}$

Table 19. Model for subjective flavor scores in rehydrated cooked carrots

Independent Variable	R Square	R Square Change
FINRH	0.23089	0.23089
AIFLOW	0.50321	0.27232
FINTEMP	0.52374	0.02053
INTEMP	0.54274	0.01900
RHS	0.55534	0.01260
RHIN	0.57273	0.01739

$Y = 6.316 - 0.002\ \mathrm{FINRH} + 0.484\ \mathrm{AIRFLOW} + 0.048\ \mathrm{FINTEMP} + 0.025\ \mathrm{INTEMP} + 0.122\ \mathrm{RHS} + 0.011\ \mathrm{RHIN}$

standard error of estimate = 0.303

p for model $< 10^{-7}$

Table 20. Model for acceptability in rehydrated cooked carrots

Independent Variable	R Square	R Square Change
RHS	0.10416	0.10416
FINTEMP	0.17938	0.07522
FINRH	0.44912	0.26973
INTEMP	0.57709	0.12797
TEMPSLOP	0.61744	0.04035
TOTIME	0.64206	0.02462
AIRFLOW	0.69897	0.05691

$Y = 16.613 + 0.393\ \mathrm{RHS} - 0.262\ \mathrm{FINTEMP} - 0.110\ \mathrm{FINRH} + 0.094\ \mathrm{INTEMP} - 0.588\ \mathrm{TEMPSLOP} + 0.154\ \mathrm{TOTIME} + 0.961\ \mathrm{AIRFLOW}$

standard error of estimate = 0.553

p for model $< 10^{-8}$

Dehydrated Tomato Juice Analyses

Ascorbic Acid Determination

There was a significant difference ($p < 0.05$) in ascorbic acid levels between treatments. Rehydrated samples compiled from each dehydrator ranged from 50 percent to 75 percent retention of the ascorbic acid found in the fresh blanched juice (Table 21, Figure 17).

Table 21. Mean ascorbic acid content in dehydrated tomato juice

Ascorbic acid ug/g tomato juice dry weight basis						
	Dehydrator					
Section	A	B	C	D	E	F
1	1088^{cde}	1111^{cde}	912^{ab}	844^{a}	996^{bc}	1535^{h}
2	1080^{cd}	1292^{fg}	933^{ab}	902^{ab}	1195^{def}	
3	1146^{de}	991^{abc}	1014^{bc}		1086^{cd}	
4	1348^{g}	1290^{fg}	1216^{ef}		1627^{h}	

experimental standard deviation = 194.0
LSD at $p < 0.05$ = 131.0. Means with no common letters following are significantly different at that level.

The model which included the data for all the treatments with regard to ascorbic acid content, explained only 32.3 percent of the variability using AIRFLOW, INTEMP, RHIN, TEMPSLOP and FINTEMP. When the data from dehydrator E was removed, and the multiple regression was run, 68 percent of the variation could be explained (Table 22).

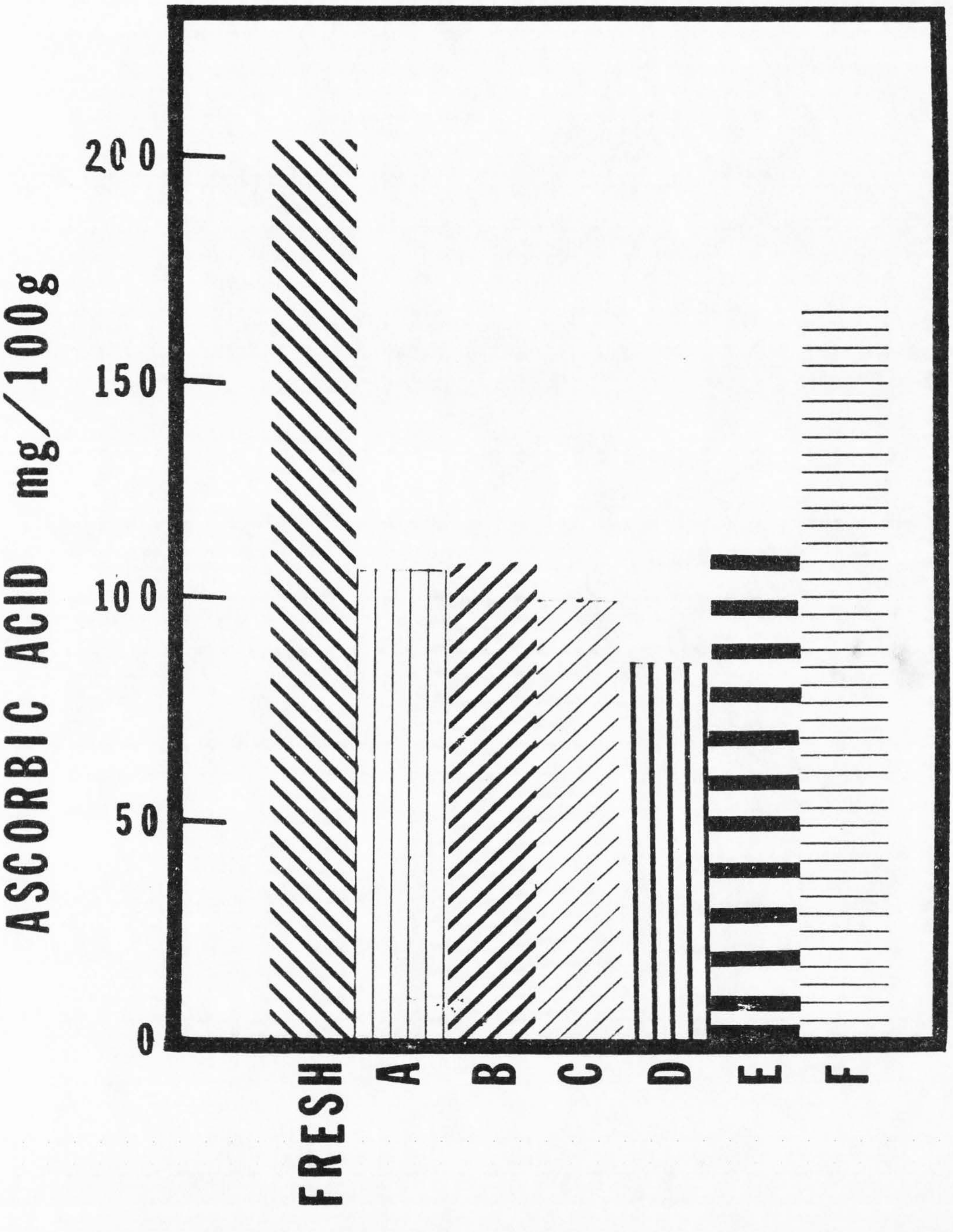

Figure 17. Average ascorbic acid content of tomato juice dehydrated in dehydrators A-F, compared with fresh blanched juice.

Table 22. Model for ascorbic acid concentration in dehydrated tomato juice

Independent Variable	R Square	Simple R
RHIN	0.26587	-0.51563
FINTEMP	0.47048	0.00545
AIRFLOW	0.56097	0.49723
FINRH	0.59250	-0.35834

$Y = 675.507 - 2.780\ \text{RHIN} - 14.039\ \text{FINTEMP} + 745.997\ \text{AIRFLOW} - 23.333\ \text{FINRH} + 103.365\ \text{TOTIME} - 93.513\ \text{TEMPSLOP}$

standard error of estimate = 142.100

p for model $< 5 \times 10^{-7}$

Moisture Analysis

The average moisture content of the dehydrated tomato juice samples was 5.546 percent with a standard deviaton of 1.105 percent. The average moisture content of samples ranged from 2.292-8.081 percent (Appendix D).

Objective Color Measurements

No significant difference was detected by the analysis of variance ($p < 0.05$) for lightness and darkness, redness or yellowness. Means from three replications for each treatment are listed in Table 23. Models, however, for predicting objective color scores were good (Tables 24-27).

Table 23. Mean Hunter L, a, b and CIE Y values for dehydrated tomato juice

Dehydrator	Section	L	a	b	Y
A	1	28.0	15.2	13.6	7.8
	2	27.7	15.1	13.6	7.7
	3	26.6	15.0	13.2	7.1
	4	26.8	13.8	13.3	7.2
B	1	27.4	15.0	13.7	7.5
	2	25.0	13.9	12.6	6.5
	3	28.0	15.4	13.7	7.8
	4	27.0	14.7	13.6	7.4
C	1	23.0	12.3	10.8	5.8
	2	24.7	13.5	12.4	6.5
	3	27.5	15.6	13.5	7.6
	4	28.4	16.4	14.1	8.1
D	1	28.9	16.7	14.1	8.6
	2	28.7	16.7	13.9	8.2
E	1	29.0	16.4	14.0	8.4
	2	28.7	16.4	13.9	8.2
	3	28.2	16.9	13.4	8.0
	4	28.6	16.9	13.4	8.2
F	1	29.2	17.0	13.7	8.6
		28.1	16.4	13.2	7.9
Fresh Blanched Sample		28.0	16.2	13.3	7.9
Fresh Blanched Sample		28.8	15.8	13.5	8.3
Fresh Blanched Sample		28.1	16.4	13.2	7.9

Table 24. Model for Hunter L values in rehydrated tomato juice

Independent Variable	R Square	R Square Change
FINRH	0.29950	0.29950
AIRFLOW	0.37768	0.07818
TOTIME	0.50452	0.12684
TEMPSLOP	0.53313	0.02861
FINTEMP	0.54266	0.00953
INTEMP	0.56265	0.01999

$Y = 14.479 - 0.152\ \text{FINRH} + 7.152\ \text{AIRFLOW} + 1.257\ \text{TOTIME} - 0.444\ \text{TEMPSLOP} - 0.173\ \text{FINTEMP}\ 0.122\ \text{INTEMP}$

standard error of estimate = 2.144

p for model $< 10^{-7}$

Table 25. Model for Hunter a values in rehydrated tomato juice

Independent	R Square	R Square Change
AIRFLOW	0.35067	0.35067
TOTIME	0.52432	0.17365
FINRH	0.57068	0.04636
RHIN	0.60851	0.03783

$Y = 0.298 + 6.01\ \text{AIRFLOW} + 0.881\ \text{TOTIME} - 0.92\ \text{FINRH} + 0.038\ \text{RHIN}$

standard error of estimate + 1.341

p for model $< 10^{-8}$

Sensory Evaluation

The dehydration process had a measurable effect on rehydrated tomato juice as indicated by 59 panel members (Table 28). Samples dehydrated in dehydrator E received the lowest scores for color, flavor and acceptability. The pilot plant dehydrator produced the most acceptable product, with a relatively high color and flavor score. Multiple regression models were excellent in predicting sensory scores for rehydrated tomato juice (Tables 29-32).

Table 26. Model for Hunter b values in rehydrated tomato juice

Independent	R Square	R Square Change
FINRH	0.28439	0.28439
AIRFLOW	0.32538	0.04099
TOTIME	0.41516	0.08978

$Y = 6.512 - 0.057$ FINRH $+ 2.93$ AIRFLOW $+ 0.470$ TOTIME
standard error of estimate = 1.190

p for model $< 2.6 \times 10^{-6}$

Table 27. Model for CIE Y in rehydrated tomato juice

Independent Variable	R Square	R Square Change
FINRH	0.29890	0.29890
AIRFLOW	0.39852	0.09962
TOTIME	0.54425	0.14573
TEMPSLOP	0.57330	0.02905
FINTEMP	0.58306	0.00976
INTEMP	0.60190	0.01884

$Y = 0.803 - 0.070$ FINRH $+ 3.706$ AIRFLOW $+ 0.634$ TOTIME $- 0.220$ TEMPSLOP $- 0.081$ FINTEMP $+ 0.562$ INTEMP
standard error of estimate = 0.973

p for model $< 10^{-8}$

Table 28. Sensory scores for rehydrated tomato juice from dehydrators A - F

Dehydrator	Typical Tomato Juice Color	Tomato Juice Flavor	Acceptability
A	5.6^{b}	4.8^{bc}	4.3^{bc}
B	5.3^{b}	4.4^{b}	4.2^{bc}
C	5.6^{b}	4.9^{bc}	4.5^{bc}
D	5.8^{b}	5.2^{c}	4.9^{c}
E	4.4^{a}	2.8^{a}	2.2^{a}
F	5.6^{b}	5.0^{bc}	5.0^{c}
standard deviation	0.05	0.03	0.25
LSD at $p = 0.05$	0.77	0.65	0.58

Means with no common letters following are significantly different at that level.

Table 29. Model for subjective color score in rehydrated tomato juice

Independent Variable	R Square	R Square Change
INTEMP	0.67302	0.67302
TOTIME	0.77191	0.09890
AIRFLOW	0.85518	0.08327
FINRH	0.87813	0.02295
RHIN	0.90899	0.03085
TEMP	0.92440	0.01542

$$Y = -1.398 + 0.044\ \text{INTEMP} + 0.202\ \text{TOTIME} + 0.884\ \text{AIRFLOW} - 0.019\ \text{FINRH} + 0.012\ \text{RHIN} + 0.023\ \text{FINTEMP}$$

standard error of estimate = 0.144

p for model $< 10^{-8}$

Table 30. Model for subjective flavor score in rehydrated tomato juice

Independent Variable	R Square	R Square Change
INTEMP	0.71577	0.71577
FINRH	0.81632	0.10055
TOTIME	0.86009	0.04378
AIRFLOW	0.89575	0.03566
RHIN	0.92186	0.02611
FINTEMP	0.93762	0.01676

$Y = -6.082 + 0.973\ \text{INTEMP} - 0.037\ \text{FINRH} + 0.292\ \text{TOTIME} + 1.313\ \text{AIRFLOW} + 0.020\ \text{RHIN} + 0.040\ \text{FINTEMP}$

standard error of estimate = 0.228

p for model $< 10^{-8}$

Table 31. Model for acceptability score in rehydrated tomato juice

Independent Variable	R Square	R Square Change
INTEMP	0.68014	0.68014
FINRH	0.82047	0.14033
TOTIME	0.85282	0.03245
AIRFLOW	0.87830	0.02548
RHIN	0.90683	0.02647
FINTEMP	0.95678	0.04994

$Y = -5.936 + 0.075\ \text{INTEMP} - 0.054\ \text{FINRH} + 0.291\ \text{TOTIME} + 1.311\ \text{AIRFLOW} + 0.022\ \text{RHIN} + 0.034\ \text{INTEMP}$

standard error of estimate = 0.308

p for model $< 10^{-8}$

DISCUSSION AND CONCLUSIONS

This study was conducted on home dehydrators to determine the effect of time and physical parameters such as temperature, relative humidity and air flow, on product color, flavor, nutrient content, acceptability and cost. It was designed to identify which of the parameters had the greatest effect and how much variablity with respect to a particular quality in the final product could be attributed to a particular parameter.

Evaluation of Home Dehydration

Claims about home dehydrators made by manufacturers are neither proved nor disproved easily. Since there is such a wide variety of foods dehydrated and the care and preparation they recieve varies so much, comparative data are difficult to find. The data from this study for carotenes in carrots indicate that if carrots are blanched, most of the carotene is retained during dehydration under a broad range of relative humidity and temperature schemes. Retention of the ascorbic acid in the tomato juice, however, varies with the dehydration process, even when the preparation and handling are identical. Nearly all the manufacturers of the home dehydrators used in this study made claims concerning nutrient retention. Retention of ascorbic acid in the tomato juice dried in the home dehydrators was approximately 50 percent of that in the fresh juice. Juice dried using the pilot plant dehydrator, retained a greater amount of ascorbic acid (75 percent). In other studies (Mendenhall and Willis, 1977) home canned tomato juice assayed for ascorbic acid shortly after processing retained nearly 100 percent of the ascorbic acid present in the fresh tomatoes. In the same study, tomato juice stored at 25C and assayed for ascorbic acid 50 days after canning, had lost very little of its ascorbic acid content. It may be concluded that home dehydration destroys more ascorbic acid in tomato juice than home canning. Carotenes in carrots are retained well by the home dehydration process (Figure 16). Carotene retentions in this study agree with the previous work of Shelley (1978).

Data from this study did not substantiate manufacturer claims concerning product cost where cost of produce, depreciation on the dehydrator, energy costs and cost of time were considered. Retail prices for nitrogen-vacuum packed tomato juice crystals at the same period of time that the study was done ranged from \$14.15-\$15.41/kg. These products were also more concentrated than the home dehydrated product making them approximately half the cost of home dehydrated tomato juice (Table 10). Commercially dehydrated vacuum-nitrogen packed diced carrots ranged from \$10.30-\$12.43/kg retail. This was within the same range as data from this study for home dehydrated carrots (Table 9). Other claims concerning the theraputic value of dehydrated foods were not investigated in this study.

Carrots and tomato juice were more acceptable when dehydrated at higher more constant temperatures (about 60C), lower relative humidity (below 40 percent) and higher air flow (above 0.50kg air/min). These conditions were not always achievable with the home dehydrators evaluated in this investigation. Optimum conditions for dehydration vary with the type of product to be dried. Consumers wishing to produce high quality home dehydrated products should look for features in dehydrators such as variable temperature settings and fan speed settings in order to optimize dehydration parameters for each specific food.

High correlations between energy usage per kg in both carrot and tomato juice dehydrations with maximum temperature difference, indicate that the dehydration process is most energy efficient where there is a minimum of difference in temperature within the cabinet. When mass flow rates of air are higher, the maximum inside cabinet temperature differences are smaller, demonstrating the ability of faster moving air to uniformly warm the cabinet. Variation of temperature within home dehydrators is a factor that consumers should consider in order to avoid spending extra time shifting trays during the dehydration process. Dehydrators with mass flow rates of air greater than 0.50kg/min, probably circulate air sufficiently within the dehydrator to minimize temperature variation within the dehydration cabinet.

The high correlation of initial cost of dehydrators with mass flow rate of air, total square meters and total cubic meters can be interpreted to mean that consumers are paying for larger motors and more space when they spend more for home dehydrators. The large differences in mass flow rates of air had multiple effects on the product cost and quality. High positive correlations between mass flow rate of air and the sensory qualties of both rehydrated carrots and tomato juice indicate that increased airflow has a positive effect on quality. Unlimited airflow, however, in combination with thickly sliced pieces has a tendency to cause case hardening, or drying and hardening of the outer layer of the food, inhibiting the outward movement of internal moisture. If home dehydrators were equiped with a mechanism to vary airflow over a wide range of airflow rates, consumers would be able to adjust the airflow according the piece size and food type. Although dehydrator C contained a fan, due to the design of the dehydrators, there was no measurable advantage in mass flow rate of air over dehydrator E which contained no fan. The presence of a fan does not necessarily mean that a dehydrator has adequate airflow.

AIRFLOW had a greater effect on TOTIME for carrot dehydation than did TOTIME for tomato juice dehydration. This was probably due to the difference in the nature of food (solid vs. liquid). The amount of tomato juice decreased in the dish and became more concentrated as dehydration progressed, however, the surface was continually wet until most of the water had been removed. The percentage of time in the critical-rate period was greater for tomato juice than for the carrots.

The high negative correlation between TOTIME and INTEMP shows the importance of the ability to quickly heat the dehydration cabinet in order to speed up dehydration. In the initial stages of dehydration, food can tolerate higher air temperatures because the evaporation rate maintains the product temperature lower than air temperature.

Sensory quality in rehydrated tomato juice is affected by dehydration temperature and relative humidity more than rehydrated carrots are affected. Presumably this was due to the nature of the two foods. Since the water molecules in tomato juice are not bound in cells, they are free to move within the dish and product temperature can be fairly uniform throughout dehydration.

Carrots, however, have temperature gradients. In the initial stage of dehydration the surface temperature is close to air temperature and the temperature in the center of the dish is probably much lower. Dehydrated carrot cost correlated highly with kW.hr (r= 0.917) consumed and temperature differences within the dehydration cabinet (r= 0.944), whereas, the cost of dehydrated tomato juice did not correlate well with these parameters (0.199 and 0.060 respectively.) The cost of fresh tomatoes, which is usually much greater than the cost of fresh carrots, masks the effects of energy consumption on product cost. Carrot dehydration uses more kW.hr in every case than the corresponding tomato juice dehydration so that energy costs are a more important consideration in home dehydrated carrots than home dehydrated tomato juice. Since the cells in tomato juice are largely ruptured, dehydration consisted mainly of evaporation, whereas many cell walls are left intact in ground carrots. Intercellular water in carrots is required to move by osmosis from the inside of the cell wall and plasmalemma through these barriers to be evaporated. This situation decreases the dehydration rate, especially during the constant rate period.

The Effect of Physical Paramaters on Carrot Dehydration

The Effect of Physical Parameters on Carotene

Variations in physical parameters from dehydrator to dehydrator produce no significant difference in carotene content. These data are compatible with those of Shelley (1978), who reported very high retention of carotene, in some cases up to 100 percent in a variety of home dehydrated foods. Calloway (1962) reported 70-100 percent retention for blanched dehydrated foods. Calloway, however, stated that higher heat processes such as retort sterilization result in greater destruction. Product temperatures of the carrots are very low during the initial stage of dehydration where carotene degradation is favored due to high moisture, and only reach air temperature (always well below retort temperatures) when the product is less vulnerable to carotene degredation.

The multiple regression model for carotenes rejected at the $p < 0.05$ level. Variability was as great within treatments as it was between treatments. Considering the small losses of carotenes, this could be expected.

The Effect of Physical Parameters on Objective Color

The difference in visible color, as measured by Hunter "L", "a", and "b" scores, for the 19 treatments is reflected by only slight differences which are not statistically measurable. However, samples from dehydrator C were lighter in color to the eye and were closer to yellow than other samples. The data on dehydrator C are higher than average for the "L" and lower for "a" values than the data from other dehydrators. This indicates a lighter and less red product, as was observed. Samples from dehydrator E were visibly darker and less orange than samples from other dehydrators. The "L" and "a" values for dehydrator E reflect this trend and are on the average the lowest for "L" and second to the lowest for the "a" value of any dehydrator tested.

Dehydrators C and E required the longest dehydration times, began with relatively low dehydration temperatures, and both had very poor air flow, therefore, the product was in the constant-rate period for an extended time. In the model for Hunter "a" or redness, TOTIME was the most important parameter, next was AIRFLOW. It can be concluded then that although only slight differences occured between these dehydrators, regimes which exposed the carrots to lower temperatures in the initial stages and lower air flows for a longer time resulted in an inferior colored product.

The statistical difference between the "Y" values in the treatments demonstrates the difference in lightness between treatments. Although "L" and "Y" both express lightness or reflectance, "L" is linear with respect to visual perception, whereas "Y" is not (Francis and Clydesdale, 1975). The relationship of "L" to "Y" is: $L = 100Y^{1/2}$. The error term is often amplified by this transformation (Rich, 1980). It is logical that statistical tests such as the analysis of variance and multiple regressions are affected by this transformation. Fresh carrots had greater reflectance as shown by "L" and "Y" values (Table 12). The measurement of color intensity was probably confounded by colors resulting from nonenzymatic browning and carotene breakdown. The amount of nonenzymatic browning is proportional to time spent in the constant-rate period because the reaction occurs fastest at water activities of 0.7 (Bluestein and Labuza, 1975). Treatment C likely had "L" and "Y" values similar to other treatments due to oxidation of carotenoids which occured during the extended constant-rate period, rather than lack of nonenzymatic pigments. This idea is substantiated by the fact that panel members detected a color difference in samples the constant-rate period favored microbial growth. This idea is supported by the fact that AIRFLOW contributed the greatest amount of information in the model (27.2 percent) for flavor (Table 18). High FINRH was deleterious to flavor probably due to the adverse effects of surface rehydration. High FINTEMP and INTEMP were favorable to higher flavor scores. This is possibly due to increased dehydration rate and therefore minimum time of exposure to heat.

Acceptability in carrots is shown to be highly correlated with the physical parameters (Table 20). A more positive RHS results in better acceptability. In this study, all the RHS's were negative (Figures 4-15). The most positive RHS's were in dehydrators with low RHIN's. Relative humidity did not drop as rapidly when the zero time intercept was lower. High FINTEMP, low FINRH, higher INTEMP and high AIRFLOW resulted in the most acceptable product (Table 20). These conditions favor a faster constant-rate period and thus do not favor nonenzymatic browning or microbial growth.

Evaluation of Physical Parameters on Tomato Dehydration

Effect of Physical Parameters on Ascorbic Acid Retention

The greatest amount of information regarding the final concentration of ascorbic acid in tomato juice was contributed by RHIN (Table 22). High exit relative humidity in this stage results in the greatest loss of ascorbic acid. High relative humidity at the exit port was characterisitic of dehydrator D in which temperature rose sharply from time = 0 to time = 1 hr and in which the relative humidity rose sharply and then fell sharply (Figure 13). High product temperatures in the constant-rate period may result from this regime.

from dehydrator C. Although they judged the sample more typically carrot colored than the rest, they found it unacceptable.

The multiple regression model for "L" listed FINRH and TOTIME first (Table 13). High FINRH and longer TOTIME decreased the color intensity in the final product. Longer TOTIME, undoubtedly increased the time for carotenes to break down to compounds such as beta-ione, less colored isomers, off-colored and colorless compounds. Higher relative humidity may have caused some surface rehydration and thus favored this reaction.

As AIRFLOW increased, the "L" value decreased in the model. Mass flow rate of air determines to a large extent the constant-rate (Harper, 1976; Heldman, 1977). During the constant rate period moisture potential of 0.7 favors degredation of carotenes. This may be the explanation for the inclusion of AIRFLOW in the model.

The introduction of FINTEMP to the model indicates that some carotene pigments are broken down even when food is in the low moisture stages of dehydration if the temperature is high enough. FINTEMP, due to low moisture, has a greater effect on product temperature in the constant-rate stages. Higher INTEMP probably increases the L value in the model because it increases the constant-rate with less effect on product temperature than high FINTEMP has.

As greater INTEMP values were used in the model, the "L" value increased. Low relative humidity in the constant-rate period allows more cooling and thus increases the rate in the constant-rate period. This results in lower product temperatures during dehydration. The product also spends less time at high moisture levels. Both these factors aid in pigment retention.

The Hunter "b" value model explained only 20.5 percent of the variability in "b". The model was considered poor.

The Effect of Physical Parameters on Sensory Quality

Panelists indicated that rehydrated carrots from treatments B, C, D, and E exhibited the most typical carrot color, whereas acceptability for these treatments was the lowest. This may be due to the color and flavor change involved with nonenzymatic browning in these treatments as discussed in the previous section.

TOTIME explained most of the variability between treatments for COLORS (Table 18). TOTIME and FINTEMP increased concurrently with COLORS. This can be explained largely by the fact that long dehydration times and high temperature are favorable conditions for nonenzymatic browning. Relative humidity and mass flow rate of air have the greatest effect on rate during the constant-rate period (Harper, 1976; Heldman, 1977) when the product is most suceptible to browning. As RHS increased in negativity, and as AIRFLOW increased the conditions became less favorable for browning and a lower sensory score color resulted. These parameters explain about 66.5 percent of the variability in the experiment.

Carrot flavor intensity did not correlate well with acceptability. Many comments on the carrots from treatment C indicated that there was a strong off-flavor which may have masked the typical carrot flavor. During dehydration yeasty odors were detected coming from this dehydrator. Apparently slow dehydration, low AIRFLOW and long time in

High product temperature may result from high air temperature and the absence of the cooling effect of evaporation which was prevented by high vapor pressure in the air. Dehydration regimes with high mass flow rate of air (Table 22) results in reduced relative humidity and an increased constant-rate both of which contributed to better ascorbic acid retention. A lower FINTEMP, lower relative humidity and shorter TOTIME increases ascorbic acid values in the model. Low relative humidities are indicative of faster dehydration especially in the falling-rate period. High FINTEMP's supply energy to overcome the increased activataion energy for ascorbic acid degradation, and result in its destruction, especially when relative humidity is higher and the possibility of surface rehydration are great.

The Effect of Physical Parameters on Objective Color

Although no significant difference could be measured in the color of tomato juice from Hunter "L", "a", "b" and CIE "Y" values, the multiple regression models explained 56-60 percent of the variability that occured. Color changes during processing are mainly due to isomerization of ATL to cis-lycopene, further oxidation to aldehydes and other smaller molecules, nonenzymatic browning and scorching (Lovric, Sablak and Boskovic, 1970; Wong and Bohart, 1957; Boskovic, 1979; Hodge, 1953; Tannenbaum, 1976).

The models for "L" and "Y" were very similar (Tables 24 and 27), so only "Y" will be discussed. Final relative humidity had the greatest effect on the model of any parameter. In those dehydrators where FINRH was lowest, AIFLOW was greatest and scorching was less likely to occur because of the more even distribution of heat.

Increased TOTIME resulted in a darker product according to the "Y" model. In dehydration processes where it took longer to dehydrate the samples, the product spent more time in a moist condition (around 0.7 moisture potential) which favors enzymatic browning. Higher TEMPSLOP's favored lighter products. Higher TEMPSLOP's decreased TOTIME (Table 27). TEMPSLOP, FINTEMP and INTEMP, however, were not very important in the model.

Effect of Physical Parameters on Sensory Quality

The change of ATL to cis-lycopene, the degree of subsequent autoxidation, nonenzymatic browning, and scorching probably are the major influences on tomato juice color. In the model for subjective color the scores are affected greatest by INTEMPT (Table 29). Higher temperatures at this point increase the constant-rate and thus minimize the time the product spends at high moisture content, where nonenzymatic browning is favored. Shorter dehydration times also favor a greater intensity of color in tomato juice. This is due to the extended exposure to heat which increases the time in which browning reactions may occur. AIRFLOW and RHIN correlate positively with color intensity. High AIRFLOW favors lower product temperatures in the constant-rate period and a faster constant-rate period results in conditions which are least favorable for nonenzymatic browning and other destructive reactions. The meaning of a positive correlation coefficient) for RHIN is not understood. High FINTEMP and low FINRH favored higher color scores in the model, probably due to their high correlation with increased drying rate (Table 6). As can be seen from Table 23, treatment E had nearly the same values as other treatments.

The subjective color score, however, was very low. This color had to do with an almost inevitable scorching which occured when the product moisture dropped in the bottom section near the coil. The coil lacked a thermostat and product temperature would reach 75C, the temperature of the air surrounding the coil, in the latter stage of dehydration.

The design of the step by step multiple regression model was the same for FLAVORS, ACCEP and COLORS. The equations of these models are very similar. Since the sensory scores are very highly correlated with each other, (Table 6) it is understandable that the models are similar. The same independent parameters which influence the FLAVORS and ACCEP models, influenced the COLORS model for the same reasons. The same chemical reactions which change color also affect flavor. Nonenzymatic browning produces many sensory defects, strong odors and volitile compounds (Pangborn and Russell, 1976).

SUMMARY

The design of home dehydrators influences the cost, flavor, color, acceptability, and nutrient retention of the dried product. Total time and energy consumption also varied with dehydrator. None of the home dehydrators had mass flow rates as high as those of the pilot plant dehydrator. Products from home dehydrators were generally more costly and less acceptable than products dried in the larger pilot plant dehydrator. Comparable commercial products were the same or less costly than home dehydrated products when depreciation and labor costs were considered.

In general, quality of both carrots and tomato juice, particularly ascorbic acid retention in tomato juice, increased in products dehydrated as total dehydration time decreased, mass flow rate of air increased and temperature difference in the cabinet decreased. Initial temperatures between 50-60C were the most favorable for overall quality retention. Energy usage and product costs were lower under these same conditions.

The following recommendations for consumers wishing to purchase a dehydrator are based on this study:

1. A home dehydrator should allow temperature selection (40-70C), have a short come up time, and contain a thermostat. A thermometer could be used to test the veracity of the temperature selector.
2. Consumers ought to test the air flow of a dehydrator prior to purchasing by switching on a demonstrator model and testing air movement inside the cabinet and at the exit to determine

if air moves adequately within the cabinet over dehydrating food and to insure that moisture laden air is replaced by heated drier air. Air should circulate to every corner of the dehydrator and the the replacement rate of air within the dehydrator should be greater than five dehydrator volumes of air per minute. Good airflow helps minimize temperature differences inside dehydrators and speeds up the dehydration process. In this study it was also shown that although immediate energy demands increases as airflow increases, the decrease in required time make home dehydrators with airflows greater than the figure listed above, more efficient and less costly to operate. It was also shown that the higher the airflow, the greater the nutrient and quality retention in the product.

3. Variable fan speeds (0.40-3.0kg air/min) are desirable since optimum mass flow rates of air vary with the product to be dehydrated.
4. The size of the dehydrator should be selected according to the needs of the consumer. If the consumer plans to dehydrate large quantities of produce frequently, a large dehydrator is more economical. A small dehydrator, while resulting in larger costs per batch is more suitable for small infrequent batches.
5. Cost of home dehydration should be considered. When retail cost of energy and depreciation on the dehydrator and minimum wages for the labor involved were considered, home dehydration was less economical than purchasing comparable retail goods.

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APPENDICES

Appendix A. Fortran program for conversion of wet and dry bulb temperatures to relative humidity

```
GO TO 5
3 WRITE (6,92)
92 FORMAT (  'YOU REVERSED THE WET AND DRY BULB TEMPS!')
5 WRITE (6,90)
90 FORMAT ('INPUT WET BULB AND DRY BULB TEMPERATURES',T2,/)
READ (5,/)CWB,CDB
IF(CWB.GT.CDB) GO TO 3
PG2 = 2044660*EXP(-7071.3/CWB*1.8+417))*6.89473
HG1=2502.7563+1.7829*CDB
HF2+0.40484+4.17892*CWB
HG2=2502.7563+1.7829*CWB
PG1=2044660*EXP(-7071.3/(CDB*1.8+417))*6.89473
W1=((CWB-DCB)+(0.622*PG2/(86-PG2))*(HG2-HF2))/(HG1-HF2)
PHI=W1*86/(PG1*(0.622+W1))
WRITE (6,91)CWB,CDB,PHI*100
91FORMAT(T3,F4,1,2X,F4.1,2X,F6.2)
GO TO 5
STOP
END
```

Where:

CWB = Celsius wet bulb temperature
CDB = Celsius dry builb temperature
PG2 = saturation pressure at CWB
HG1 = enthalpy of water vapor at CDB
HF2 = enthalpy of liquid water at CWB
HG2 = enthalpy of water vapor at CWB
PG1 = saturation pressure at CDB
W1 = absolute humidity
PH1 = relative humidity

Note: 86 kPa was used for atmospheric pressure

Appendix B. Mass energy balances for a pilot plant dehydrator

Mass Energy Balance for Dehydration

$$\text{Energy in} = w + q + M_1(h_{f2} - h_{f1}) + M_2\,(h_{g2} - h_{f1}) + M_3\,C_{ps}$$

$$(T_2 - T_1) + M_4\,C_{pa}(T_2 - T_3) + M_5\,(h_{g2} - h_{g3})$$

Where:

w = work done by fan and air compressor

q = energy loss through the walls of the dehydrator for the total energy process

M_1 = mass of water in kg remaining in food after dehydration

h_{f2} = enthalpy of liquid water at final temperature

h_{f1} = enthalpy of liquid water at initial temperature

M_2 = mass of water in kg vaporized from food

h_{g2} = enthalpy of water vapor at final temperature

M_3 = Mass solids in food in kg

C_{ps} = heat capacity of solids in food

T_2 = final temperature of air and food

T_1 = initial temperature of food

M_4 = mass of air in kg

C_{pa} = heat capcity of air

T_3 = initial temperature of air

M_5 = mass of moisture vapor in kg in inlet air

h_{g1} = enthalpy of water vapor at initial air temperature

$$\dot{q} = \frac{T_2 - T_1}{\frac{1}{h_1} + \frac{x}{k} + \frac{1}{h_o}} \times A$$

Where:

$\dot{q}$ = rate of energy per hour loss through the walls of the dehydrator for the total process

h_i = convective coefficient adjacent to inside wall

k = thermal conductivity of the insulation

h_o = convective coefficient adjacent to the outside wall

T_2 = temperature inside dehydrator

T_1 = outside temperature

A = surface area

Energy Calculations for Pilot Plant Dehydration of Carrots

Mass Energy Balance

Energy in = $w + q + M_1(h_{f2} - h_{f1}) + M_2(h_{g2} - h_{f1}) + M_3\ C_{ps}$ $(T_2 - T_1) + M_4\ C_{pa}(T_2 - T_3) + M_5\ (h_{g2} - h_{g3})$

w = (4.3amps x 208volts x 23hrs) (for fan) + (4.3amps x 208 volts x 0.166hr running/hr x 23hr) for compressor = 23.99kW.hr x 3600kJ/kW.hr = 8.63 x 10^{-4}kJ

$$q/A = \frac{40.6C}{\frac{1}{5W/m^2.C} + \frac{0.004m}{0.038W/m_2.C} + \frac{1}{5W/m^2.C}} =$$

$80.354W/m_2$ x $24.17m_2$ x = 1.94kW x 23hr x 3600kJ/kW.hr = 1.60 x 10^5kJ

Energy in = 8.63 x 10^4kJ + 1.60 x 10^5kJ + 0.18kg(292.98kJ/kg -104.89kJ/kg) + 51.06kg(2626.8 - 104.89kJ/kg) + (8.97kg) (1.38 kJ/kg.C)(70.6C-25C) + 1.004 kJ/kg.C (70.6C - 29.0C) + 16.72(2626.8kJ/kg - 2556.3kJ/kg) = 4.92 x 10^5kJ

Energy Calculations for Pilot Plant Dehydration of Tomato Juice

Mass Energy Balance

Energy in = $w + q + M_1(h_{f2} - h_{f1}) + M_2(h_{g2} - h_{f1}) + m_3\ C_{ps}$ $(T_2 - T_1) + M_4\ C_{pa}(T_2 - T_3) + M_5\ (h_{g2} - h_{g3})$

w = (4.3amps x 208 volts x 14hrs) (for fan) + (4.3amps x 208 volts x 0.166hr running/hr x 12hr) (for compressor) = 12.51 kW.hr x 3600kJ/kW.hr = 4.51 x 10^4 kJ

$$q/A = \frac{39.0C}{\frac{1}{5W/m^2.C} + \frac{0.004m}{0.038W/m^2.C} + \frac{1}{5W/m^2.C}} =$$

77.188W/m^2 x 24.17m^2 = 1.87kW x 12hr x 3600kJ/kW.hr = 8.06 x 10^4kJ

Energy in = 6.41 x 10^3 kJ + 8.06 x 10^4kJ + 0.21(272.06kJ/kg - 83.96kJ/kg) + 49.19kg (2618.3kJ/kg - 83.96kJ/kg) + 3.6kg (1.38kJ/kg.C- (64C - 25C) + 5.81kg (2618.3 -2538.1) = 3.47 x 10^5kJ

Appendix C. Cost analyses for dehydrated carrots and dehydrated tomato juice

Estimated Cost of Carrot Dehydration (Dehydrator A)

Energy Costs

$$\frac{7.962\text{kW.hr} + 4.322\text{kW.hr} + 4.837\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$.30$$

Produce Cost

$0.44/kg ground carrots x 3.78 kg = $1.66

Preparation Cost

(1.20hr washing + 0.50hr grinding + 1.0hr blanching +

1.06hr loading)/20 kg x 3.78kg = 0.71hr x $2.90/hr = $2.06

Unloading, Packaging and Cleaning Costs

$$\frac{1.35\text{hr unloading, packaging and cleanup} \times 0.45\text{kg}}{10\text{kg}} =$$

0.06hr x $2.90 = $0.18

Depreciation Costs

$$\frac{\$99.00}{2500\text{hr}} \times \frac{15.50\text{hr} + 10.50\text{hr} + 12.17\text{hr}}{3} = \$0.50$$

Summation of Costs

Energy	$0.30
Produce	1.69
Preparation	2.06
Unloading etc.	0.18
Depreciation	0.50
	$4.70

$$\frac{\$4.70}{0.45\text{kg}} = \frac{\$10.44}{\text{kg}}$$

Estimated Cost of Carrot Dehydration (Dehydrator B)

Energy Costs

$$\frac{3.640\text{KW.hr} + 3734\text{kW.hr} + 4.551\text{kW.hr}}{3} = \$0.21$$

Produce Cost

$0.44/kg ground carrots x 5.25g - $2.31

Preparation Cost

(1.20hr washing + 0.50hr grinding + 1.0hr blanching +

1.06hr loading)/20kg x5.25kg = 0.99hr x $2.90/hr = $2.84

Unloading, Packaging and Cleaning Costs

$$\frac{1.35\text{hr unloading, packaging and cleanup}}{10\text{kg}} \times 0.63\text{kg} =$$

0.09hr x $2.90 = $0.24

Depreciation Costs

$$\frac{\$119.00}{2500\text{hr}} \times \frac{13.33\text{hr} + 14.00\text{hr} + 11.17\text{hr}}{3} = \$0.61$$

Summation of Costs

Energy	$0.21
Produce	2.31
Preparation	2.84
Unloading etc.	0.24
Depreciation	0.61
	$6.21

$$\frac{\$6.21}{0.63\text{kg}} = \frac{\$9.81}{\text{kg}}$$

Estimated Cost of Carrot Dehydration (Dehydrator C)

Energy Costs

$$\frac{6.999\text{kW.hr} + 6.765\text{kW.hr} + 8.700\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0.40$$

Produce Cost

$0.44/kg ground carrrorts x 6.05kg = $2.66

Preparation Cost

(1.20hr washing + 0.50hr grinding + 1.0hr blanching +

1.06hr loading)/20kg x 6.05 kg = 1.14hr x $2.90/hr = $3.30

Unloading, Packaging and Cleaning Costs

$$\frac{1.35\text{hr unloading, packaging and cleanup}}{10\text{kg}} \times 0.72\text{kg} =$$

0.10hr x $2.90 = $0.29

Depreciation Costs

$$\frac{\$150.00}{2500\text{hr}} \times \frac{15.50\text{hr} + 15.25\text{hr} + 15.17\text{ hr}}{3} = \$0.91$$

Summation of Costs

Energy	$0.40
Produce	2.66
Preparation	3.30
Unloading etc.	0.29
Depreciation	0.91
	$7.56

$$\frac{\$7.56}{0.72\text{kg}} = \frac{\$10.50}{\text{kg}}$$

Estimated Cost of Carrot Dehydration (Dehydrator D)

Energy Costs

$$\frac{3.876\text{kW.hr} + 3.257\text{kW.hr} + 3.876\text{ kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0.19$$

Produce Cost

$0.44/kg ground carrots x 6.43kg = $2.83

Preparation Cost

(1.20hr washing + 0.50hr grinding + 1.0hr blanching +

1.06hr loading)/20kg x 6.43kg = 1.21hr x $2.90/hr = $3.51

Unloading, Packaging and Cleaning Costs

$$\frac{1.35\text{hr unloading, packaging and cleanup}}{10\text{kg}} \times 0.77\text{kg} =$$

0.10hr x $2.90 = $0.29

Depreciation Costs

$$\frac{\$109.00}{2500\text{hr}} \times \frac{14.50\text{hr} + 11.00\text{hr} + 14.50\text{hr}}{3} = \$0.58$$

Summation of Costs

Energy	$0.19
Produce	2.83
Preparation	3.51
Unloading etc.	0.29
Depreciation	0.58
	$7.40

$$\frac{\$7.40}{0.77\text{kg}} = \frac{\$9.61}{\text{kg}}$$

Estimated Cost of Carrot Dehydration (Dehydrator E)

Energy Costs

$$\frac{1.375\text{kW.hr} + 1.500\text{kW.hr} + 1.600\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0.08$$

Produce Cost

$0.44/kg ground carrots x 1.01kg = $0.44

Preparation Cost

(1.20hr washing + 0.50hr grinding + 1.0hr blanching +

1.06 hr loading)/20kg x 0.44kg = 0.08 hr x $2.90/hr =$0.24

Unloading, Packaging and Cleaning Costs

$$\frac{1.35\text{hr unloading, packaging and cleanup}}{10\text{kg}} \times 0.05\text{kg} =$$

0.01hr x $2.90 = $0.03

Depreciation Costs

$$\frac{\$25.99}{2500\text{hr}} \times \frac{13.25\text{hr} + 15.00\text{hr} + 16.00\text{hr}}{3} = \$0.15$$

Summation of Costs

Energy	$0.08
Produce	0.44
Preparation	0.24
Unloading	0.03
Depreciation	0.15
	$0.94

$$\frac{\$0.94}{0.05\text{kg}} = \frac{\$18.80}{\text{kg}}$$

Estimated Cost of Carrot Dehydration (Dehydrator F)

Energy Costs (assuming 60 percent efficiency for coal)

$$\frac{\text{kg coal}}{27\ 888\text{kg}} \times \frac{\$0.05}{\text{kg coal}} \times \frac{1}{0.6\ \text{efficiency}} \times 4.06 \times 10^{5}\ \text{kJ} =$$

\$1.21

Produce Cost

\$0.44/kg ground carrots x 5.25 = \$2.31

Preparation Cost

(1.20hr washing + 0.50hr grinding + 1.0hr blanching +

1.06hr loading)/20kg x 60.21kg = 11.32hr x \$2.90/hr

= \$32.83

Unloading, Packaging and Cleaning Costs

$$\frac{\text{1.35hr unloading, packaging and cleanup}}{\text{10kg}} \times 9.15\text{kg} =$$

1.24hr x \$2.90 = \$3.58

Depreciation Costs

$$\frac{\$119.00}{2500\text{hr}} \times \frac{13.33\text{hr} + 14.00\text{hr} + 11.17\text{hr}}{3} = \$0.50$$

Summation of Costs

Energy	\$ 1.27
Produce	26.55
Preparation	32.83
Unloading	3.58
Depreciation	0.15
	\$64.32

$$\frac{\$64.32}{9.15\text{kg}} = \frac{\$7.03}{\text{kg}}$$

Estimated Cost of Tomato Juice Dehydration (Dehydrator A)

Energy Costs

$$\frac{6.467\text{kW.hr} + 6.467\text{kW.hr} + 5.738\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0{\cdot}32$$

Produce Cost

$$\$0.89/\text{kg juice} \times 1.8\text{kg} = \$1.62$$

Preparation Cost

(0.25hr washing = 0.2hr whole blanching + 0.5hr quartering + 0.5hr juicing + 0.3hr blanching juice and cooling + 0.67 hr loading)/20kg x 1.8kg = 0.22 x \$2.90/hr = \$0.64

Unloading, Packaging and Cleaning Costs

$$\frac{1.5\text{hr}}{10\text{kg}} \times 0.12\text{kg} = 0.02\text{hr} \times \$2.90/\text{hr} = \$0.06$$

Depreciation Costs

$$\frac{\$99.00}{2500} \times \frac{13.33 + 14.00 + 11.17}{3} = \$0.57$$

Summation of Costs

Energy	\$0.32
Produce	1.62
Preparation	0.64
Unloading	0.06
Depreciation	0.57
	\$3.21

$$\frac{\$3.21}{0.12\text{kg}} = \frac{\$26.75}{\text{kg}}$$

Estimated Cost of Tomato Juice Dehydration (Dehydrator B)

Energy Costs

$$\frac{3.640\text{kW.hr} + 3.734\text{kW.hr} + 4.551\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0.21$$

Produce Cost

$0.89/kg juice x 2.5kg = $2.23

Preparation Cost

(0.25hr washing = 0.20hr whole blanching + 0.50hr quartering + 0.5hr juicing + 0.30hr blanching juice and cooling + 0.67hr loading)/20kg x 2.5kg = 0.30 x $2.90/hr = $0.89

Unloading, Packaging and Cleaning Costs

$$\frac{1.5\text{hr}}{10\text{kg}} \times 0.12\text{kg} = 0.02\text{hr} \times \$2.90/\text{hr} = \$0.06$$

Depreciation Costs

$$\frac{\$119.00}{2500\text{hr}} \times \frac{13.33 + 14.00 + 13.58}{3} = \$0.65$$

Summation of Costs

Energy	$0.21
Produce	2.23
Preparation	0.89
Unloading	0.06
Depreciation	0.65
	$4.04

$$\frac{\$4.04}{0.12\text{kg}} = \frac{\$33.67}{\text{kg}}$$

Estimated Cost of Tomato Juice Dehydration (Dehydrator C)

Energy Costs

$$\frac{6.999\text{kW.hr} + 6.765\text{kW.hr} + 8.700\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0{\cdot}40$$

Produce Cost

\$0.89/kg juice x 2.9kg = \$2.58

Preparation Cost

(0.25hr washing = 0.20hr whole blanching + 0.50hr quartering + 0.50hr juicing + 0.30hr blanching juice and cooling + 0.67hr loading)/20kg x 2.9kg = 0.35 x \$2.90/hr = \$1.02

Unloading, Packaging and Cleaning Costs

$$\frac{1.5\text{hr}}{10\text{kg}} \times 0.20\text{kg} = 0.03\text{hr} \times \$2.90/\text{hr} = \$0.09$$

Depreciation Costs

$$\frac{\$150.00}{2500\text{hr}} \times \frac{15.00 + 15.25 + 15.17}{3} = \$0.91$$

Summation of Costs

Energy	\$0.40
Produce	2.58
Preparation	1.02
Unloading	0.09
Depreciation	0.91
	\$5.00

$$\frac{\$5.00}{0.2} = \frac{\$25.00}{\text{kg}}$$

Estimated Cost of Tomato Juice Dehydration (Dehydrator D)

Energy Costs

$$\frac{3.876\text{kW.hr} + 3.257\text{kW.hr} + 3.876\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0.19$$

Produce Cost

$0.89/kg juice x 3.1kg = $2.76

Preparation Cost

(0.250hr washing = 0.20hr whole blanching + 0.50hr quartering + 0.50hr juicing + 0.30hr blanching juice and cooling + 0.67hr loading)/20kg x 3.1kg = 0.38 x $2.90/hr = $1.09

Unloading, Packaging and Cleaning Costs

$$\frac{1.5\text{hr}}{10\text{kg}} \times 0.21\text{kg} = 0.03\text{hr} \times \$2.90/\text{hr} = \$0.09$$

Depreciation Costs

$$\frac{\$109.00}{2500\text{hr}} \times \frac{11.85 + 12.50 + 11.17}{3} = \$0.52$$

Summation of Costs

Energy	$0.19
Produce	2.76
Preparation	1.09
Unloading	0.09
Depreciation	0.52
	$4.65

$$\frac{\$4.65}{0.21\text{kg}} = \frac{\$22.14}{\text{kg}}$$

Estimated Cost of Tomato Juice Dehydration (Dehydrator E)

Energy Costs

$$\frac{1.375\text{kW.hr} + 1.500\text{kW.hr} + 1.600\text{kW.hr}}{3} \times 5.3\text{C/kW.hr} = \$0.08$$

Produce Cost

$\$0.89\text{/kg juice} \times 0.60\text{kg} = \$0.53$

Preparation Cost

(0.250hr washing = 0.20hr whole blanching + 0.50hr quartering + 0.50hr juicing + 0.30hr blanching juice and cooling + 0.67hr loading)/20kg x 0.60kg = 0.07hr x $2.90/hr = $0.21

Unloading, Packaging and Cleaning Costs

$$\frac{1.5\text{hr}}{10\text{kg}} \times 0.04\text{kg} = 0.01\text{hr} \times \$2.90\text{/hr} = \$0.03$$

Depreciation Costs

$$\frac{\$25.99}{2500\text{hr}} \times \frac{14.58 + 14.00 + 15.00}{3} = \$0.15$$

Summation of Costs

Energy	$0.08
Produce	0.53
Preparation	0.21
Unloading	0.03
Depreciation	0.15
	$1.00

$$\frac{\$1.00}{0.04\text{kg}} = \frac{\$25.00}{\text{kg}}$$

Estimated Cost of Pilot Plant Dehydration of Tomato Juice

Energy Costs (assuming 60 percent efficiency for coal)

$$\frac{\text{kg coal}}{27888\text{kJ}} \times \frac{\$0.05}{\text{kg coal}} \times \frac{1}{0.6\ \text{efficiency}} \times 2.63 \times 10^{5}\ \text{kJ} =$$

$0.79

12.51 kW.hr (fan and air compressor) x 5.30/hW.hr = $0.66

Produce Cost

$0.89/kg juice x 5.3kg = $47.17

Preparation Cost

(0.250hr washing = 0.20hr whole blanching + 0.50hr quartering + 0.50hr juicing + 0.30hr blanching juice and cooling + 0.67hr loading)/20kg x 5.3kg = 6.41 x $2.90/hr = $18.60

Unloading, Packaging and Cleaning Costs

$$\frac{1.5\text{hr}}{10\text{kg}} \times 3.81\text{kg} = 05.7\text{hr} \times \$2.90/\text{hr} = \$1.66$$

Depreciation Costs

Summation of Costs

Energy	$ 0.79
	0.66
Produce	47.17
Preparation	18.60
Unloading	1.66
Depreciation	0.08
	$68.96

$$\frac{\$68.96}{3.81\text{kg}} = \frac{\$18.10}{\text{kg}}$$

Appendix D. Exit temperature and relative humidity data for three replications of carrot dehydration (dehydrators A-F)

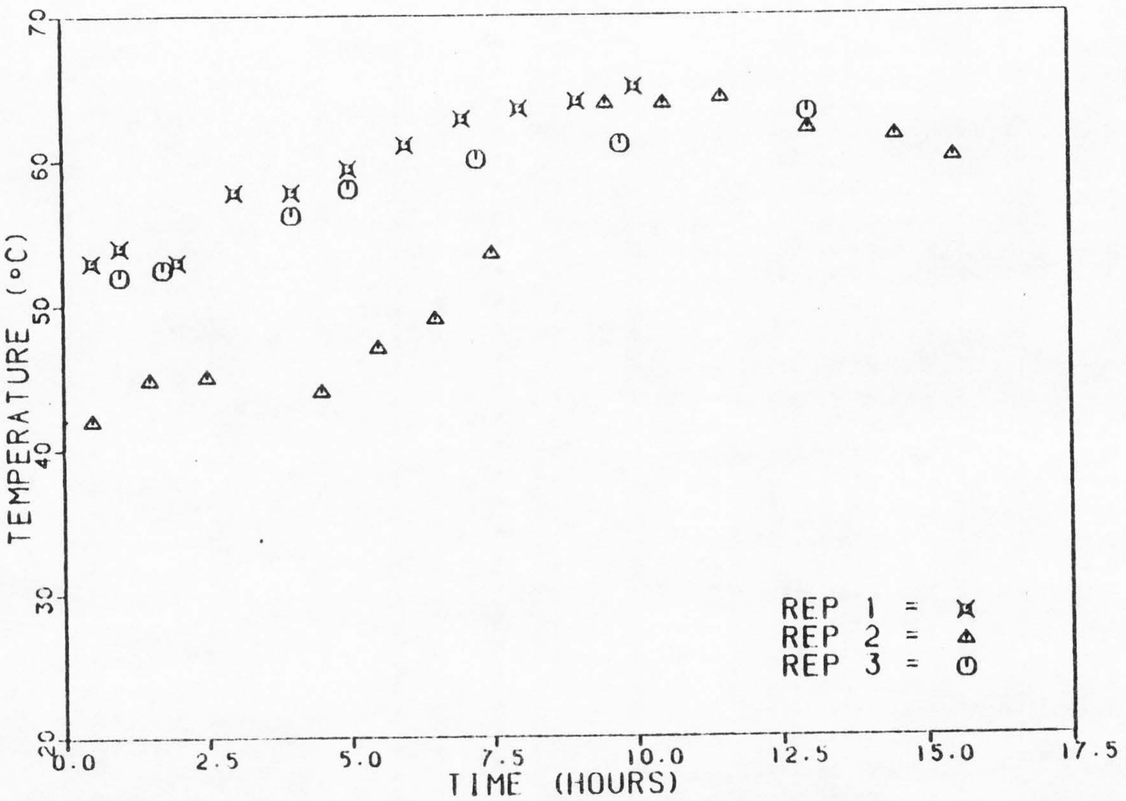

Figure 18. Exit temperature data for three replications of carrot dehydration (dehydrator A).

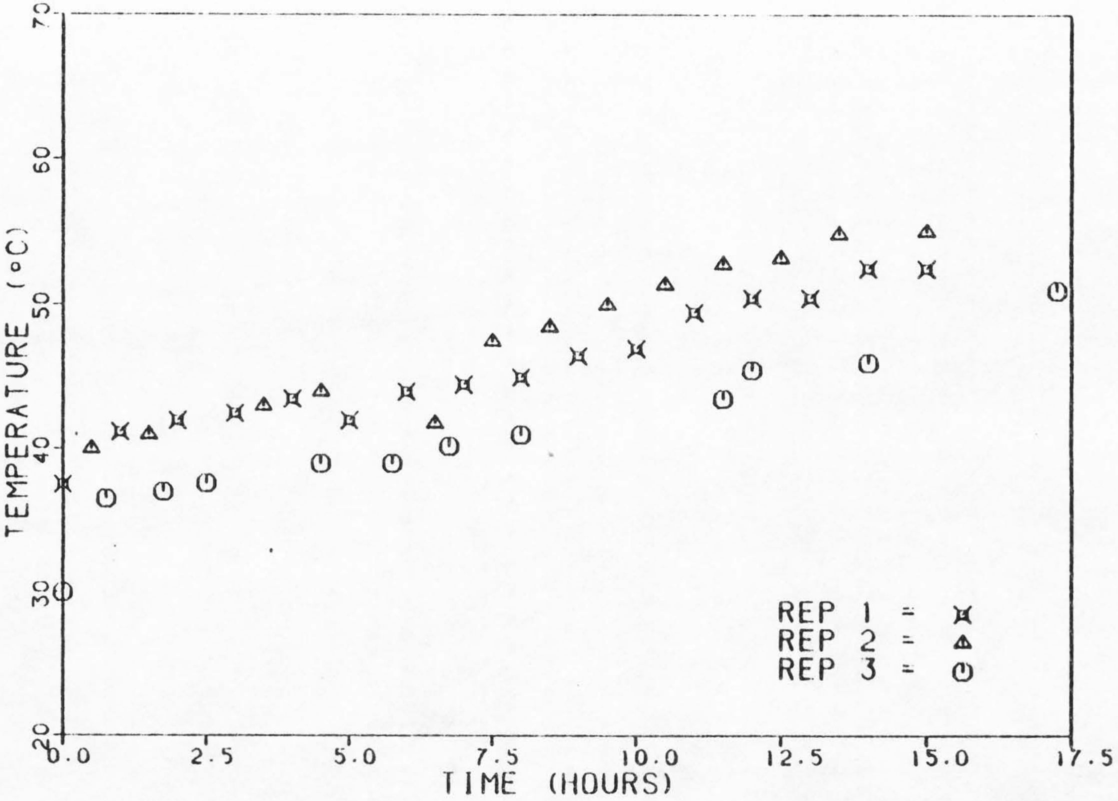

Figure 19. Exit temperature data for three replications of carrot dehydration (dehydrator B).

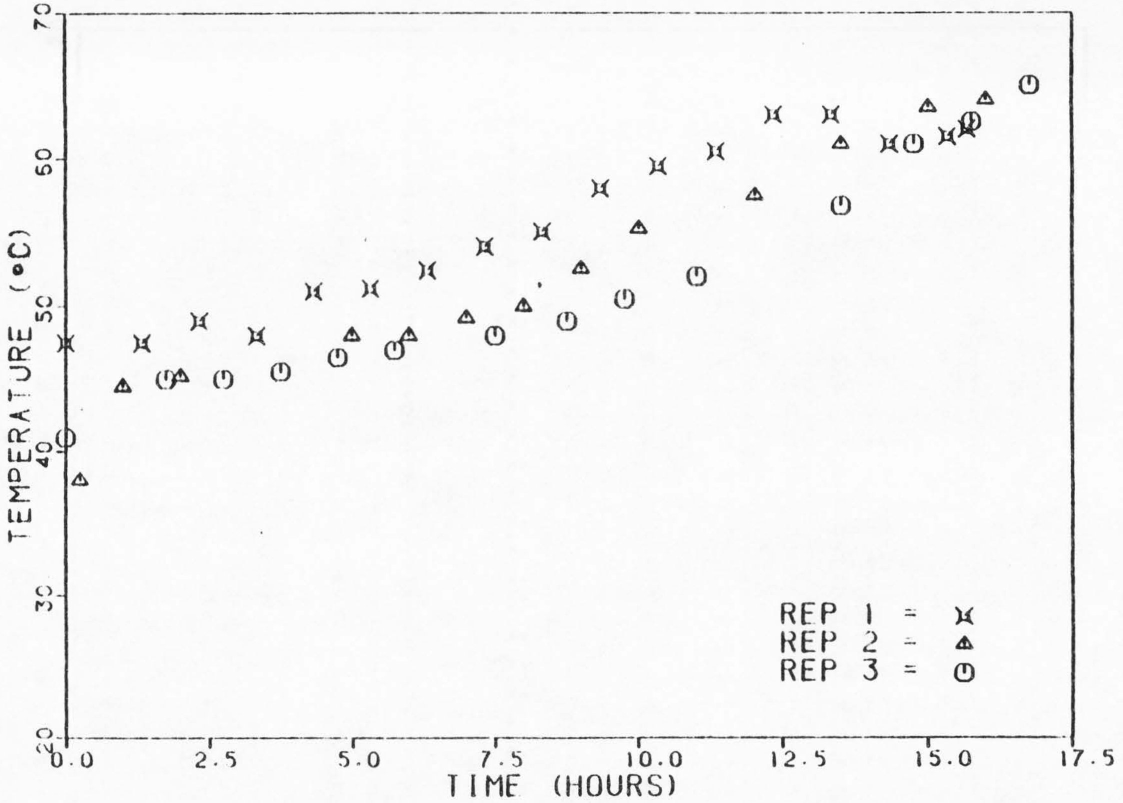

Figure 20. Exit temperature data for three replications of carrot dehydration (dehydrator C).

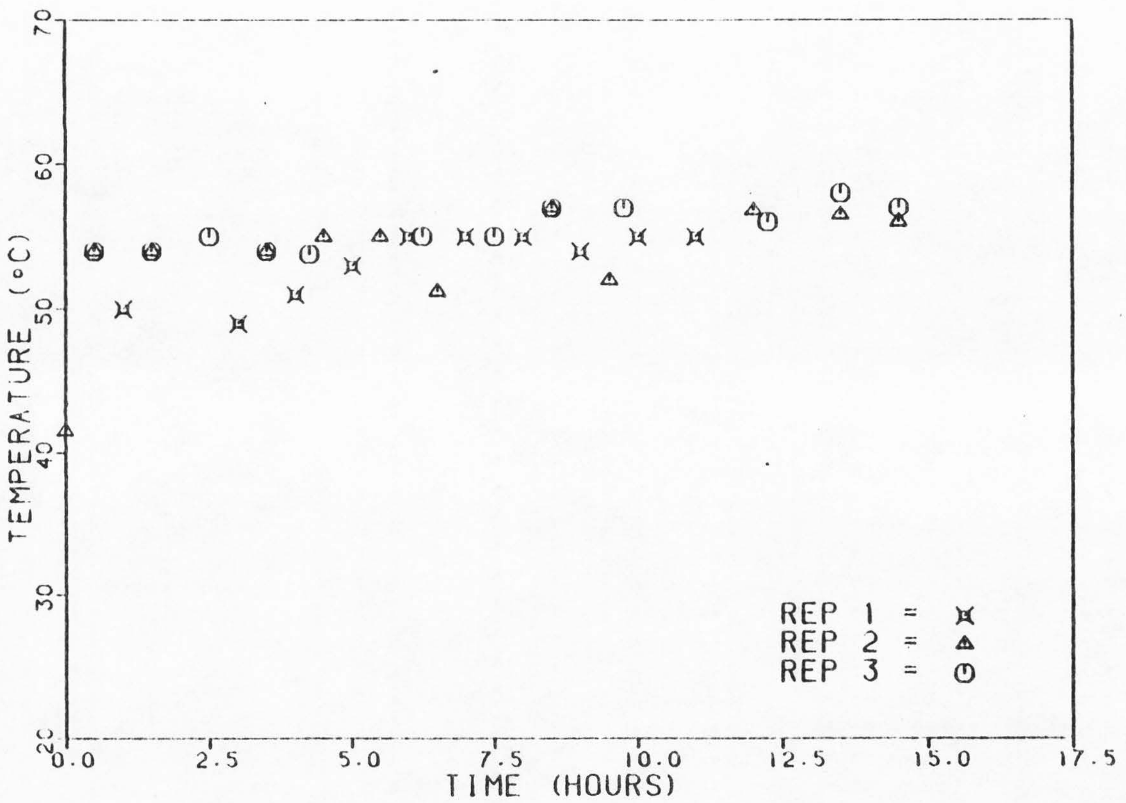

Figure 21. Exit temperature data for three replications of carrot dehydration (dehydrator D).

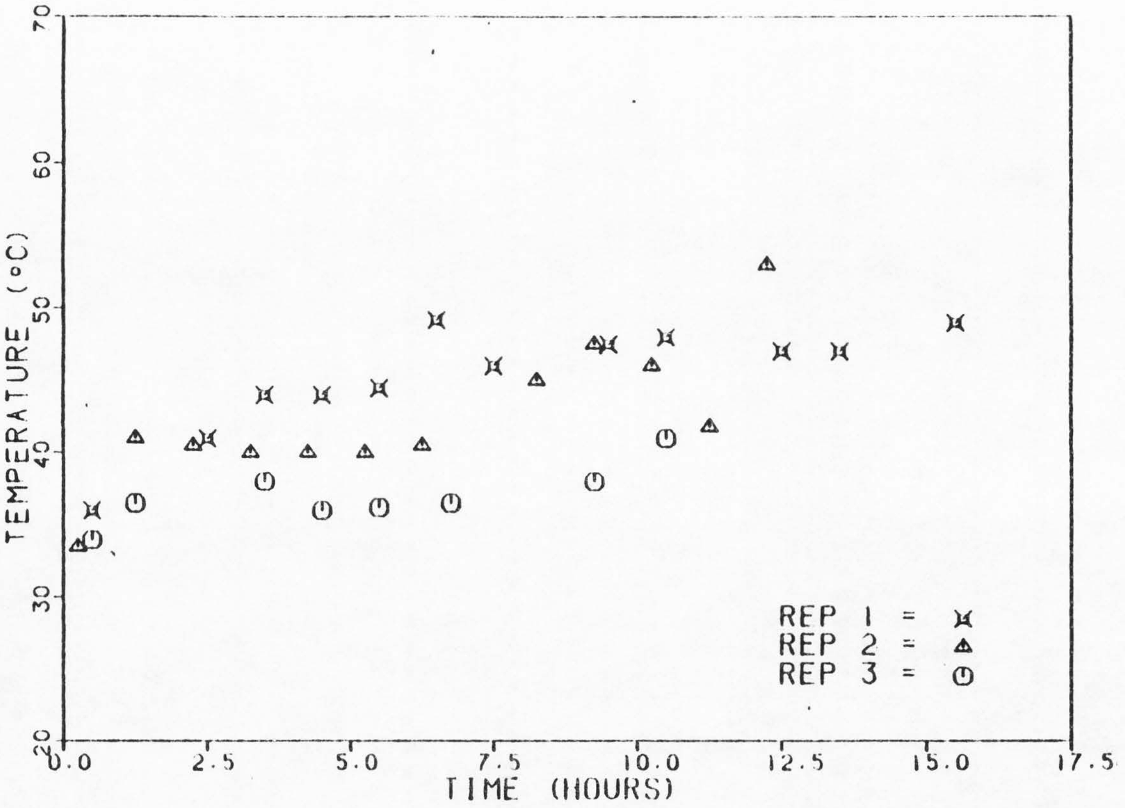

Figure 22. Exit temperature data for three replications of carrot dehydration (dehydrator E).

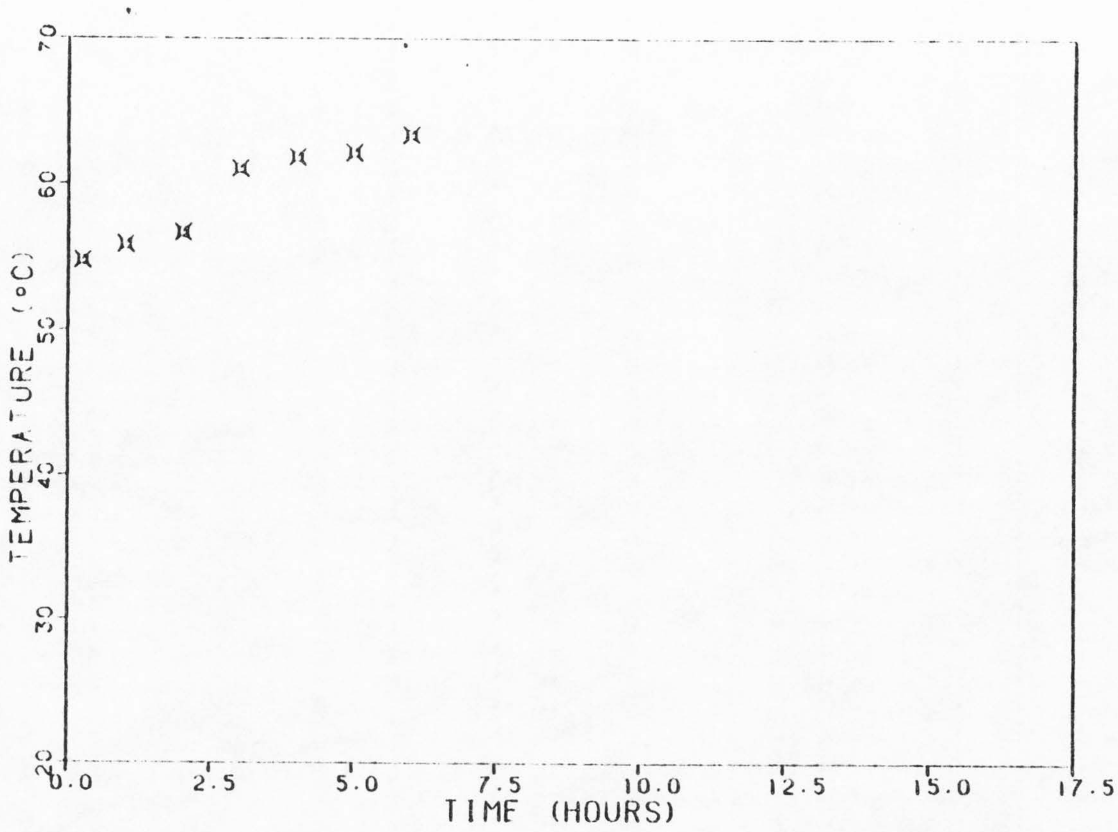

Figure 23. Exit temperature data for three replications of carrot dehydration (dehydrator F).

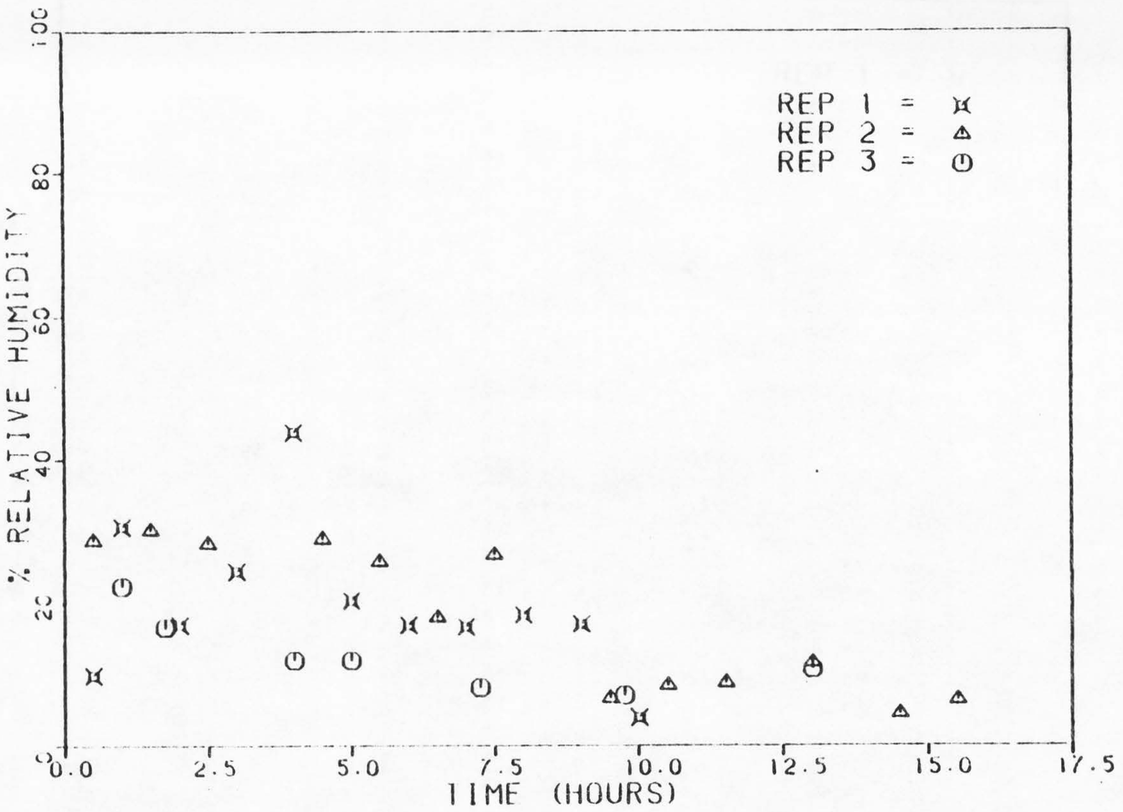

Figure 24. Exit relative humidity for three replications of carrot dehydration (dehydrator A).

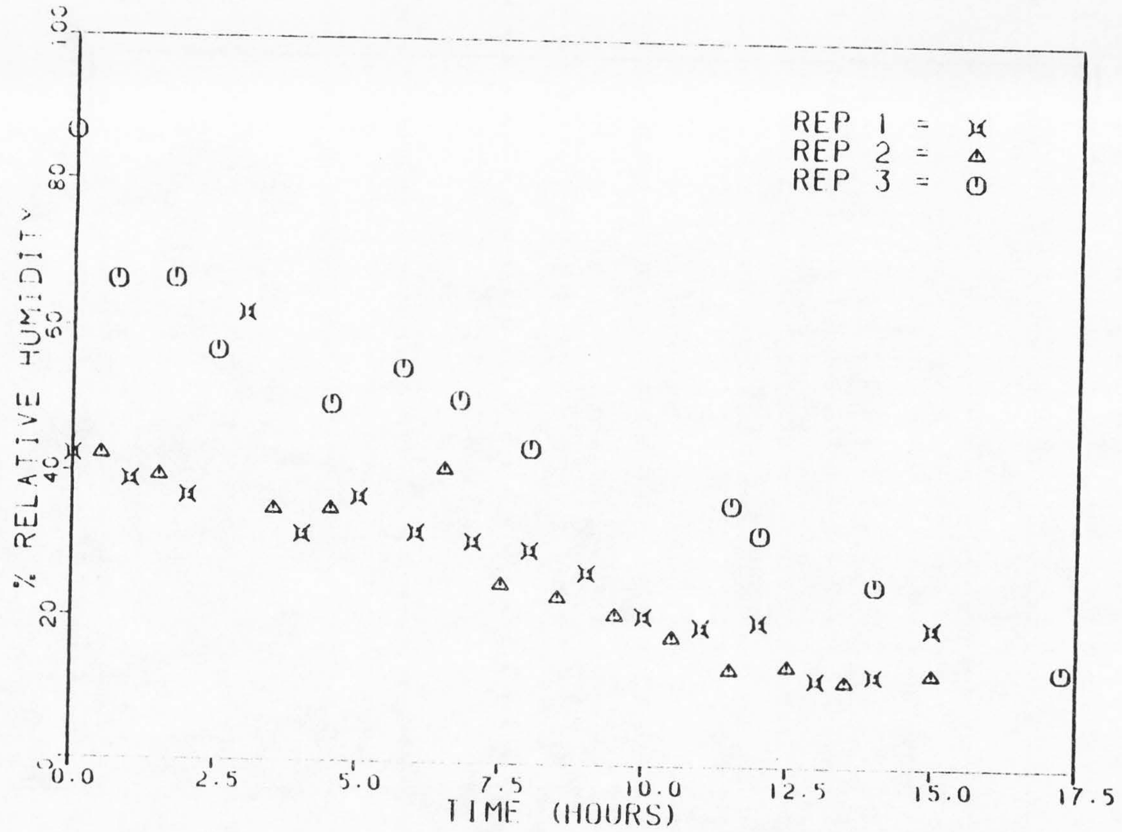

Figure 25. Exit relative humidity for three replications of carrot dehydration (dehydrator B).

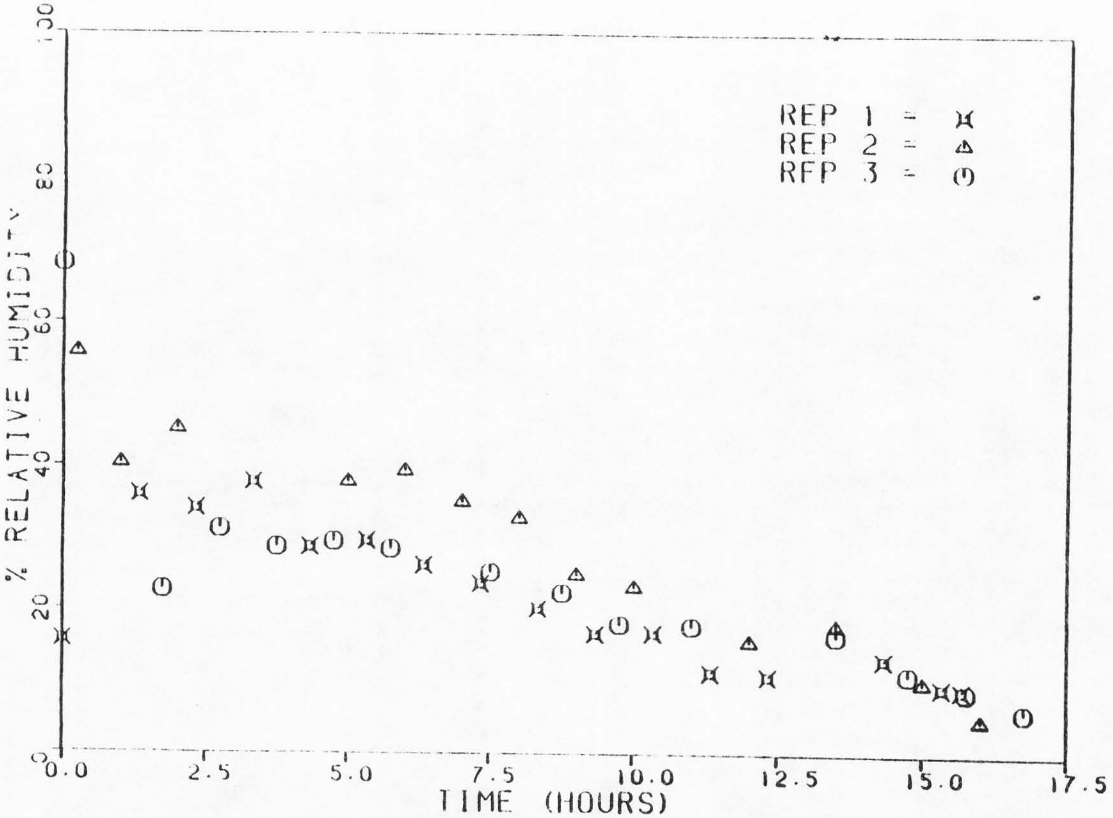

Figure 26. Exit relative humidity for three replications of carrot dehydration (dehydrator C).

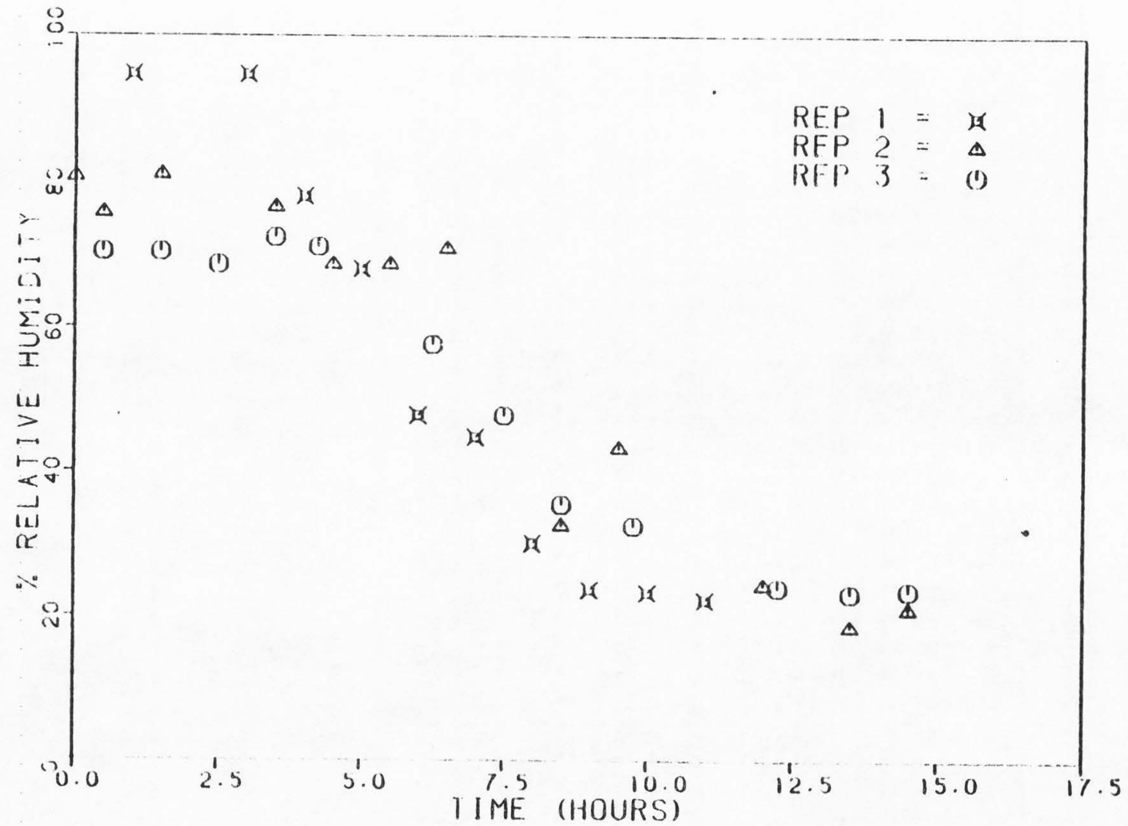

Figure 27. Exit relative humidity for three replications of carrot dehydration (dehydrator D).

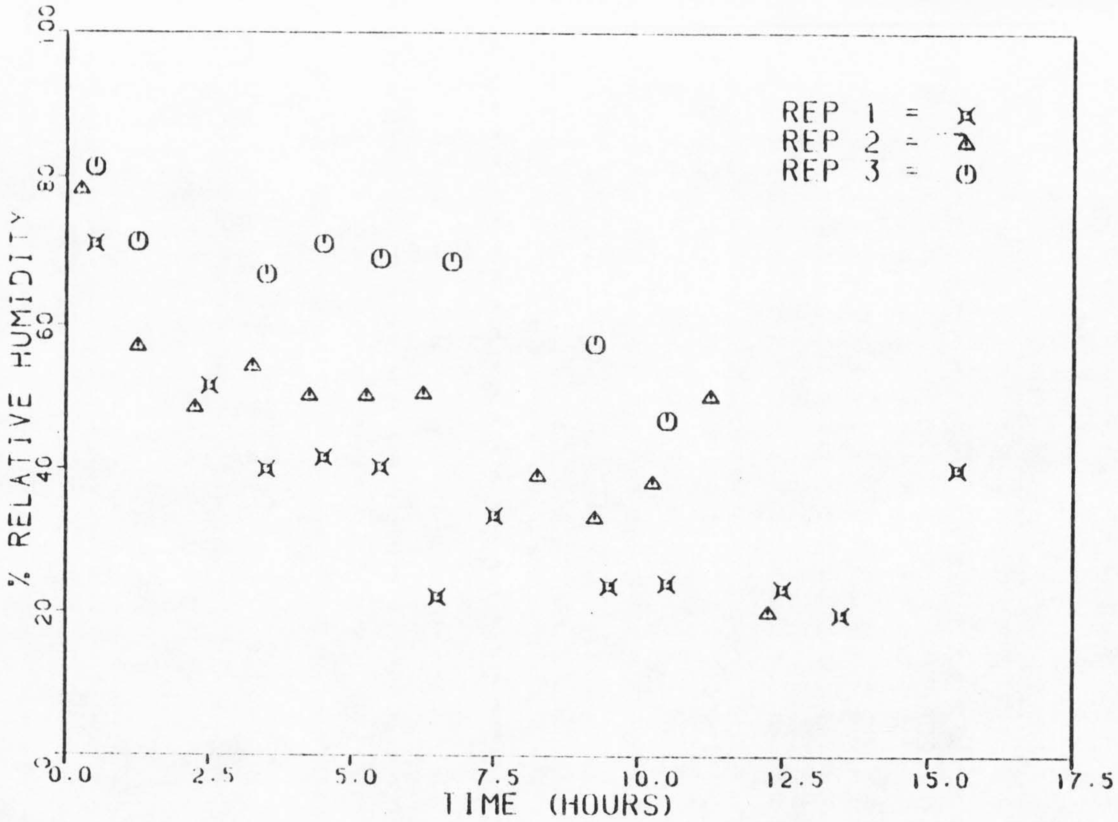

Figure 28. Exit relative humidity for three replications of carrot dehydration (dehydrator E).

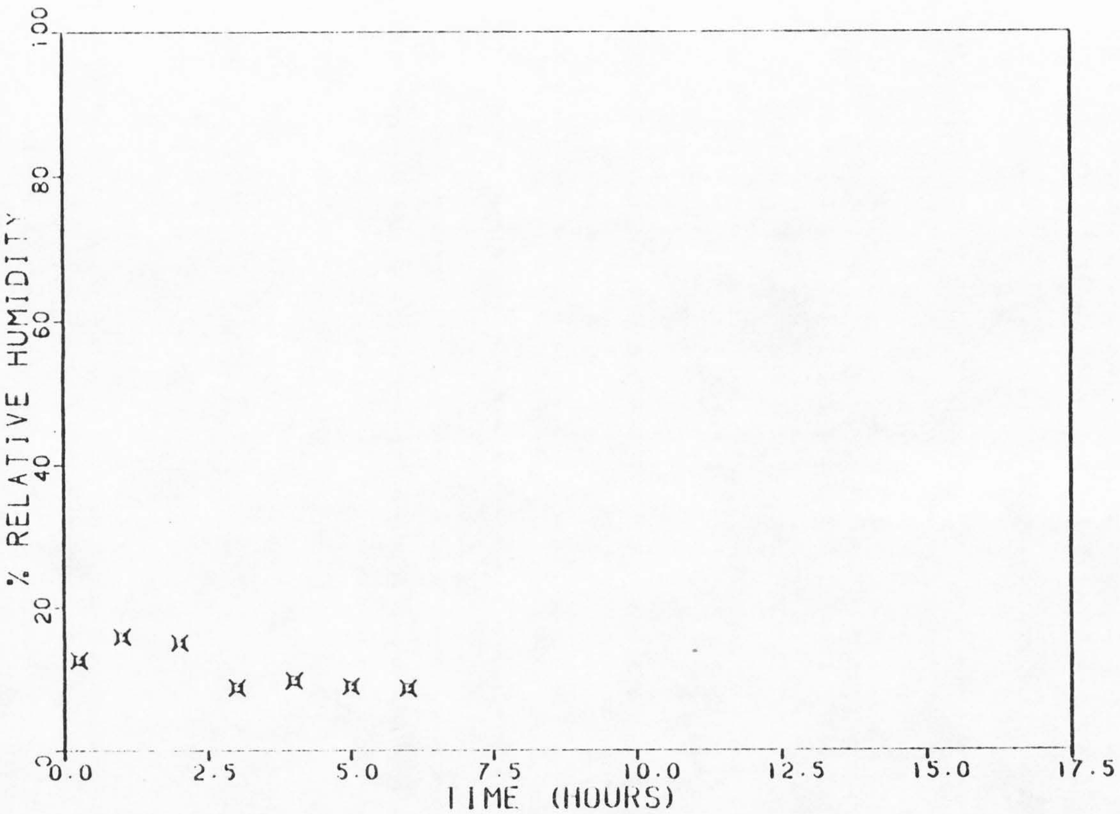

Figure 29. Exit relative humidity for three replications of carrot dehydration (dehydrator F).

Appendix E. Exit temperature and relative humidity data for three replications of tomato juice dehydration (dehydrators A-F)

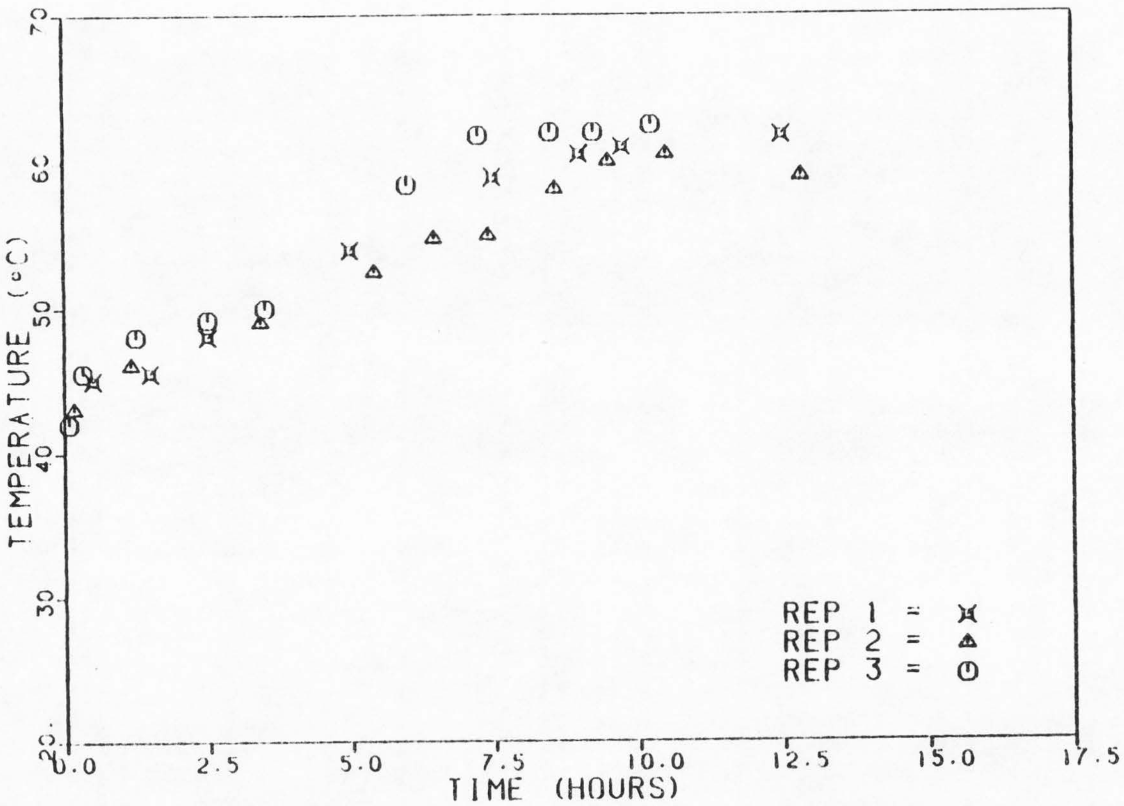

Figure 30. Exit temperature data for three replications of tomato juice dehydration (dehydrator A).

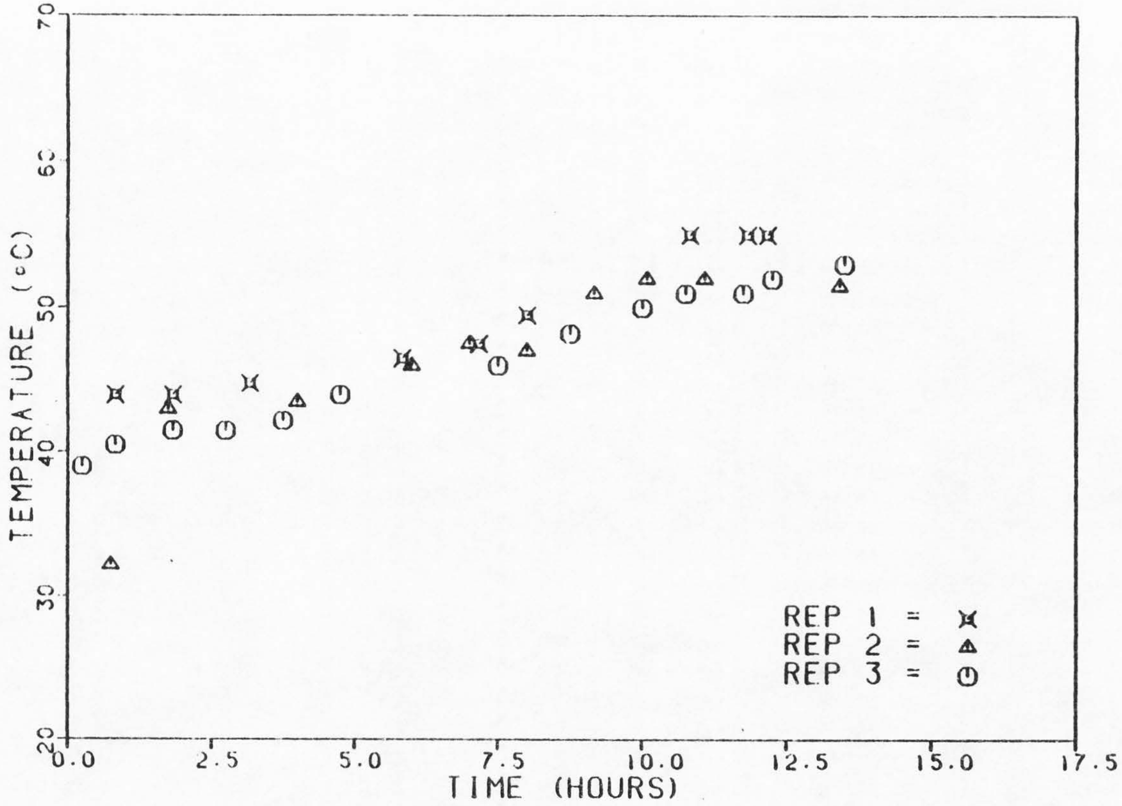

Figure 31. Exit temperature data for three replications of tomato juice dehydration (dehydrator B).

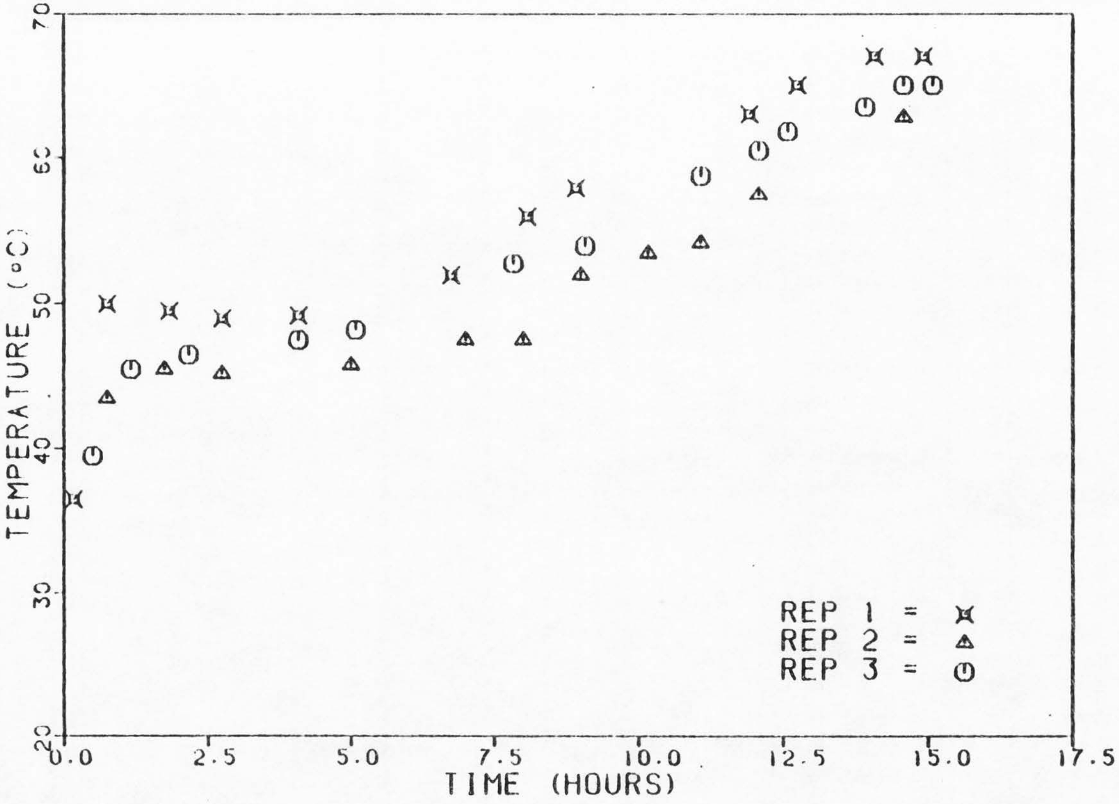

Figure 32. Exit temperature data for three replications of tomato juice dehydration (dehydrator C).

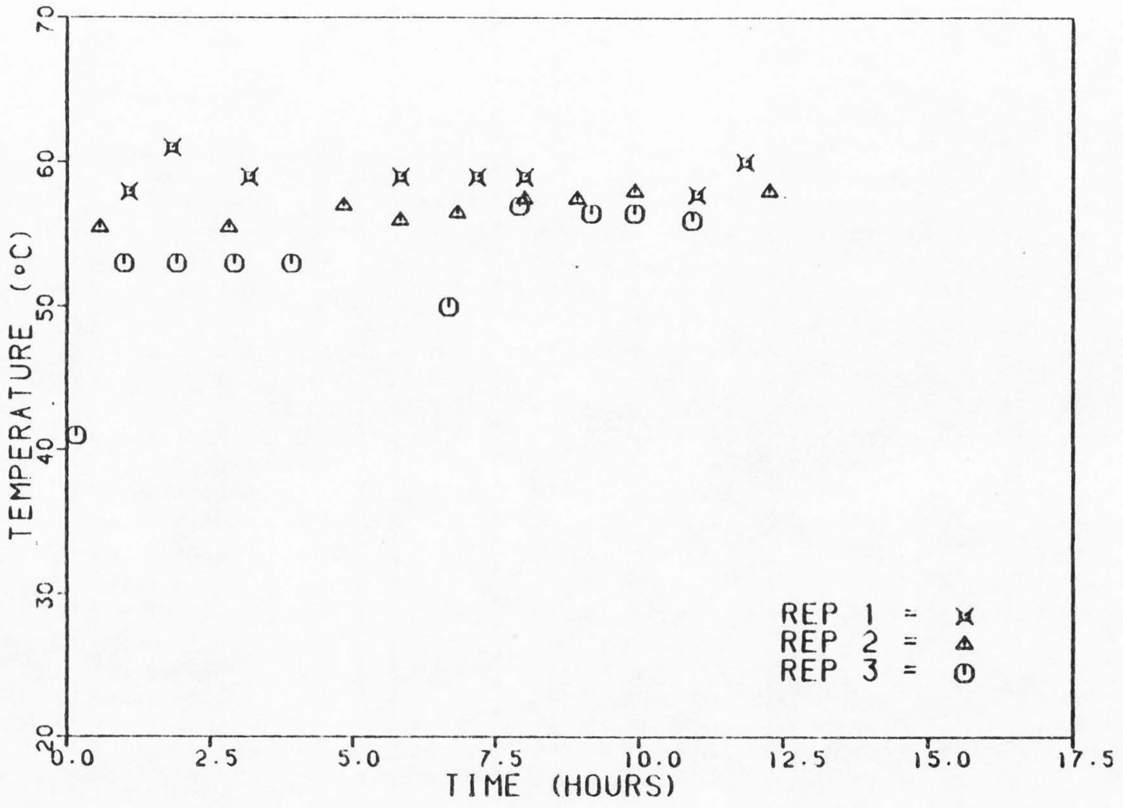

Figure 33. Exit temperature data for three replications of tomato juice dehydration (dehydrator D).

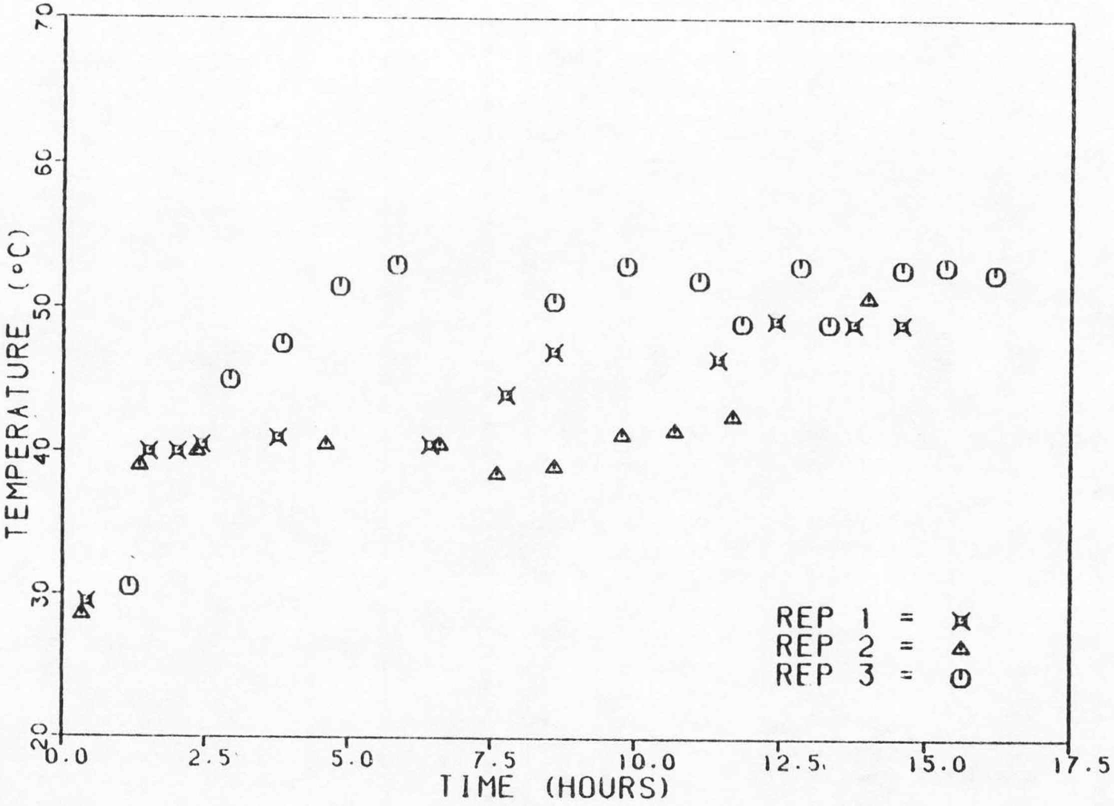

Figure 34. Exit temperature data for three replications of tomato juice dehydration (dehydrator E).

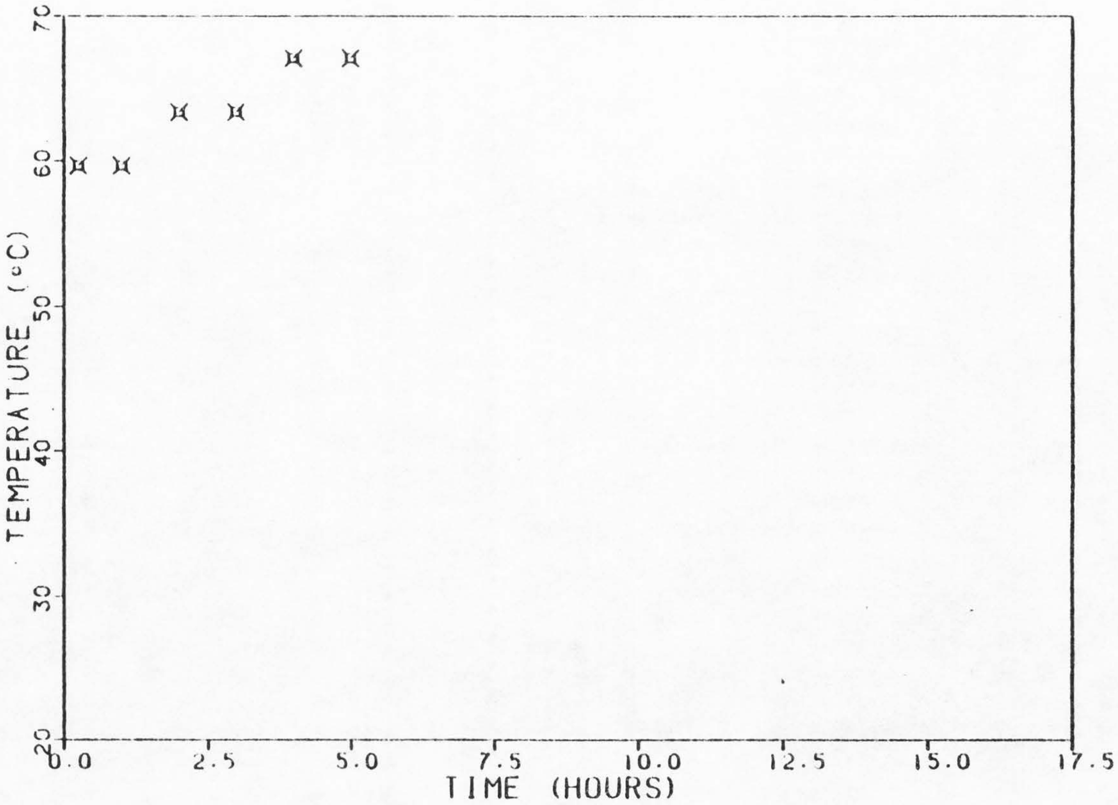

Figure 35. Exit temperature data for three replications of tomato juice dehydration (dehydrator F).

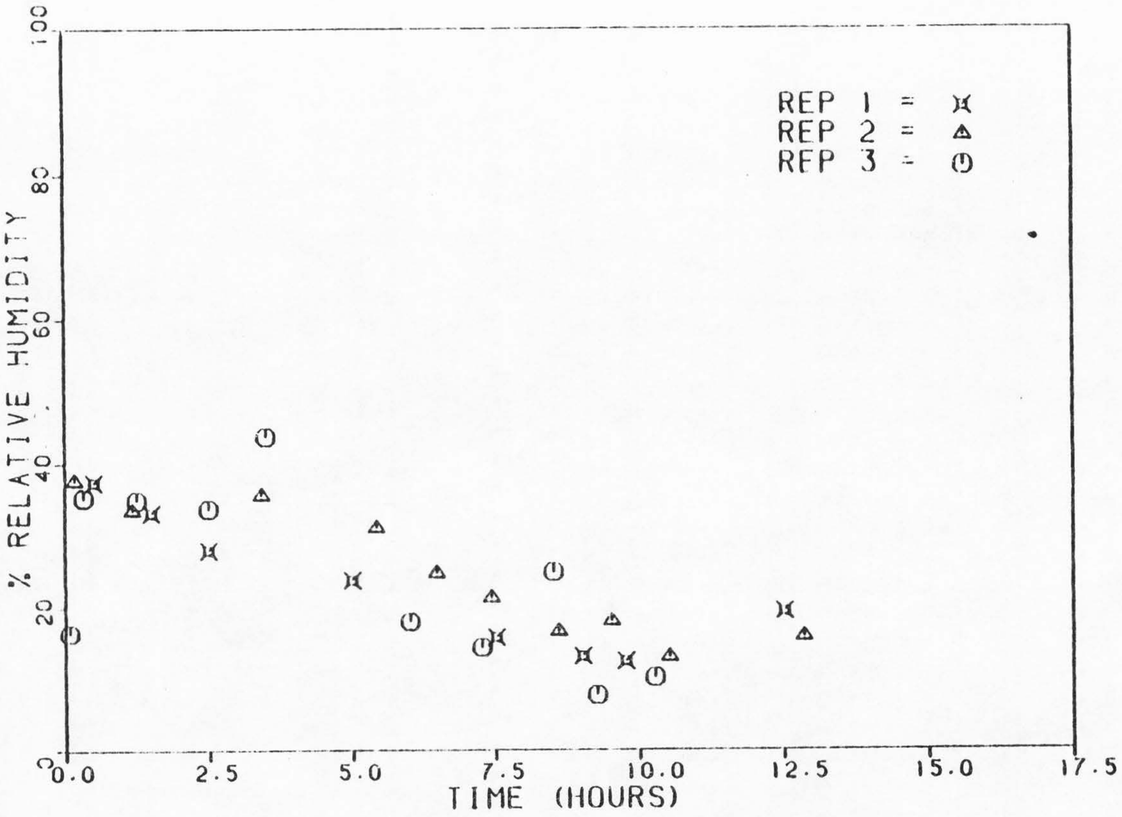

Figure 36. Exit relative humidity for three replications of tomato juice dehydration (dehydrator A).

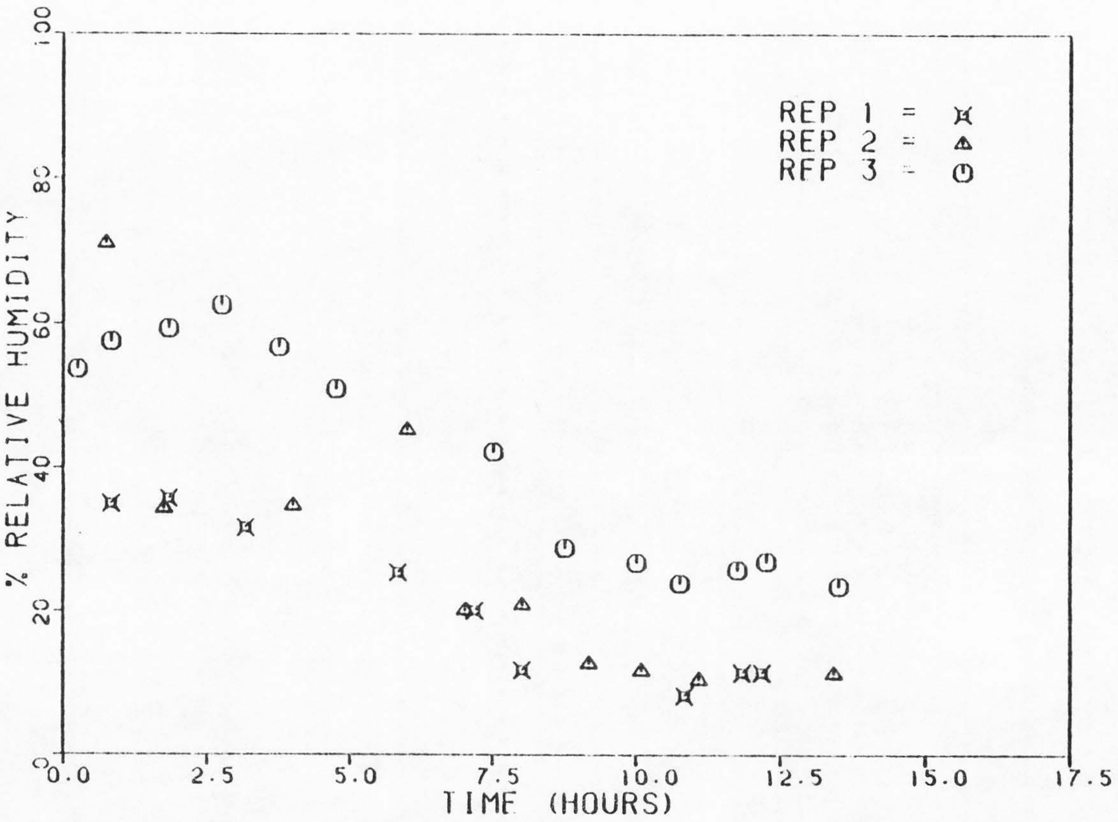

Figure 37. Exit relative humidity for three replications of tomato juice dehydration (dehydrator B).

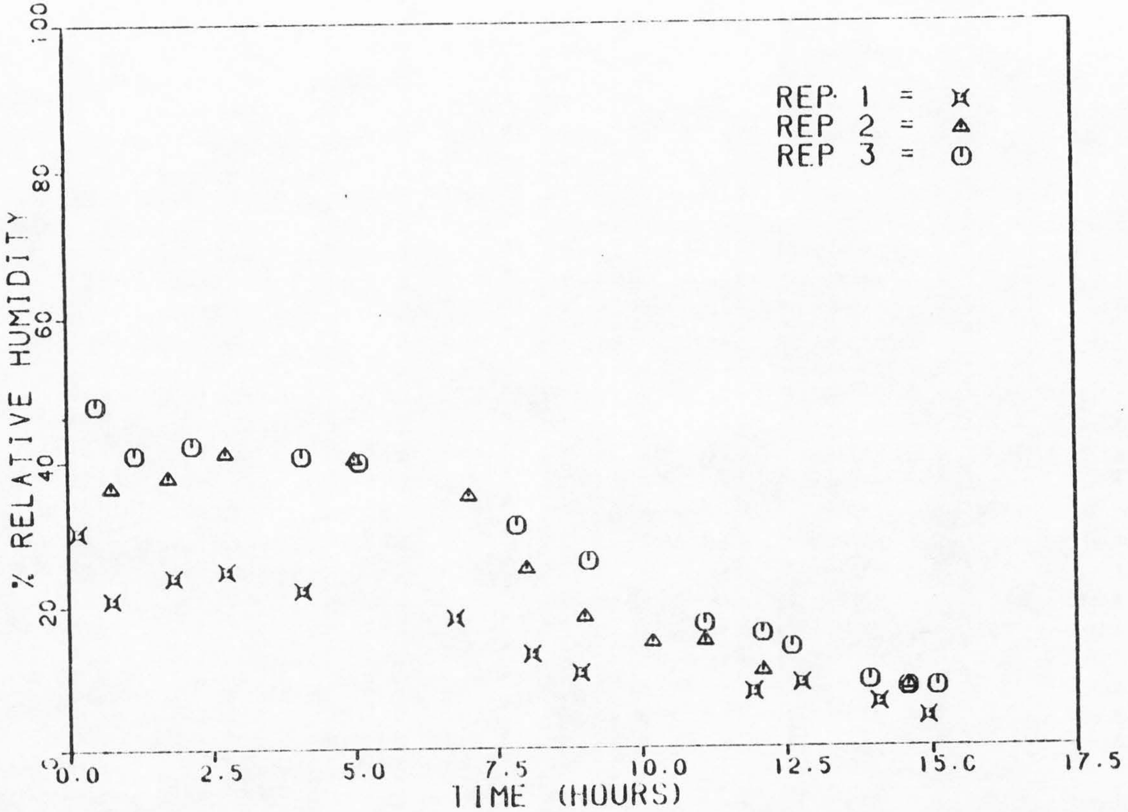

Figure 38. Exit relative humidity for three replications of tomato juice dehydration (dehydrator C).

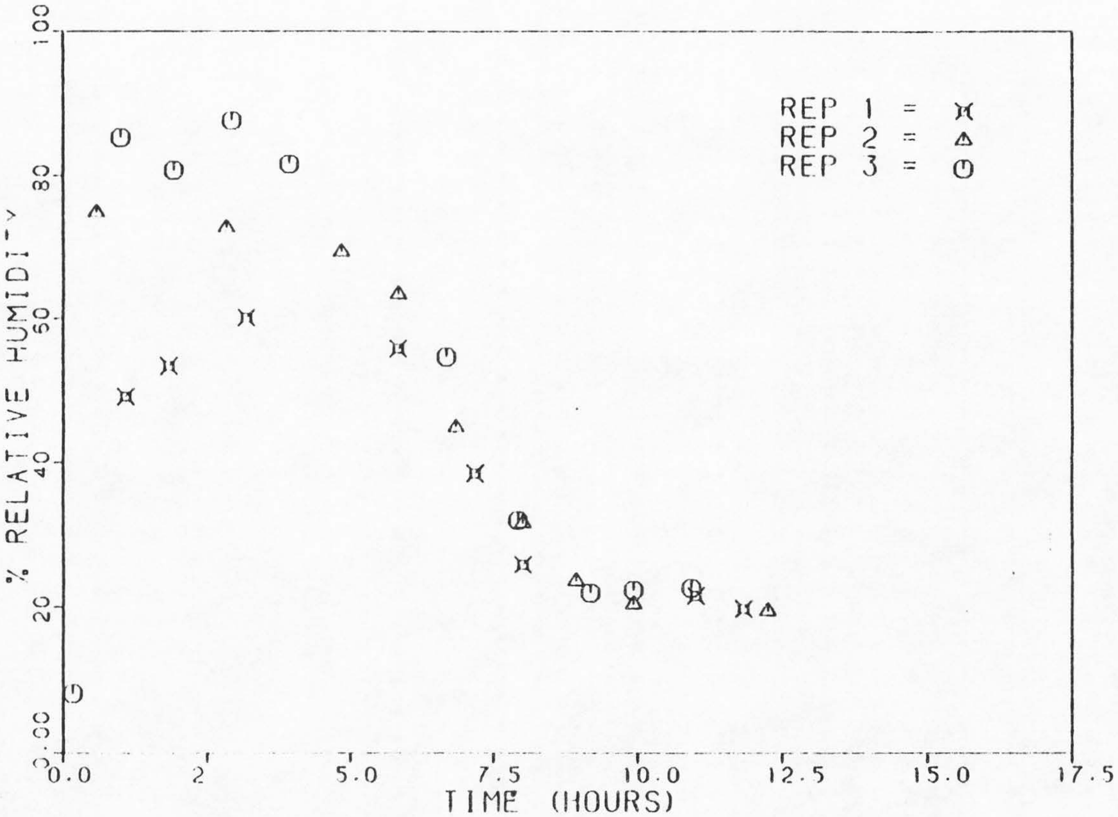

Figure 39. Exit relative humidity for three replications of tomato juice dehydration (dehydrator D).

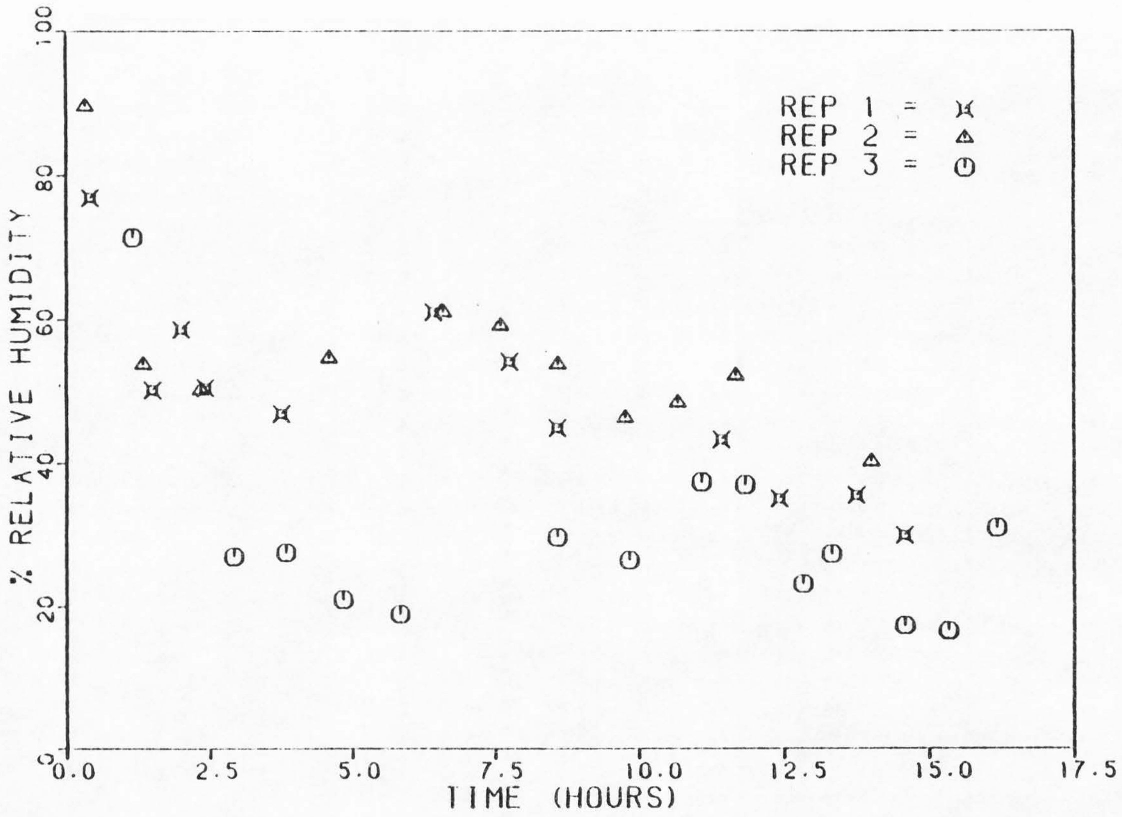

Figure 40. Exit relative humidity for three replications of tomato juice dehydration (dehydrator E).

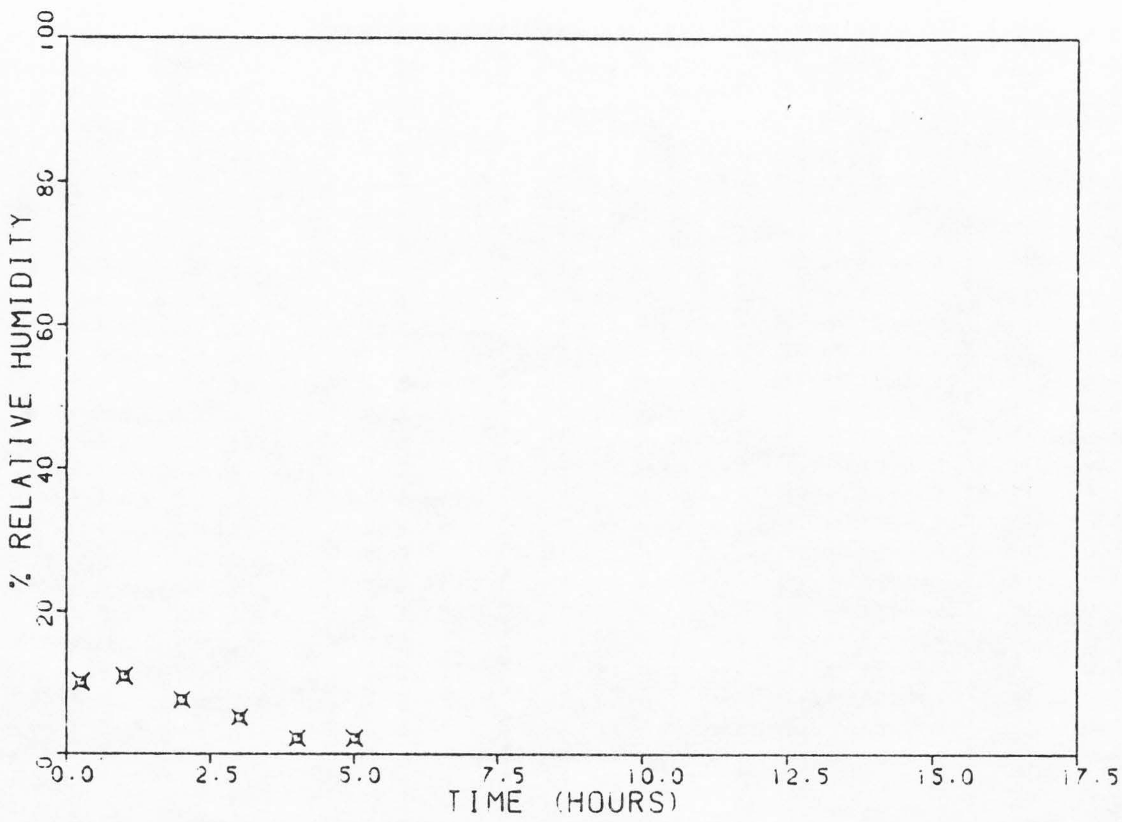

Figure 41 . Exit relative humidity for three replications of tomato juice dehydration (dehydrator F).

Appendix F. Moisture data for dehydrated ground carrots and tomato juice

Table 32. Moisture data for dehydrated ground carrots

	Dehydrator					
	A	B	C	D	E	F
Rep I						
Sec 1	2.528	6.896	3.612	5.063	1.574	2.623
	2.690	7.374	3.579	4.462	1.416	2.603
	2.644	7.355	3.669	4.917	1.237	2.843
2	1.442	3.482	2.145	4.086	2.212	
	3.535	3.461	2.452	4.084	2.444	
	2.578	3.339		3.907	2.412	
3	3.132	4.334	2.962		2.492	
	3.141	4.187	2.626		2.458	
	3.129	4.354				
4	2.779	3.569	1.589		2.632	
	2.595	3.200	1.753		2.412	
		3.710	1.713		2.594	
Rep II						
Sec 1	2.437	4.208	3.431	2.603	4.007	2.828
	2.723	4.419	3.496	2.533	3.904	2.715
	2.749	3.856		2.624		2.540
2	1.993	3.117	3.055	4.284	2.540	
	2.393	3.056	3.219	3.990	2.563	
		3.127	3.167	4.297		
3	2.881	5.321	3.487		3.802	
	3.095	5.020	4.924		3.754	
	3.095	4.929	3.467			
4	2.805	2.358	2.764		3.658	
	2.543	2.515	2.898		3.775	
	2.042		2.869			
Rep III						
1	3.565	4.581	4.925	3.211	2.764	4.283
	3.371	3.825	4.853	3.547	2.898	4.414
	3.219	4.538	4.645	3.246	2.869	4.487
2	3.962	4.379	3.054	5.915	3.760	
	3.830	4.062	3.121	5.734	3.763	
	3.848	5.575	3.205	5.727		
3	4.524	3.972	3.337		4.793	
	4.785	4.440	3.484		4.792	
	4.485	4.485	3.509			
4	3.846	4.512	2.521		5.867	
	3.657	4.187	2.4 5		5.797	
	3.644	4.278				

Table 33. Moisture data for dehydrated tomato juice

	Dehydrator					
	A	B	C	D	E	F
Rep I Sec 1	5.124 5.155	6.280 6.434 6.288	6.327 6.359 6.267	5.369 5.329 5.256	5.071 4.984	
2	5.675 5.437 5.281	5.775 5.720 5.540	4.440 4.476 4.505	5.983 6.207 5.780	5.432 5.432	4.818 5.367 5.318
3	4.527 4.631 6.350	6.615 5.833 6.448	6.553 6.189 6.073		6.350 6.282	
4	4.604 4.840	5.466 4.785 4.880	3.490 3.263 3.475		4.734 4.352	
Rep II Sec 1	5.835 5.851 5.274	8.378 8.102 7.762	8.099 7.579 7.012	5.948 5.783 5.819	5.501 5.042	
2	5.861 4.967 6.165	6.392 5.952 6.286	5.564 3.371	6.804 6.905 7.195	5.038 5.432	6.229 6.075 6.664
3	6.534 6.020 6.588	6.488 6.477 6.430	7.797 6.458 6.191		7.244 7.117	
4	5.234 5.919 6.487	5.790 5.938	3.942 3.875 4.498		3.792 3.774	
RepIII Sec 1	4.995 5.049 5.633	6.903 6.647 6.716	7.086 6.605 7.188	5.707 5.871 5.313	6.136 5.948	
2	4.574 4.448 3.795	5.678 5.596 4.813	6.744 7.118 5.831	4.967 4.711 4.753	3.751 4.013	5.115 4.577 4.382
3	6.456 5.510 5.415	5.539 5.570 5.142	4.177 4.817 3.066		4.669 4.475	
4	5.196 5.880 5.531	5.005 4.383 5.199	4.027 3.634		2.461 2.124	