DEVELOPMENT OF A PROCESS TECHNOLOGY FOR PRODUCTION OF TOMATO POWDER USING FOAM-MAT DRYING TECHNIQUE

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by
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CERTIFICATE

This is to certify that the thesis entitled **"Development of a Process Technology for Production of Tomato Powder using Foam-mat Drying Technique"** submitted by ***Mr. Shadanan Patel*** to the Indian Institute of Technology, Kharagpur for the award of the degree of ***Doctor of Philosophy,*** is a record of the bonafide research work carried out by him under our supervision and guidance. He has worked on this project for a period of more than three and half years. The thesis, in our opinion, is worthy of consideration for the award of the degree of ***Doctor of Philosophy*** in accordance with the regulations of the Institute. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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α : Fourth root of the number of factorial points in CCRD
α_b, β_b, τ_b and δ_b : Constants in Eqn. (2.3)
ΔH_v : Latent heat of vaporization of water, kJ mole^{-1}
ΔT_b : Boiling-point rise of tomato juice, °C
η : Response
θ : Diffusion time, min
θ_c : Concentration time, min
θ_d : Drying time/diffusion time, min
θ_s : Storage period, days
λ_i : Characteristics roots (eigenvalues)
σ_1 and σ_2 : Constants in Eqn. (3.21)
ϕ : Diameter, mm
ϕ_c : Cutting angle, degrees
a : Thickness of the slab being dried, m
A : Packaging area, m^2
A' : Apparent colour, TU
Aa_{ret} : Retention of ascorbic acid, %
A_b, B_b, A_b', B_b' & C_b : Constants in Eqns. (2.1 and 2.2)
a_d : Constant in Eqn. (4.18)
A_f : Air flow rate, *l* min^{-1}
a_o, a_1 a_2 : Constants in Eqn. (3.3)
a_w : Water activity
B' : Value of blue units, TU
c : Concentration of moisture in a two component system, %
C : Constant in BET and GAB equation (Eqn. 3.1 and 3.2)
C_o' : Initial colour of the juice, TU
C' : Tintometer colour, TU
D : Moisture diffusivity, m^2 s^{-1}
D_{AB} : Moisture Diffusivity, m^2 s^{-1}
D_b : Diameter of whipping blade, mm
df : Degrees of freedom
d_i : Interval of variation of factor
D_{pred} : Predicted value of moisture diffusivity, m^2 s^{-1}
D_t : Diameter of holding tank, mm
E : Distance of whipping blade from the bottom, mm

Ea : Activation energy for colour change during concentration, kJ kg^{-1} mole^{-1}

F : Additive concentration, %

FE : Foam expansion, %

FE_o : Foam expansion at the stationary point, %

FE_{Sa} : Actual foam expansion in sugar solution, %

FE_{Spred} : Predicted foam expansion in sugar solution, %

FE_{Ta} : Actual foam expansion in tomato concentrate, %

FE_{Tpred} : Predicted foam expansion in tomato concentrate, %

FS : Foam stability, %

J_b : Width of baffle, mm

k : Constant in GAB equation (Eqn. 3.1)

k_d : Drying rate constant, s^{-1} (Eqn. 4.18)

K_p : Water vapour transmission rate of the packaging material, g m^{-2} day^{-1} Pa^{-1}

$k_{T'}$: Kinetic rate constant at temperature T_C

L_c : Length of cutting edge of the whipping blade, mm

L_h : Depth/height of liquid in the holding tank, mm

Ly_{ret} : Retention of lycopene, %

M : Moisture content at any time, %

M_c : Critical moisture content, %

M_e : Equilibrium moisture content, %

M_i : Initial moisture content, %

m_o and m_t : Constants in Eqn. (4.11)

Mo : Monolayer moisture content, %

MR : Moisture ratio

N : Number of data points

p and q : Constants in Eqn. (3.14)

P : Absolute pressure, Pa

P_d : Mean relative percentage deviation, %

p^o : Water vapour pressure at storage condition, Pa

r : Distance in the direction of diffusion, m

R : Universal gas constant, kJ mol^{-1} K^{-1}

R' : Value of red units, TU

R_F : Ratio of actual foam expansion of tomato concentrate with any concentration of foaming agent to the actual foam expansion of sugar solution containing 1% GMS
Rh_d : Relative humidity of the drying air, %
RS : Reducing sugars, %
SE : Standard error of estimate, %
β_o, β_i, β_{ii}, β_{ij} : Regression constants in Eqn. (3.10)
S_T : Weight of solids in tomato powder, g
T_A : Boiling temperature of pure water, °C
T_c : Concentration temperature, °C
T_d : Drying air temperature, °C
T_S : Boiling temperature of solution (tomato juice), °C
TS : Total solids, %
TSS : Total soluble solids, °B
v : Volume, ml
V_a : Drying air velocity, m s^{-1}
w : Weight, g
W : Mass concentration of soluble solids in solution (Eqns. 2. 1 to 2.3)
W_θ : Whipping time, min
W_i : Canonical variables
W_s : Whipping speed, rev min^{-1}
x : Concentration of tomato juice, °B
X_B : Mole fraction of solute
X_i : Coded variables
Y : Observed value
Y" : Predicted value
Y' : Value of yellow units, TU
ε_i : Factors
$\bar{\varepsilon}_i$: Mean of high and low levels of the factor

List of Abbreviations

% : Per cent
μm : Micrometer
AA : Ascorbic acid
abs. : Absolute
AC : Alternating current
Agril. : Agricultural
AOAC : Association of Official Analytical Chemists
atm : Atmosphere
BET : Brunauer-Emmett-Teller
BOPP : Biaxially oriented polypropylene
BP : Boiling point
BPR : Boiling-point rise
CA : Citric acid
Cal : Calories
CBEJ : Cold-break extracted juice
CCRD : Central composite rotatable design
cm : Centimetre
CMC : Carboxyl methylcellulose
cv. : Cultivar
db : Dry basis
DC : Direct current
Deptt. : Department
e.g. : For example
ed(s) : Editor(s)
EMC : Equilibrium moisture content
Engg. : Engineering
Eqn(s). : Equation(s)
ERH : Equilibrium relative humidity
et al. : et alibi, and others
etc. : et cetra
Expt. : Experiment
f : Function
F_{cal} : Calculated F-value
FE : Foam expansion
Fig(s). : Figure(s)
FS : Foam stability
g : Gram
GAB : Guggenheim-Anderson-de Boer
GMS : Glycerol monostearate
h : Hour(s)
HBEJ : Hot-break extracted juice
Hg : Mercury
i.e. : ed est, that is
IIT : Indian Institute of Technology
ISI : Indian Standards Institute
IU : International unit
kg : Kilogram
kJ : Kilojoule
kW : Kilowatt
l : Litre

Ly : Lycopene
m : Meter
mc : Moisture content
MF : Microfiltration
mg : Milligram
min : Minute(s)
ml : Millilitre
mm : Millimetre
MPC : Metallised polyester/adhesive coextruded LD/LLD/HD
MSS : Mean sum of squares
nm : Nanometer
No. : Number
NS : Non-significant
OD : Optical density
OTR : Oxygen transmission rate
Pa : Pascal
PM : Packaging material
r^2 : Coefficient of determination
rev : Revolution(s)
RH : Relative humidity
RO : Reverse osmosis
rpm : Revolutions per minute
Rs. : Rupees
RSM : Response surface methodology
s : Second(s)
S. No. : Serial Number
SD : Standard deviation
SE : Standard error of estimate
Sec. : Section
SP : Storage period
Temp. : Temperature
TU : Tintometer unit
UF : Ultrafiltration
viz. : Videlicet, namely
vs : *Versus*
wb : Weight basis
WVTR : Water vapour transmission rate
°B : Degrees Brix
°C : Degrees Celsius
°F : Degrees Fahrenheit
°K : Degrees Kelvin

ABSTRACT

The high nutritional value and multiple uses of tomato (*Lycopersicon esculentum* MIll) in culinary preparations have made it an important vegetable outranking all others except potato in popularity and value. India produces about 5 million tonnes of tomato annually. However, a substantial quantity of this is lost every year owing to its perishable nature and inadequate processing facilities causing a great revenue loss to the country. The need is to develop a suitable technology for the processing of tomato which will not only check the losses but also generate additional revenue. Benefit to the farmers and processors will be an added advantage. In this context, development of a process technology for preparation of dehydrated tomato juice has considerable potential. Dehydrated tomato juice of tomato powder will not only involve inexpensive handling and storage costs but will also be highly stable against deteriorative reaction. It can be used as base material for the preparation of baby foods, soft drinks, soup, ketchup *etc.*

This project was undertaken to standardize the process parameters involved in the preparation a of free-flowing tomato powder using foam-mat drying technique. The study also included quality and shelf-life evaluation of the product. Ripe tomato (cv. *Pusa Ruby*) was used for the extraction of juice which was subsequently concentrated under vacuum. Effects of extraction method and concentration on quality of juice and concentrate were studied. Tomato concentrate prepared under optimum conditions was foamed using a foaming device developed for the purpose. The machine and operating parameters were optimized for the maximum foam expansion. Different food grade chemicals were tested as foam inducer and stabilizer. The foamed tomato concentrate prepared using optimum machine, operating and material parameters was dried in the form of a thin sheet (foam-mat) in a tray dryer under varying air conditions. Drying parameters were optimized for an end product of 2.5-3 percent moisture content and maximum retention of colour and nutritional values. The dried mats were converted into a free-flowing powder and the powder thus obtained was subjected to storage studies in three different packaging materials under accelerated storage conditions.

A good quality tomato powder was successfully prepared using foam-mat drying technique. The hot-break extracted tomato juice (5.5°B TSS) concentrated to 25°B TSS was converted into stable foam (114% volume expansion) using 2% glycerol monostearate (total solids basis) as foaming agent. Foam slabs of 3 mm thickness spread on aluminum trays were dried to 3% final moisture content using air at 62-65°C temperature, 10-15% relative humidity and 2.0 $m\ s^{-1}$ velocity for 90 min. Hygroscopicity and thermoplasticity were the major problems encountered during grinding of the dried product. Conditioning of the dried product under reduced relative humidity (below 30%) and temperature (below 20°C) helped the grinding operation. The powder retained 77.32% of lycopene and 52.2% of ascorbic acid (fresh tomato basis), and had good reconstitution properties in lukewarm water. The powder remained free flowing in metallised polyester laminated packages upto 75 days under accelerated condition of storage (38°C temperature and 90% relative humidity) without any appreciable loss in colour, flavour, nutritional qualities and acceptability.

Key words: *Tomato juice, tomato concentrate, tomato powder, dehydrated tomato juice, foaming, foaming device, foam-mat drying*

CHAPTER - I

INTRODUCTION

Fruits and vegetables are important ingredients of the human food as they provide, apart from calories, the much-needed vitamins and micronutrients in the diet. India's varied agro-climatic conditions provide an enormous scope for cultivation of almost all varieties of tropical, sub-tropical and temperate fruits and vegetables. As of now, all horticultural crops put together, account for 12 million hectares (7% of the cropped area) of the country, the estimated produce from which is 100 million tonnes per annum contributing 18 per cent of the gross agricultural output (GOI, 1995).

India has emerged as the second largest producer of fruits and vegetable in the world after Brazil and China (GOI, 1995; Singh and Verma, 1995). A huge quantity of these produce goes waste due to lack of handling, storage, transportation and processing facilities. The total losses of fruits and vegetables are estimated to be 20-40 per cent amounting to nearly Rs. 30000 million per annum (Chadha, 1995; Channappa Gowda, 1995) which calls for proper preservation and processing facilities in areas where surplus quantities are grown.

Many methods of food preservation relie on removal of water in order to decrease water activity below a level that causes growth retardation of spoiling microorganisms. Decreased water content also influences unwanted chemical reactions affecting not only the nutritive value of food but also its sensory properties. Further, domestic and defence demands for economical and convenient food preparations in the past few years have started an ever-increasing trend toward preparation of concentrated foods produced by either partlial or complete dehydration. Such preparations offer reductions in cost of packaging, shipping, and storing, and frequently offer greater convenience in addition to longer shelf-life and higher degree of inhibition to bacterial attack. Dehydrated food saves 86 per cent of costs incurred in shipping, 77 per cent in storage space and 82 per cent in handling cost (Cruess, 1958).

Tomato (*Lycopersicon esculentum* Mill) is the second largest vegetable crop of India. The world production of tomato is placed at 70.5 million tonnes annually of which India's share can be estimated at about 5 million tonnes representing 7.1 per cent of the world production (Patnaik, 1993). Fresh tomatoes are highly refreshing, appetizing and a good source of minerals and vitamins, particularly ascorbic acid. Being perishable in nature, whole tomato, however, has limited shelf-life, *i.e.*, 5-10 days at 21-34°C temperature and 45-85 per cent relative humidity (Onwuzulu *et al.*, 1993). Although tomato products rank first among the processed vegetables, the fact is that this industry has not progressed well in India with only about 1-2 per cent of its total produce processed and marketed in the form of puree, paste, ketchup, sauce, *chutney*, pickles *etc.* These products are popular and have good market in India and abroad (Lal *et al.*, 1990; CFTRI, 1993). However, they continue to be produced by traditional methods involving energy intensive thermal processes which generally downgrade their quality. Short shelf-life coupled with inadequate processing facilities results in heavy annual loss (20-30%) of tomatoes (Onwuzulu *et al.*, 1993). A need, therefore, exists to develop suitable technology for processing this valuable produce in a way that will not only check losses but also generate additional revenue for the country.

Tomato has the potential for meeting the increasing demand for quality fruit and vegetable juices in India and abroad. Among the various methods of processing fruit and vegetable juices, dehydration is the most economical. This is not only because dehydrated products require inexpensive packaging and almost no energy during storage, but they are also highly stable against deteriorative microbial, chemical and enzymic reactions. The application of various vegetable juice powders is growing and the main field of use are instant juices, drinks, baby foods, soups, food premixes, gravies, spice mixtures, snacks, bakery products, pharmaceutical preparations *etc.*

For conversion into powders, majority of the fruit and vegetable juices are generally subjected to two-stage moisture removal processes keeping in view energy conservation and product quality. They are first concentrated and then dried to 2-3 per cent residual moisture content. Concentration is the major unit operation of critical importance as it determines the quality of the final product. A few commercially feasible methods for concentrating aqueous foods include evaporation, freeze concentration and membrane processes, such as reverse osmosis and ultrafiltration. Though considerable progress has taken place in all these methods, evaporation is still the most developed and widely used by the industry (Ramteke *et al.*, 1993). The main limitations of freeze and membrane concentration are the loss of soluble solids and higher capital costs. In membrane process, viscosity of the concentrate and fouling are the other serious drawbacks (Fellow, 1988).

Concentrated juices can be dehydrated using the existing standard methods for drying of the liquid foods. These are spray drying, vacuum drying, freeze drying and drum drying. Conventional spray dryers are not suitable for dehydration of tomato juice/concentrate as they induce thermoplasticity in the dried product owing to its high sugar content, and the powder does not flow easily out of the drying chamber. Also the spray-dried powder forms sticky, tenacious lumps upon wetting (Miers *et al.*, 1958). Despite quality advantages, economic considerations of high production costs and large capital investment have deterred commercial exploitation of freeze-drying technology for manufacture of fruit and vegetable juice powders. Vacuum drying is a time consuming batch process. It takes several hours for completion of drying a batch of concentrated juice. Standard drum dryers are unsuitable for drying food stuff having high sugar content such as tomato concentrate, due to sticking of the dried product on to the doctor blade. Moreover, drum drying yields products which reconstitute with difficulty.

Foam-mat drying is a promising new development in the field of drying aqueous foods. This method offers a wide scope for application in vegetable and fruit juice processing industry and in such other difficult-to-dry, sticky, and heat sensitive materials. On a commercial scale, it is finding increasing application and importance in drying of liquids that turn out a high quality concentrate such as milk, fruit juices, soluble coffee, *etc.* (Chandak and Chivate, 1972; Dodeja and Sharma, 1989).

Foam-mat drying is a process in which the transformation of products from liquid to a stable foam follows air drying at relatively low temperatures to form a thin porous sheet or mat which is disintegrated to yield a free-flowing powder (Morgan and Ginnette, 1960; Hart *et al.*, 1963; Anjaria and Chivate, 1966). Concentration of the material prior to conversion into a stable foam may or may not be an essential requirement and will depend on its surface tension and consistency. A thick mass of a fluid may be difficult to be converted into a good stable foam, but this can be achieved by the use of certain additives. The advantages of the foam-mat drying process are that the material can be dried in a relatively short period of time and the dried powder reconstitutes readily. The process is of potential interest for developing countries for its simplicity and economics (Anjaria and Chivate, 1966; Akintoye and Oguntunde, 1991; Beristain, 1993).

Published literature is rather limited on details of vacuum concentration of tomato juice. Also, very little work has been done on foam-mat drying of tomato concentrate. For process upgradation and quality improvement, intensive engineering and technological support are necessary. Keeping the above facts in mind, the present investigation was initiated to study foam-mat drying of tomato juice/concentrate for the preparation of dehydrated tomato juice (tomato powder).

However, not only must the initial quality of such powders be satisfactory, it must be reasonably stable during storage. A storage study would make it possible to decide upon the shelf-life of the prepared dehydrated tomato powder.

The objectives of the study were:

1. To study the relevant physico-chemical characteristics of tomato and effects of extraction method on the quality and yield of juice,
2. To optimize process variables for vacuum concentration of tomato juice,
3. To study moisture desorption characteristics of tomato concentrate,
4. To develop a foaming device and optimize machine and operating parameters for maximum foam expansion,
5. To study the effect of additives on foaming characteristics of tomato concentrate and identify a suitable foaming agent,
6. To study drying characteristics of tomato foam and standardize foam-mat drying process parameters, and
7. To study the effect of packaging material on quality and acceptability of tomato powder during storage.

CHAPTER - II

REVIEW OF LITERATURE

The tomato plant (*Lycopersicon esculentum* Mill) had its origin in the Peru-Ecuador area of South America. Improved varieties of the wild fruit crop are grown widely throughout the world in many different soils under a variety of climatic conditions.

In view of its importance in food, tomato has enjoyed an unprecedented attention among the scientific activities worldwide. The result has been an extensive published literature on the different aspects of tomato production, processing and utilization. The classified literature relevant to the present investigation on tomatoes has been presented in the following paragraphs.

2.1 Composition and Nutritive Value

The high nutritional value and multiple uses in culinary preparations have made tomato an important vegetable outranking all others except potato in popularity and value. The fruit consists of an outer wall called pericarp, the radial walls, the core and the locular cavities which contain the seeds embedded in a jelly-like parenchyma tissue originating from the placenta as shown in Fig. 2.1 (McColloch *et al.*, 1952). The pericarp consists of three distinct sections: the epidermis, a simple layer of cutinized cell; the epicarp, consisting of 3 or 4 layers of collenchyama cells; and the mesocarp, consisting of parenchyama tissue which constitutes the bulk of the pericarp. Although there is considerable variation, the total pericarp makes up approximately 45 per cent of the fruit, and the radial walls and core about 35 per cent. The remaining 25 per cent is represented by locular cavities (Narkviroj and Ranganna, 1976).

The composition and nutritional value of tomato varies with variety, maturity, ago-climatic conditions and cultural practices. Proximate composition and nutritive value of raw tomato are given in **Table 2.1** (Sherman, 1971).

Tomatoes contain usually from 7 to 8.5 per cent of total solids of which about 1 per cent is due to the skins and seeds. The acid content varies from 0.2 to 0.6 per cent wherein citric acid constitutes a major part (about 60%). The pH of tomato is related to total acidity. Tomato is a good source of vitamin A, B-vitamins and ascorbic acid. It is looked upon as the most dependable source for ascorbic acid of about 15 mg/100 g of the edible portion. The red colour of tomato fruit is due to its content of carotenoid pigments consisting of about

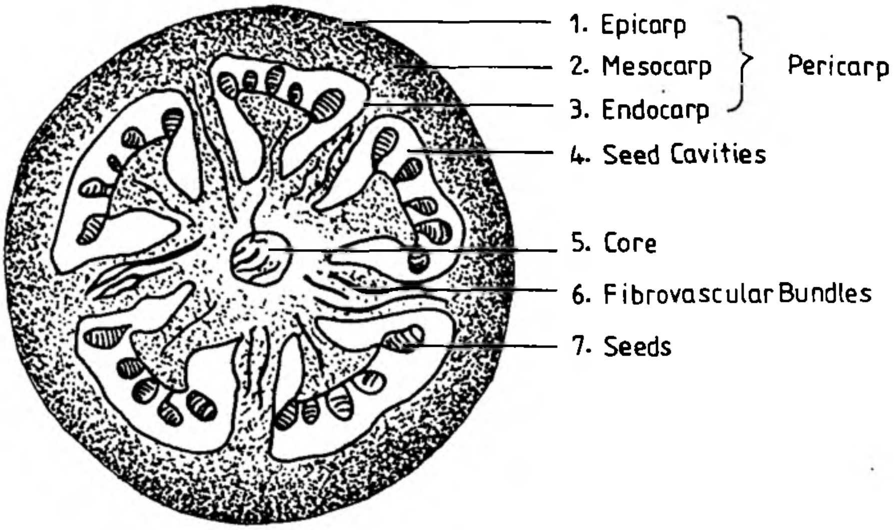


FIG.2.1 Cross section of tomato fruit
(Sherman , 1971)

87 per cent lycopene and 7 per cent ß-carotene (Bradely, 1964; Sherman, 1971; Goose and Binsted, 1973; and Gould, 1974, 1978).

Table 2.1 Proximate composition and nutritive value of raw tomato (Sherman, 1971)

Constituents		per 100 g
Food energy, Cal	....	20.0
Water, g	....	94.1
Protein, g	....	1.0
Fat, g	....	0.3
Carbohydrates:	....	4.0
Total, g	....	0.6
Fibre, g	....	0.6
Ash, g	....	11.6
Calcium, mg	....	27.0
Phosphorus, mg	....	0.6
Iron, mg	....	1100.0
Vitamin A (IU)	....	0.06
Thiamine, mg	....	0.04
Riboflavin, mg	....	0.5
Niacin, mg	....	23.0
Ascorbic acid, mg		

2.2 Processing of Tomato

The seasonal availability and perishable nature of tomato necessitate its processing and preservation in one or the other form. Indian fruit and vegetable processing industries handle only about 1.5 to 2 per cent of the total tomato processed into products, like juice, paste, puree, ketchup, sauce, *chutney*, pickles *etc.* using conventional methods, such as canning, pickling, freezing, concentration, and dehydration. The major consideration during processing of these products is either the total soluble solids or the total solids. In the production of these products tomatoes are subjected to a series of processing operations such as sorting, washing, pulping (extraction), clarification/ filtration and concentration to the desired level of solids content; and addition of certain chemical preservatives and taste enhancers like salt, sugar, acid, vinegar, spices *etc.*

2.3 Concentration of Tomato Juice

The most common and convenient mode in which fruits are processed and preserved, is in the form of juices/pulps (purees). Preservation of single strength juices is, however, not economical, since their water content is very high *i.e.* about 75 to 95 per cent (Young, 1975).

Concentration can be described as a separation process and forms one of the basic unit operations in fruit technology. In this the solids content in the material is increased upto 65 to 75 per cent and the final product is in the form of a concentrated solution or dispersion or a semi-solid (Sulc, 1984). During the last sixty years, several methods for concentrating liquid foods have been developed, among which evaporative concentration, freeze-concentration and membrane concentration (reverse osmosis) have found commercial applications for fruit juices (Bomben *et al.*, 1973; Thijssen, 1975; Sulc, 1984 and Van Pelt, 1984).

Freeze-concentration, though an ideal method for concentrating fruit juices, has major problems of loss of soluble solids of juice in the separated ice (Muller, 1967 and Braddock and Marey, 1987) and, due to the steep increase in viscosity of ice-concentrated mixture at the lower operating temperatures, the final concentration of juice obtained is as low as 40-55 per cent of dry matter (Deshpande *et al.*, 1984). Further, the presence of pectins, proteins and other colloidal substances in the fruit juices increases the viscosity and retard water crystallization and thereby necessitate their depectinization and filtration prior to freeze-concentration.

The success of membrane technology in fruit juice concentration depends on the development of suitable membranes (Sheu and Wiley, 1983; Chua *et al.*, 1987 and Cheryan, 1991). The use of reverse osmosis in fruit juice processing industries has been reported by Sheu and Wiley (1984), Braddock *et al.* (1988) and Chou *et al.* (1991). Fouling is a serious problem which necessitates frequent cleaning of the membrane. Low solid content achieved by the conventional reverse osmosis is another drawback (Sheu and Wiley, 1983). Several studies have been performed applying hyperfiltration to the concentration of tomato juice (Merlo *et al.*, 1986a and 1986b). One of the limiting factors of these studies has been the concentration limits obtainable with membranes while maintaining reasonable flux. Demeczky *et al.*,(1981) reported that the clear tomato juice can be concentrated to as high as 29°B only by reverse osmosis process, whereas Patil and Mishra (1993) could concentrate tomato juice only upto 20°B beyond which the pore blocking factor increased substantially even at lower operating pressures.

2.3.1 Concentration by evaporation

Evaporation is probably the oldest and most widely used method for the concentration of liquid foods. The first juice concentrate produced through vacuum evaporation dates from the beginning of the 1920's (Sulc, 1984). Different aspects of evaporation methods used in the food industry have been discussed by various workers (Armerding, 1966; Mannheim and Passy, 1974 and Karel, 1975a).

The choice of a proper evaporator for concentrating a given material is based upon many factors which include properties of the feed material, quality requirements of the product, operating conditions of the evaporator and economic considerations (Mehra, 1986). Fruit juices are produced as pulpy, cloudy or clear juices which have considerable differences in their physico-chemical characteristics, suspended solids and pectin concentration. Thermal and rheological properties are the primary concern in designing an evaporator and optimizing the operating and processing variables (Billet, 1989 and Khalil, 1990).

Fouling, the deposition of burnt layer of organic matter on the hot surface of the evaporator, is a severe problem during concentration of fruit juices, particularly the pulpy and cloudy juices (Carlson and Morgan, 1962 and Mannheim and Passy, 1974). Among the operating variables which affect fouling rate, temperature of heating surfaces is reported to be the major contributor (Carlson and Morgan, 1962). Evaporation of cloudy apple juice at a temperature higher than 65.6°C causes considerable fouling. Flow direction of fluid has also been reported to affect the fouling rate (Sarvacos, 1974). Rising film evaporators pose less fouling problem than falling film evaporators due to improper distribution of liquid in the latter which results in local hot spot and scaling. Agitated thin film and rotary evaporators minimize fouling and scale formation considerably.

Depectinized, clarified and filtered juices contain only water soluble solids such as sugars, organic acids, vitamins, pigments, minerals and flavour volatiles. According to Sulc (1984) concentration of such juices can be achieved without any major technological problems as the increase in viscosity during concentration (evaporation) is not great. Khalil (1990) opined that the chemical composition of cloudy juices is almost similar to that of clear juices. They contain variable amounts of suspended particles comprising mainly of pectin substances, celluloses and hemicelluloses. These suspended particles in cloudy juices exhibit much higher viscosities during concentration. Cloudy juices are, therefore, difficult to concentrate in falling film and plate evaporators without the risk of thermal damage. Centrifugal evaporators have been found suitable for concentration of cloudy juices. Use of a combination of different types of evaporators has been reported to overcome such problems (Sulc, 1984).

Pulpy fruit juices form viscous and sticky mass during concentration due to their high contents of suspended pulp particles and thereby present a great problem of fouling and reduced evaporation rates. As a consequence of this the concentrated product is more likely to undergo thermal damage causing changes in quality characteristics, particularly colour and flavour. Pulpy fruit juices behave almost as non-Newtonian pseudoplastic fluids and the apparent viscosity decreases with increasing shear rate (Sarvacos, 1974). Evaporators with proper arrangements for agitation are better suited for concentration of pulpy juices (Carlson *et al.*, 1967). Alternatively, the pulpy fruit juices are centrifuged to separate the solid phase (pulp) and the remaining liquid phase (serum) is concentrated in an evaporator followed by adding back the pulp (Sulc, 1984).

Economic aspects of the concentration process which play an important role in the selection of proper method and equipment, cannot be overlooked (Renshaw *et al.*, 1982 and Sapakie and Renshaw, 1984). The cost of water removal in various concentration processes has been reported by various workers (Thijssen and Van Oyen, 1977; Renshaw *et al.*, 1982; Robe, 1983 and Marshall, 1985). According to Thijssen and Van Oyen (1977), even though the cost of water removal can be reduced to 0.18 (steam equivalent), it is much higher than those for freeze-concentration and reverse osmosis. However, with aroma recovery and multi effect evaporation, the cost becomes comparable.

Ramteke *et al.* (1993) presented a critical review on different methods for concentration of fruit juices and concluded that the concentration by vacuum evaporation still remains the best option.

2.3.2 Physico-chemical properties of concentrate

Physico-chemical changes during preparation of plum juice concentrate under vacuum at 50-60°C have been reported by Wani *et al.* (1990). The plum pulp could not be concentrated beyond 26°B, while the juice could be concentrated upto 73°B. An increase in total solids, total soluble solids, reducing sugars, browning and viscosity with negligible decrease in acidity and pectin during concentration process was observed.

Sandhu and Bhatia (1985) successfully concentrated orange, pineapple, banana, guava and mango juices under vacuum at 50-55°C in a glass evaporator. Cloudy juice of orange could be concentrated upto 40-42°B, while the clear juices of pineapple, banana, guava and mango could be concentrated upto 45-48°B. There was an increase in the reducing sugars with the increase in concentration. Ascorbic acid was observed to be highly heat labile and its losses increased with the increase in concentration. Further, pulpy juices were more prone to loss of ascorbic acid as compared to clear juices particularly at higher concentrations. Slight decrease in acidity and pectin occurred with the increase in concentration.

Molwane and Gunjal (1985) while concentrating hot and cold break extracted tomato juices studied the effect of vacuum evaporation on chemical composition of concentrate and reported that the loss of ascorbic acid and inversion of sugar increased with the increase in concentration, whereas the pH and acidity remained unaffected. However, they did not consider the effect of temperature and limited their study only upto 18°B concentration at a constant vacuum of 450 mm of Hg column.

2.3.3 Boiling-point rise of tomato juice

The vapour pressure of aqueous solutions is less than that of pure water at the same temperature. Consequently, for a given pressure the boiling point (BP) of solutions is greater than that of pure water. The increase in BP over that of water is known as the boiling-point elevation or boiling-point rise (BPR) of the solution. For the efficient operation of the evaporation process, the properties of juices including BPR are important (McCabe *et al.*, 1993).

Data on BP of different fruit and vegetable juices are limited in literature (Bernnan *et al.*, 1974; Moresi and Spinosi, 1980). Desrosier and Desrosier (1977) for the first time reported boiling points of some typical fruit juice/ sugar mixtures at various concentrations ranging from 50 to 76 per cent by weight. These data, however, are for unknown fruit/sugar mixtures and, therefore, have limited use in evaporation design and operation.

Different methods have been used to describe the BPR of sugar solution and fruit juices as a function of pressure (or BP of pure water) and concentration of soluble solids.

Moresi and Spinosi (1984a, 1984b) studied the BP of grape and apple juices at different concentrations and used the following correlations based on the Clausias-Clapeyron and Antonie equations to describe the BPR of juices

$$\ln P = A_b(W) - B_b(W)/T_S \qquad \text{... (2.1)}$$

$$\ln P = A'_b(W) - \frac{B'_b(W)}{[T_S + C_b(W)]} \qquad \text{... (2.2)}$$

where P is the absolute pressure, T_S the temperature of ebullition, W the mass concentration of soluble solids (expressed as °Brix), and A_b, B_b, A'_b, B'_b and C_b are empirical constants that were found to be complex polynomial functions of W. Crapiste and Lozano (1988) expressed the BPR (ΔT_b) as a function of W and P

$$\Delta T_b = \alpha_b \, W^{\beta_b} \exp\left(\tau_b W\right) P^{\delta_b} \qquad \text{... (2.3)}$$

where α_b, β_b, τ_b and δ_b are constants and evaluated from the experimental data. Similar expression was used by Ilangantileke *et al.* (1992) to describe the BPR of Thai tangerine juices.

Moresi and Spinosi (1980) described the BPR of orange juice as a function of concentration and independent of pressure. In another approach, theoretical expression was derived to estimate the extent of BPR in solutions. From thermodynamic considerations it can be shown that the integral form of the BPR equation is given by

$$\ln a_w = \frac{\Delta H_V}{R}\left[\frac{1}{T_S} + \frac{1}{T_A}\right] \qquad \text{... (2.4)}$$

where a_w is the water activity, ΔH_V the latent heat of vaporization of water, R the gas constant, and T_A and T_S are the boiling temperatures of pure water and solution, respectively. **Eqn. (2.4)** can be used to predict the BPR if a_w of the solution as a function of temperature and concentration is known. However, this experimental information is not easily available.

The BPR (ΔT_b) of any dilute ideal solution can be predicted by using the relationship resulting from thermodynamics and *Rault's Law* (Moore, 1962).

$$\Delta T_b = \frac{R T_A^2}{\Delta H_V} \cdot X_B \qquad \text{... (2.5)}$$

Where X_B is the mole fraction of solute.

Eqn. (2.5) requires accurate knowledge of the fraction of solutes in the solution, which in the case of juices is difficult because they contain many solutes. Moreover, the error in the estimation of BPR of juices from this equation is compounded as the concentration increases, since in the derivation of this equation many simplifications are made which at higher concentrations may cause substantial error (Foust *et al.*, 1960).

According to Crapiste and Lozano (1988), the BPR of complex solutions might be predicted by estimating the boiling-point elevation (ΔT_{bi}) due to the generic ith solute and combining such data as follows

$$\Delta T_b = \Sigma \Delta T_{bi} \qquad \text{... (2.6)}$$

Regardless of any theoretical estimation, the approach by Varshney and Barhate (1978) consisted of correlating the BP of tropical fruit juices, *viz.*, pineapple, mango and lemon with solute concentration, with the overall result of a single equation for each pressure examined.

A very useful plot to estimate the BPR is *Duhring's* plot which states that the BP of a given solution is a linear function of the BP of pure water at the same pressure. The resulting plots are straight lines and different lines are obtained for different concentrations. Over a wide range of pressure the rule is not exact, but over a moderate range the lines are very nearly straight, though not necessarily parallel (McCabe *et al.*, 1993).

Although boiling point for a variety of fruit juices at different concentrations have been reported in the literature (Varshney and Barhate, 1978; Moresi and Spinosi, 1980, 1984a, 1984b; Crapiste and Lozano, 1988 and Ilangantileke *et al.*, 1992), no information on boiling point of vegetable juices, especially the tomato juice is available. Therefore, there is a need to study the BPR of tomato juice at different concentrations.

2.3.4 Desorption isotherm of tomato concentrate

Water activity (a_w) is the ratio of vapour pressure of water in food to the saturation vapour pressure of water at the temperature at which the food remains in equilibrium. The moisture content which the food attains in a particular relative humidity (RH) of atmosphere is called the equilibrium moisture content (EMC) and its relative humidity as equilibrium relative humidity (ERH). Although they mean two different physical entities, a_w is numerically equal to ERH/100. The EMC-a_w or EMC-ERH relationships for food products are known as sorption isotherms and they are required for understanding the behaviour of food during handling, drying, processing and storage.

Absorption of moisture from atmosphere and consequent discoloration due to enzymatic browning are problems encountered during storage of hygroscopic foods (Rao and Roy, 1980). The water activity (a_w) influences product stability and its physical characteristics like texture. The sorption isotherms can be used to determine the optimum moisture content of the dried product (Rockland and Nishi, 1980 and Slade and Levine, 1991). In addition, the EMC-a_w data can also be used to predict foods storage stability (Labuza, 1974).

Water sorption isotherms at room temperature are known for many foods (Iglesias and Chirife, 1982). But, only a few reports are available on sorption isotherms for fruits and vegetables at elevated temperatures (Roman *et al.*, 1982; Labuza *et al.*, 1985 and Mir and Nath, 1995). Gal (1981) reviewed the methodology for obtaining the sorption behaviour of foods and identified three basic methods, *viz.*, gravimetric, manometric and hygrometric for the determination of moisture sorption isotherm. He suggested the gravimetric technique be preferred for obtaining complete isotherm data.

Labuza (1968) reviewed the existing sorption equations for food systems and recommended the use of Clausius-Clapeyron equation to predict a_w value at any temperature if the corresponding heat of sorption was known at constant moisture content. Chirife and Iglesias (1978) discussed the validity of different sorption equations proposed by various workers. The two isotherm models, Brunauer-Emmett-Teller (BET) and Guggenheim-Anderson-de Boer (GAB) are commonly used for the analysis of a_w-EMC data of foods. The GAB equation which has a common theoretical background with the BET model has been applied successfully to various foods (Bizot, 1983 and Van den Berg, 1984). The GAB equation has an advantage over the BET model since it generally remains valid upto 0.9 a_w. The BET model is limited to 0.45-0.50 a_w (Labuza *et al.*, 1985).

2.4 Dehydration of Tomato

Dehydration is an important unit operation in fruit and vegetable processing industries. Tomatoes, because of high moisture content, require extensive water removal during drying. Dehydration of tomatoes in the form of slices as well as juice/concentrate has been attempted by various researchers in the past. The available literature on dehydration of tomatoes and other similar fruits has been reviewed in the following paragraphs.

2.4.1 Drying of tomato slices

Tomato slices of different thicknesses were dried by Hohl and Smith (1944) downto 10% moisture content using a forced-draft heated air dehydrator at 60°C (140°F). The dried tomato slices, however, could not be converted into a free flowing powder. Gupta and Nath (1984) studied both sun drying and hot air drying of tomato slices (1-3 cm thick) and reported that it required 22-35 h of sun drying to bring down the moisture content to 10 per cent whereas it took only 6-8 h in hot air at 70 and 80°C to reduce the moisture content of slices to 8.5 and 5.5 per cent, respectively. There was substantial loss of ascorbic acid and the dried product did not regain its original shape upon rehydration. Ali *et al.* (1989) after studying the drying behaviour of tomato slices over the temperature range of 40 to 90°C recommended 60 to 70°C as optimum temperature at which the drying time was in the order of 5-10 h to bring down the final moisture content of the product to 2.5 per cent. However, the best quality product having the same moisture content was found after 39 h at 40°C. Grover and Grover (1993) reported that sun drying for a minimum of 4-5 days (maximum day temperature of 46°C) was required to get a dried crisp product from tomato slice of thickness 6.25 mm (1/4 inch).

2.4.2 Drying of tomato juice/concentrate

Different methods namely, spray drying, vacuum puff drying and drum drying have been attempted in the past for drying of tomato juice/concentrate.

The adherence of powder to the walls of the drying chamber is a general problem in spray drying of fruit juices because of their comparatively high contents of reducing sugars and such other solids (Miers *et al.*, 1958; Notter *et al.*, 1958 and, Breene and Coulter, 1967). Various amorphous soluble substances in the spray-dried particle matrix yield thermoplastic agglomerates that tend to adhere to the walls when the powder reaches its "sticky point". The latter is closely related to the hygroscopicity of the material and increases rapidly with decreasing moisture upto certain extent (Karel, 1975b). In fact, Kjaergaard (1974) has described tomato pulp as a typical material which is very difficult to spray-dry as the powder becomes thermoplastic and sticky, particularly during the later stages of drying operation and is highly hygroscopic and caking. Dehydration of tomato juice/concentrate through spray drying technique required substantial deviations from the usual design of conventional spray dryers, establishment of specific operational procedures, and careful control of composition and properties of the feed (Lazar *et al.*, 1956 and Masters 1970, 1983, 1985). An example cited by Karel (1975b) is a 76 m (250 feet) high tower with dehumidified air at a temperature below 52°C (125°F) for spray drying of tomato paste.

Kaufman *et al.* (1955) while studying the preparation of tomato powder from concentrate using puff drying technique in a shelf drier under vacuum observed that the temperature of the product during drying operation should be kept below 65.6°C in order to prevent its heat degradation.

Damage to sensitive quality factors and problems of formation and handling dry product sheets are the major drawbacks of drum drying of fruit juices which owing to their relatively high-sugar contents form cohesive sheets that tend to roll into an amorphous mass at the doctor blades and do not slide down the product chutes (Kiston and MacGregor, 1982). Henig and Mannheim (1971) have reported the unsuitablility of conventional drum dryers for drying of tomato concentrate.

Various forms of drying in vacuum offer quality advantages but suffer from high cost (Kaufman *et al.*, 1955). Air drying, though inexpensive, results in poor quality products. Very rapid processes, such as spray or drum drying, involve difficult problems if overheating is to be avoided entirely (Lazar, *et al.* 1956).

2.5 Foam-mat Drying of Tomato Juice/Concentrate

Foam-mat drying technique developed in 1959 at the Western Regional Research Laboratory of the U.S. Department of Agriculture was a promising development in the field of drying (Morgan *et al.*, 1959 and Morgan *et al.*, 1961a). This method still offers wide scope for drying applications in vegetable and fruit juice processing industries and in drying of other difficult-to-dry sticky, viscous and heat sensitive materials, like glue, gelatin, pigments, varnishes *etc.* Any fluid material that needs to be dried gently could be dried by the foam-mat method provided it is capable of forming a stable foam.

The foam-mat process involves drying thin layers of foamed material in heated undehumidified air at atmospheric pressure and is reported to be considerably cheaper than vacuum, drum, puff, freeze and spray drying methods (Morgan *et al.*, 1961a; Lawler, 1962; Rockwell *et al.*, 1962; Sjogren, 1962; Beck, 1968; Sinnamon *et al.*, 1971; Berry *et al.*, 1972, and Akintoye and Oguntunde, 1991).

2.5.1 Principles of foam-mat drying

The essential steps in foam-mat drying include

(a) pre-treatment of the raw material and preparation of liquid concentrate;

(b) conversion of the concentrate into a stable foam by incorporating air or other gases and a suitable foaming agent;

(c) exposing the foam in the form of a thin sheet to a current of hot air until it is dehydrated; and

(d) conditioning and grinding of the dried porous mass into an easily rehydratable powder.

The advantage of foam is that the structure provides a large surface at which water may rapidly evaporate. Water vapour produced below the already dry outermost portions diffuses through the thin, warm walls of these outer parts, and not through the thick, dense skin which would result from shrinkage of an unfoamed mat. The same structure ensures rapid rehydration of the dry product. The water travels along the web of solid material, like ink onto blotting paper. Formation of a gummy capsule is avoided by the small gas inclusions which do not escape until the solids outside have dissolved or dispersed. When the foams are sufficiently stable, the dry product is uniform and has foam structure. When the foam bubbles are sufficiently small, the dried product may be subdivided fairly finely without losing the advantages of foam structure. From the point of view of rehydration, foam structure provides the advantages of natural porosity (Morgan, 1966).

2.5.2 Foam-formation and breakdown

Food foams are usually dispersions of gas bubbles in a continuous liquid or semisolid phase that contains a soluble surfactant. In many cases the gas is air (occasionally carbon dioxide or nitrogen) and the continuous phase is an aqueous solution or suspension containing proteins. Some food foams are very complex colloidal systems. A continuous phase of thin liquid layers, called lamellae, separates the gas bubbles in foams. The gas/liquid interface may measure 1 m^2 ml^{-1} of liquid (Cheftal *et al.*, 1985). As with emulsions, mechanical energy is required for the creation of this interface. Maintaining the interface against coalescence of gas bubbles usually necessitates the presence of surface-active agents. These agents lower the interfacial tension and form an elastic protective barrier between entrapped gas bubbles.

Gas bubbles in a foam can vary greatly in size varying in diameter from a few microns to several centimeters depending on numerous factors, such as surface tension and viscosity of the liquid phase and energy input. Uniform distribution of fine bubbles usually imparts body, smoothness and lightness to the product (Bikerman, 1973).

2.5.3 Methods of foam formation

Three methods are generally used in the formation of food foams. In one method gas is bubbled through a porous spurger such as sintered glass into an aqueous solution of low protein concentration (0.01-2% w/v). The liquid may be completely converted to foam if a large amount of gas is introduced.

Secondly, foams can be formed by whipping (beating) an aqueous solution containing a foaming agent in the presence of a bulk gas phase. Whipping can be carried out in a variety of devices that vigorously agitate the liquid and its interface with a bulk gas phase. The method has been preferred for most of the "functional tests" of proteins, as it is the standard means of gas introduction in most aerated products. The process of bubble formation and the history of a single bubble are not well defined. The whipped foam is well mixed throughout its formation, so the stratifications often found in bubbled foam column are not observed. Compared with spurging, whipping results in a more severe mechanical stress and shear action, and a more uniform dispersion of the gas. The severe mechanical stress affects both the coalescence and formation of bubbles. The volume of air included usually goes through a maximum with increasing intensity of beating (severe mechanical beating is a standard method of foam breaking). Hence, the observation of maximum levels of gas incorporation during whipping reflects a much more real dynamic equilibrium between mechanical formation and destruction of bubbles. In addition, mechanical stresses can break up bubbles formed earlier into several smaller ones.

A third procedure for forming foam termed as shaking has been used only rarely (Franzen and Kinsella, 1976; Wang and Kinsella, 1976). Foam formation by shaking tends to be slower than by bubbling or whipping under similar conditions which is due to the relative efficiency of the process in producing gas bubbles. The maximum foam volume obtained by shaking are also rather lower than that in the other two methods (Halling, 1981).

2.5.4 Foam characteristics

LaBelle (1966) and Hart *et al.* (1963) have described the characteristics of foams suitable for drying. The most desirable characteristics of a foam is that it should consist of a large number of small and uniform bubbles which should retain their structure during drying. Foam bubbles usually burst because of air and thus surface energy of the resulting drops is smaller than that of the original system. Adequate amounts of stabilizers are added to provide stability to the foam which would otherwise collapse before all the moisture has been removed during drying. Foam stabilizers might be surface active agents, hydrophilic colloids or a mixture of both.

The key step in foam-mat drying is the preparation of a stable foam. Whippability, the capacity to form stable foams with air, is an important functional property of proteins for applications in food products. The term "whippability" and "foamability" are used interchangeably in the literature although whippability usually suggests that tests were conducted using a household-type mixer with a whipping arrangement, while foamability refers to the intensive shaking/agitation of a protein solution in a cylinder or the bubbling of air through a protein solution via a fritted disc (Yasumatsu *et al.*, 1972). Foaming methods require less protein and are measured under milder and more controlled conditions (Wang and Kinsella, 1976). The mixing method for whipping is a simple one and gives more reproducible results which can be easily translated from laboratory bench to pilot plant (Gunther, 1979 and Mansvelt, 1979).

The characteristics of the foam are measured in terms of two parameters *i.e.* foaming ability and foam stability. Foaming ability is the initial height of foam in the column immediately after formation. Foam stability is the rate of subsidence of these foams. In other words, stability of a foam or whip is its ability to retain its maximum volume and is usually measured by the rate and/or amount of leakage of fluid from the foam.

2.5.5 Factors affecting foam characteristics

The factors which greatly influence the two parameters, *viz.*, foaming power and foam stability, are the total solids contents of sample, temperature during foaming, whipping time and type and concentration of foaming agent and foam stabilizer.

According to Hart *et al.* (1963) foam stability is greatly influenced by soluble solids content of the sample, and type and concentration of the added foam inducer. Pulp content of the sample and mixing time have negligible effect on stability of the foam. In general, when the content of soluble solids in the sample is low, more amounts of foaming agent and stabilizers are required to be added. If the sample food is relatively free of pulp, the foam must be whipped to a very low specific gravity in order to acquire the necessary stiffness.

The concentration of the additive necessary to produce a given density of the foam depends on the characteristics of the material being foamed in addition to the other external variables. Bates (1964) while studying the foam-mat drying of some tropical fruits using two types of foam inducers, namely modified soybean protein (D-100) and glycerol monostearate (GMS), observed that even less than 0.25 per cent of D-100 was adequate to produce foam of a density 300-400 kg m^{-3} for most of the systems studied with or without the use of foam-stabilizer. Similarly, 0.5 per cent GMS was able to produce foam of density 330-360 kg m^{-3} in some system (papaya puree), but, on the other hand, it was impossible to foam this puree with normal quantities of soya protein. The foam density and stability was reported to increase with the increase in the soluble solids content of the juices.

Berry *et al.* (1965b) studied the effect of whipping time in the preparation of grapefruit foam using GMS as the foaming agent. Increasing the whipping time from 6.5 to 15 min did not result in significant change in bubble size. However, after 15 min some breakdown occurred at a very slow rate and even after 30 min of whipping, the foam still posed a good bubble size. The effect of stirring time and surfactant concentration on the foam density has been reported by Beristain *et al.* (1993). The concentration of surfactant (foaming agent) in the range of 1 to 3 per cent showed a decrease in bulk density till 8 min of stirring time after which the foam structure collapsed resulting in an increase in the foam density. A criterion for good foam stability was its uniformity and the lack of fluid drainage in 60 minutes after its preparation. These characters were observed in foams with bulk densities below 300 kg m^{-3}. In general, best results were obtained when the smaller amount of surfactant was added, and for the shortest stirring, to obtain a bulk density of 260 kg m^{-3}. Foams prepared under these conditions showed stability to drainage for over 1 hour.

Djelveh *et al.* (1994) studied the influence of mechanical mixing, gas input rate and a gas spurger on the foaming capacity of a model food under steady-state and found it to remain dependent on the gas flow rate. Also, rotational speed upto 1000 to 2000 rev min^{-1} improved the foaming capacity without any adverse effect on foam density. The experimental results with different gas spurgers (hole diameters) did not show any significant change in the density of foam.

According to Kabirullah and Wills (1988), who worked on functional properties of sunflower seed protein, although the foam expansion was not influenced by changes in pH of the material the stability decreased with its increase. An increase in protein concentration increased both the expansion as well as stability of the foam. Similarly, higher stirring time did not appreciably affect foam expansion but increased the foam stability, whereas higher stirring speed increased foam expansion significantly but foam stability only slightly.

2.5.6 Drying of foam

In order to dehydrate the foams different drying techniques like vacuum foam drying, foam spray drying, foam-mat drying including crater technique have been reported by various researchers (Morgan *et al.*, 1959, 1961a; Gutterson, 1971; Jayaraman *et al.*, 1974 and 1992). Literature on drying of tomato foam is scanty.

Morgan *et al.* (1959) reported the development of a belt-type foam-mat dryer and production of powders from tomato juice, milk, coffee extract and orange juice. Subsequently, several basic forms of foam-mat dryers including the laboratory type adiabatic dryer were evolved (Bissette *et al.*, 1963; Anjaria and Chivate, 1966; Noznick and Bundus, 1967; Chandak and Chivate, 1972 and Torrey, 1974). A belt-type foam-mat dryer is shown in **Fig. 2.2.** It consists of an endless steel-or teflon-coated belt which alternatively passes over the heating and cooling drums. The foamed material is spread over the moving belt and temperature of air flowing across the material through the ports is controlled in the range of 65°C to 21°C. The drying in such process takes about one hour time depending upon the characteristics of the material being dried. The difficulty with such dryers, however, is the removal of the product from the belt in certain cases.

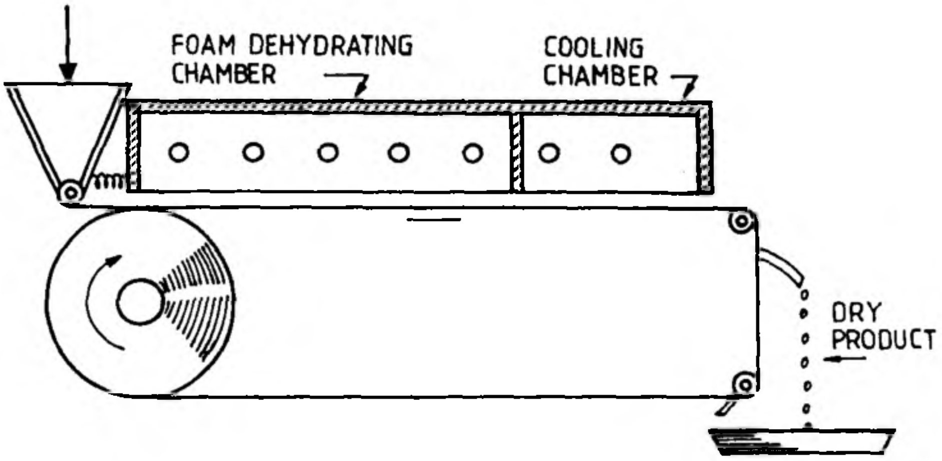


FIG.2.2 Belt type foam-mat dryer
(Torrey, 1974)

Tray-and crater-type foam-mat drying have been used by various researchers for the production of fruit/vegetable powder. Processes have been patented by Morgan and Ginnette (1960a and b) and Morgan *et al.* (1961b). The tray dryer is an improved design over the belt dryer. In this, a layer of foam is spread over metal trays and dried. In the crater technique, perforated metal trays are used on which the foam is spread. A controlled air blast is directed through the tray underneath by nozzles of approximately 0.8 mm size. The nozzles direct thin flat jets of air up through the tray perforations to pierce the foam and pile it in volcano-shaped craters around each hole (Morgan *et al.*, 1961a and 1961b; Lazar and Morgan, 1965 and 1966; Rockwell *et al.*, 1962; Ginnette *et al.*, 1963 and Morgan, 1966).

Foam-mat drying using crater technique has several added advantages. Because of the large surface exposed to the air, most of the water is removed from the material in a very short time. However, the capacity of such dryers is very low. Tray drying of foams as mats is simple and cheap in comparison to the crater technique.

Lawler (1962) studied foam drying of tomato paste using crater technique and could dry the product upto 2 per cent final moisture content within 2 to 18 minutes depending upon the paste characteristics and drying conditions. About 70-90 per cent of the moisture was removed in the first few minutes. Ginnette *et al.* (1963) while studying foam-mat drying of tomato juice (26 to 36°B) using the crater technique and keeping the foam thickness constant as 3.1 mm (1/8 inch) did not observe any constant rate period of drying. The rate of drying was initially high which began to slow down almost immediately and the trend continued throughout the drying cycle. The powder obtained had a moisture content of 2.5-3.0 per cent and was free of scorched odour or taste.

The effect of concentration of foam stabilizers on drying characteristics of citrus concentrates was investigated by Berry *et al.* (1965a) who found that the concentration of stabilizer significantly affected the drying characteristics, and higher concentration reduced the drying time. Similar observations were also recorded by Akintoye and Oguntunde (1991) while studying the preparation of soymilk powder by the foam-mat drying method. Physical characteristics and reconstitution properties of the powder prepared from foamed soymilk was found to be better than that from the unfoamed soymilk. The final moisture content attained in the foamed samples was lower than that of the unfoamed sample.

Foam-mat drying of tomato, banana and guava has been reported by Jayaraman *et al.* (1974). The foams were spread on plain aluminum trays in the form of thin sheet and dried in a cross-flow hot air dryer at 80°C for 30 min followed by 30-90 min drying at 65-70°C. The dried foams were cooled to room temperature in a dry atmosphere to prevent caking. Colour and flavour of the dried product were reported to be good and uniform.

Aminov *et al.* (1976) reported that foam drying reduced the moisture content of tomato juice from 23 to 4.6 per cent within a time period of 4-5 min, while the conventional drying could reduce the same only upto 10-12 per cent even after prolonged drying time under identical drying air temperature.

2.6 Packaging and Storage of Tomato Powder

The important factors causing quality deterioration in foods during storage include (i) inherent properties of the food which cannot be controlled by packaging, and (ii) properties which are dependent on the environment and are amenable to control by the type of packaging employed (Ranganna, 1995). Shelf-life is defined as the maximum time for which a food product can be stored under specific environmental conditions without any appreciable deterioration in quality and acceptability. During this period the product remains fit for human consumption. Environmental factors affecting food stability include humidity, oxygen, toxic vapours, contamination, light effects and the time-temperature history of the package (Khanna and Peppas, 1982).

Since most dehydrated fruits and vegetables are hygroscopic, they require a moisture resistant pack. On the contrary, if the product is packed in a flexible package having high resistance to moisture vapour, the product may sweat which may lead to mold growth. They should preferably be packed under nitrogen atmosphere owing to their susceptibility to oxygen. Smaller sized packs/samples of dehydrated vegetables are packed in heat sealable flexible films, laminates consisting of polyethylene, aluminum/metallised foil or paper. In large size packs of dehydrated vegetables, an "in-package desiccant" like calcium oxide or silica gel is used. The in-package desiccant has high absorptive capacity at very low moisture levels (Talburt *et al.*, 1954). Vacuum packaging is also used for dehydrated fruits and vegetables depending on properties of the product and packaging material. Powdered dehydrated products like fruit juice powder, soups, custard powders *etc.* require protection against ingress of moisture and oxygen, and loss of volatile flavourings and colours (Ranganna, 1995).

The functional properties of the packaging materials are important to the protection of food against oxidation, moisture, microbial contamination, and colour and flavour changes. The requirements for barrier properties of packaging materials against environmental factors vary with type and moisture content of the product (Luh and Sharpe, 1982).

Extensive research has been carried out in the past on application of various packaging materials for foods (Mayer and Klis, 1961; Luh and de la Hoz, 1964; Luh and Tsaing, 1965; Berry *et al.,* 1966; Kumar *et al.*, 1974; Kumar *et al.*, 1980; Labuza, 1982; Tubert and Iglesias, 1986). Traditional methods for selecting proper flexible packaging materials to insure high quality storage for desired market life of a food are based essentially on experience and good guessing. This leads to over protection in many cases and is very costly produce in terms of time and manpower expended (Labuza *et al.*, 1972). A number of examples are available in India where packaging has played an important role in the failure or success of the product/institution (Punjrath, 1995).

The literature on packaging and storage of tomato powder is limited. Wong *et al.* (1956) and Wong and Bohrat (1957) have reported the storage stability of vacuum-dried tomato powder quite satisfactory under proper conditions of packaging and storage. Miers *et al.* (1958) carried out extensive storage studies of spray-dried tomato powder packed in sanitary cans. Their results indicated that the temperature (37°C and above) and the presence of oxygen were the factors causing detrimental effects on storage ability of the powder. The storage stability was reported to be reasonably improved in respect of flavour, colour and retention of ascorbic acid using an in-package desiccant along with the inert atmosphere in the packages. The improvement in shelf-life of grapefruit powder in an inert atmosphere has been reported by Berry *et al.* (1966). The use of in-package desiccant and controlled storage temperatures immediately after packaging of vegetable powders was shown to prevent caking and enhance their stability as a result of further reduction in moisture content (Mylne and Seamans, 1954; Strashun and Talburt, 1954; and Talburt *et al.*, 1954). Muralikrishna *et al.* (1969) have shown the increase in non-enzymatic browning and loss of ascorbic acid during storage of guava powder in flexible packages at 37°C temperature. The use of in-package desiccation, however, improved the retention of ascorbic acid and reduced non-enzymatic browning.

The effect of storage temperature on browning, retention of ascorbic acid and other factors in pineapple juice powder (Notter *et al.*, 1958) and orange powder (Schroeder and Cotton, 1948) has been reported. Notter *et al.* (1955) reported the storage behaviour of vacuum-puff dried lemonade. Cole and Kapur (1957) established that the rate of colour loss during storage varies with availability of oxygen, temperature and intensity of illumination.

Arya *et al.* (1985) studied the storage behaviour of freeze-dried watermelon juice powder in various type of packaging materials and concluded that the moisture content of stored product was of critical importance and decisive factor for the shelf-life of the product. Ammu *et al.* (1977) observed browning and lump formation in pineapple and mango powders within 2 and 3 months of storage period respectively at 37°C in sanitary cans. The loss of ascorbic acid and browning could not be avoided even after employing the inert atmosphere.

CHAPTER - III

MATERIALS AND METHODS

The study involved determinations of properties of tomato and juice, concentration of juice, moisture desorption of tomato concentrate, measurement of boiling-point rise of juice, conversion of concentrate into stable foams, drying of tomato foam, and packaging and storage studies of tomato powder. The materials, equipment used, methodology followed and experimental techniques adopted are presented in this chapter.

3.1 Raw Material

Ripe, tomato fruits of *Pusa Ruby* variety of red colour were procured from the local market as and when required for the experiments. Efforts were made to maintain uniformity in tomatoes in each lot. The fruits were washed under running water, trimmed to remove stems, blemished portion *etc.*, if any, and dried under fan at room temperature to remove the surface moisture. They were then subjected to various physico-chemical analysis and subsequent processing as detailed in the following paragraphs.

3.1.1 Analysis of the raw material

Tomatoes were selected at random from a representative mass of 100 fruits. The weight of each fruit was determined using an electronic balance and the diameter of its three axes was measured using a vernier calliper. The size (equivalent diameter) and sphericity were calculated (Mohsenin, 1970). The true density was determined by volume displacement method using toluene. Tomatoes were dipped in boiling water for about 3 min to facilitate the removal of peel (skin); the peels were weighed and per cent skin was calculated (Shibli *et al.*, 1996). Seeds were separated from individual fruit by pulping in hot water, strained and weighed. Contents of moisture, total soluble solids, insoluble solids, pH, acidity, ascorbic acid, lycopene, fat, proteins and sugars were determined using standard analytical methods (AOAC, 1984; Ranganna, 1995). Physical measurements were replicated 25 times, whereas the physico-chemical determinations were replicated 7 times. Mean values and standard deviations were calculated.

3.2 Extraction of Juice

The two commonly used process for extraction of juice from tomato *i. e.*, 'cold-break' and 'hot-break' methods, were used to study their effect on recovery of juice and its properties.

3.2.1 Cold-break method

In the cold-break extraction method, 500 g tomato was sliced into small pieces (0.5-1.0 mm thick) and crushed in a high speed domestic mixer cum grinder for 4-5 min till they were converted into pulp with a smooth uniform body.

3.2.2 Hot-break method

In the hot-break extraction method, tomatoes were given heat treatment prior to slicing and crushing for which a 500 g sample was placed in a wire mesh (10 mm) and dipped in boiling water bath for about 60-75 s. The tomatoes were then sliced and crushed in the same manner as in case of the cold-break extraction technique.

The pulp obtained from the above two methods was filtered through a fine muslin cloth (about 36 mesh size) to separate seeds, skin and the portion of the pulp which could not be ground well into fine particles. The fines of seeds and skin, if any, were allowed to pass through the muslin cloth. The juices so obtained were collected in amber coloured sanitized glass bottles, analysed for some important physico-chemical properties as well as quality attributes and stored at -5 to -1°C in a refrigerator till further use.

3.3 Concentration of Juice

The 'hot-break' extracted tomato juice (5.5°B) was subjected to concentration at 45, 55, 65 and 75°C temperatures using a batch scale laboratory model rotary vacuum evaporator (750 ml/batch). The effect of concentration time and temperature on different physico-chemical properties of the juice was studied.

3.3.1 Experimental set-up

The apparatus and experimental set-up used for the concentration of tomato juice is shown in **Fig. 3.1.** It consisted of a round bottom flask (1) of capacity 1 litre connected to a condenser (2). Condenser was connected to a condensate collecting flask (3), a vacuum pump via a needle valve (4) and a vacuum gauge (5). The whole apparatus was mounted on a stand (6) having arrangements for vertical and inclination adjustment. In order to rotate the holding flask, a driving unit (7) consisting of a flanged induction motor (0.05 kW) was fitted on the stand. A thermostatically controlled (± 1°C) water bath (8) mounted on the stand was provided for heating the flask containing tomato juice. A *J-type* thermocouple (9) connected to a temperature indicator (10) was inserted through condenser to measure the juice temperature during concentration.

① Holding flask
② Condenser
③ Condansate collecting flask
④ Needle valve
⑤ Vacuum gauge
⑥ Base stand
⑦ Driving unit
⑧ Water bath
⑨ Thermocouple
⑩ Temperature indicator

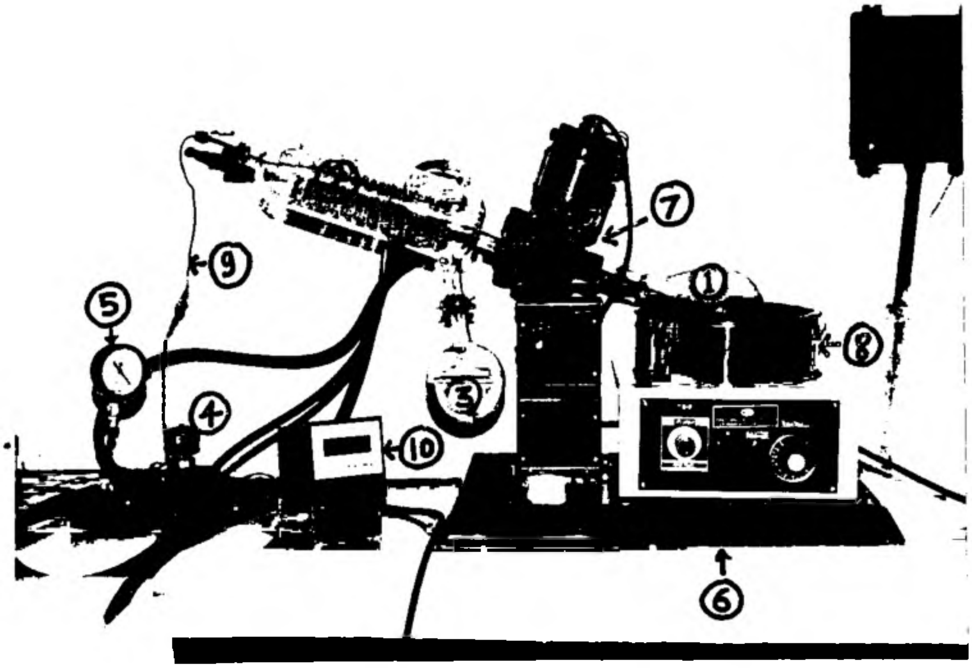


Fig. 3.1 Experimental set-up for vacuum concentration of tomato juice

3.3.2 Experimental procedure

All the joints of the evaporator were made air tight using silicon grease. The water bath was set at 3 ± 1°C higher than the desired concentration temperature. A measured quantity (750 ml) of single strength tomato juice (5.5°B) was introduced into the holding flask and rotated slowly (30-50 rev min^{-1}) till the desired temperature of juice was attained. A hand-held stroboscope was used for measuring the rotational speed (rpm) of the flask. Once the desired temperature was attained by the juice, vacuum was created inside the apparatus and maintained at a level required to keep the juice under boiling condition throughout the concentration process. Simultaneously, the rotational speed of the flask was increased gradually and maintained in the range of 110-115 rpm throughout the experiment. As the concentration progressed, the vacuum level was increased in order to keep the concentrating juice boiling. The vacuum level required to keep the material boiling with increasing concentration was found out from another experiment *i.e.*, boiling-point rise of tomato juice at different concentrations (Sec. 3.4). At 45 and 55°C, the concentration time was kept as 30 min for the first run which was then increased by 30 min for each successive run, while at 65 and 75°C, initial run time was 15 min and then followed by 15 min increase. The experiments were carried out till the maximum possible concentration at a specified process temperature after which the sticking of the material on the flask surface was noticed. At the end of each experiment, vacuum was released and the concentrated juice was taken out of the flask. Each experiment was replicated twice. The concentrated juice samples were collected in dark brown coloured glass bottles and stored in a refrigerator at -1 to -5°C till further use.

3.3.3 Analysis of the concentrate

The analysis of the concentrated juice samples was completed within 2 h of concentration. Samples were analysed for total solids, total soluble solids, pH, titrable acidity, ascorbic acid, lycopene, sugars and colour following standard analytical methods. The percentage retention of ascorbic acid and lycopene, and percentage inversion of sugars were calculated. Regression analysis and significance test were done to find out the effect of process variables on different physico-chemical properties of the concentrate.

3.4 Measurement of Boiling-point Rise

The boiling point-rise of tomato juice at different concentrations was determined by measuring the boiling point, T_S, of the juice at different pressures, P.

3.4.1 Experimental set-up

The apparatus used for the purpose was similar to that described by Moresi and Spinosi (1980). A pictorial view of the experimental set-up is shown in Fig. 3.2. It consisted of a round bottomed flask (1) of capacity 500 ml, connected to a reflux condenser (2). Sample was introduced into the boiling flask (1) by means of a tube (3) connected to it. When the juice was boiling a recirculatory flow was established between the tubes B and C. The liquid-vapour mixture, liberated from the sample (liquid) surface, went up along the tube B, a catchall (4), installed in the liquid-vapour line, removed entrained liquid particles which returned to the bulk of the liquid and allowed the vapours to enter the reflux condenser. These vapours were condensed and the condensate flowed down through the same tube C. A control valve (5) was provided between RC and the boiling vessel for controlling the recirculation flow rate. This maintained a constant concentration of the juice.

The apparatus was connected to a vacuum pump to create a pressure inside the apparatus ranging from 60 to 720 mm Hg absolute. The pressure was measured by means of a pre-calibrated (0-760 mm Hg) vacuum gauge (6) installed along with a needle valve (7) between the apparatus and vacuum pump. The sample was heated by means of a resistance heater (8), wrapped around the external surface of boiling vessel (1). The current flowing to the heater was controlled by a variac. A magnetic stirrer (9) was used for continuous mixing of the juice during boiling. The juice temperature was monitored by a thermocouple (*J*-Type) connected to an electronic indicator (10) capable of giving 0.1°C least count. The performance of the apparatus was checked using water and aqueous sucrose solutions whose boiling points at various concentrations and pressures were known.

3.4.2 Measuring technique

Tomato juice of different concentrations (9.5 to 32°B) were prepared under vacuum (60 mm Hg abs.) using rotary vacuum evaporator. Whenever there was a substantial time gap between concentration and measurement of boiling point, the concentrated juice was stored at about 4°C inside a refrigerator.

The boiling points of tomato juice at different concentrations ranging from 9.5 to 32°B were determined at 55, 93, 150, 235, 355, 525 and 760 mm Hg abs. pressure, corresponding to the boiling temperature of water of 40, 50, 60, 70, 80, 90 and 100°C, respectively. The same sample was used for determining the boiling point at pressures increasing from 55 to 760 mm Hg abs. In each experiment a 250 ml sample of concentrated

① Flask	⑥ Vacuum gauge
② Reflux condenser	⑦ Needle valve
③ Charging tube	⑧ Heater
④ Catchall	⑨ Magnetic stirrer
⑤ Control valve	⑩ Temperature indicator

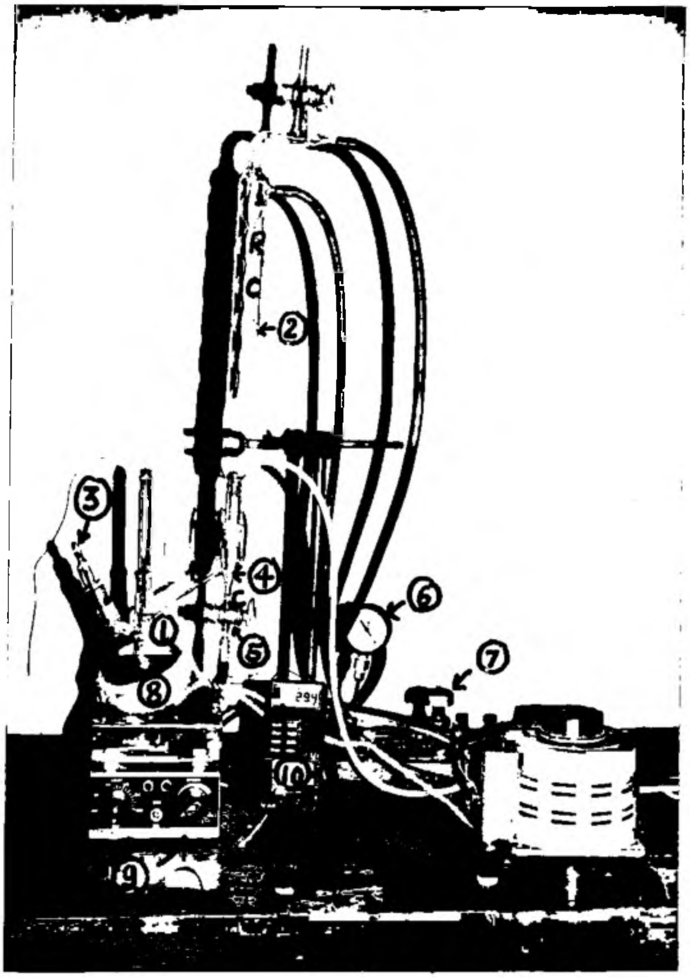


Fig. 3.2 Experimental set-up for the determination of boiling-point rise in tomato concentrate samples

tomato juice was kept in the boiling vessel (1). The cooling water flow was started in the reflux condenser and the vacuum pump was started to obtain a pressure of about 55 mm Hg abs. The fluid was mixed thoroughly and heated slowly. The boiling point of the juice at different pressures was recorded after the pressure and temperature readings remained steady for at least for 5 min. The vacuum was then decreased and set to the next observation level and the procedure repeated until the atmospheric pressure reached. The heating was stopped and the vessel cooled down to room temperature. A part of the juice was removed and its concentration checked. All the observations were made in duplicate.

Juice samples of other concentrations were similarly placed in the boiling vessel and the above procedure was repeated.

3.5 Moisture Desorption Isotherm

Samples of tomato concentrates (25°B) were used for determining equilibrium moisture content (EMC) employing static method (Iglesias and Chirife, 1982). Three to four gram samples of tomato concentrate filled in sterilised glass weighing bottles were placed in eight separate desiccators containing saturated salt solutions for maintaining (relative humidity) RH levels ranging from 10 to 90%. The salts used and corresponding relative humidities at different temperatures are given in **Table 3.1** (Young, 1967; Greenspan, 1977; Palipane and Driscoll, 1992).

When the moisture content of the tomato concentrate reached equilibrium with the relative humidity of the atmosphere maintained in the desiccator, the water activity (a_w) of the concentrate was equal to the relative humidity (fraction) of the atmosphere inside the desiccator. The desiccators containing samples were evacuated and placed in an incubator, where the temperatures were adjusted to, and regulated at 20, 30, 40, 50 and 60°C. Small glass bottles containing 5 ml toluene were placed beside the samples in the desiccators with relative humidity greater than 70% to check mold growth (Labuza, 1984). Weight of the samples was recorded at regular intervals after 48 h till they attained constant weight. The moisture content of the equilibrated samples was determined using a vacuum oven at 70°C with a vacuum below 450 mm Hg for 6-8 h (Ranganna, 1995).

Table 3.1 Relative humidity of the saturated salt solutions at different temperatures used in the experiment

Salt	Temperature, °C				
	20	30	40	50	60
Sodium hydroxide	11.3	11.3	11.2	11.1	11.0
Potassium acetate	23.1	21.6	20.8	20.4	18.1
Magnessium chloride	33.1	32.4	31.6	30.5	28.4
Potassium carbonate	43.2	43.2	40.0	38.5	36.5
Magnesium nitrate	54.4	51.4	48.4	45.4	42.0
Potassium iodide	69.9	67.9	66.1	64.5	61.1
Sodium chloride	75.5	75.1	74.1	74.4	71.5
Potassium chloride	85.1	83.6	82.3	81.2	78.5
Potassium nitrate	94.6	92.3	89.0	84.8	80.8

Water activity data were plotted against the corresponding moisture contents of the samples. From the sorption isotherms, the first point of inflation which indicated the minimum moisture content, to which the product should be dried, and second point of inflation which showed the maximum safe moisture level (Gal, 1983; Mir and Nath, 1995) were obtained. These points divided the curves into three local isotherms - LI-I, LI-II and LI-III.

The three parameter GAB model and two parameter BET model were used for fitting the experimental a_w and EMC data.

The GAB model is

$$\frac{M_e}{Mo_g} = \frac{Cka_w}{(1 - ka_w)(1 - ka_w + Cka_w)} \qquad \text{... (3.1)}$$

and the BET model is

$$\frac{a_w}{(1 - a_w)M_e} = \frac{1}{Mo_b C} + \frac{C - 1}{Mo_b C} \times a_w \qquad \text{... (3.2)}$$

where,

a_w = water activity,
M_e = equilibrium moisture content on dry basis,
Mo = monolayer moisture content on dry basis, and
C and k = constants.
(Suffix g and b representing GAB and BET respectively)

The GAB model (**Eqn.** 3.1) was transformed into second degree polynomial.

$$\frac{a_w}{M_e} = a_o + a_1 a_w^2 + a_2 a_w \qquad \text{... (3.3)}$$

The constants a_o, a_1 and a_2 are related to the physically meaningful constants by:

$$a_o = \frac{1}{Mo_g C} \qquad \text{... (3.4)}$$

$$a_1 = \frac{1}{Mo_g} \left(1 - \frac{2}{C}\right) \qquad \text{... (3.5)}$$

$$a_2 = \frac{k}{Mo_g} \left(\frac{1}{C} - 1\right) \qquad \text{... (3.6)}$$

The values of the parameters (Mo_g, C and k) were calculated from the values of a_o, a_1 and a_2 obtained by quadratic regression of **Eqn. (3.3)** and by solving **Eqns. (3.4)** and **(3.6)** after discarding the negative solutions.

A non-linear least squares regression program was used to estimate the parameters for the models. The mean relative percentage deviation (P_d) and standard error of estimate (SE) were computed for comparing the degree of fit of the experimental data to the model.

$$P_d = \frac{100}{N} \times \sum \frac{|Y - Y''|}{Y} \qquad \text{... (3.7)}$$

$$SE = \sqrt{\frac{\sum (Y - Y'')^2}{df}} \qquad \text{... (3.8)}$$

where,

Y = the measured value,
Y" = the value predicted by the model,
N = the number of data points, and
df = degree of freedom of regression model.

3.6 Foaming of tomato concentrate

The concentrated tomato juice was converted into stable foams using a chemical foaming agent. A laboratory model whipping/foaming device having the provision for air incorporation was designed and developed using perspex material.

3.6.1 Design considerations

The standard design criteria available for an ordinary turbine agitator were used for the development of the foaming device. For a typical turbine agitator shown in **Fig. 3.3** standard dimensional ratios are (McCabe *et al.*, 1993):

$$\frac{D_b}{D_t} = \frac{1}{2}, \frac{L_h}{D_t} = 1, \frac{J_b}{D_b} = \frac{1}{12}, \frac{E}{D_b} = 1, \text{ and } \frac{L_c}{D_b} = \frac{1}{4}$$

where,

D_b = diameter of agitating or whipping blade,
D_t = diameter of tank or vessel,
L_h = height or depth of liquid in the vessel,
J_b = width of baffles,
E = position of blade from the bottom, and
L_c = length of cutting edge of the blade.

These proportions were established for effective agitation of liquid in a tank. If the liquid is to be converted into foam by air incorporation, the above relations would not hold good. Following assumptions were, therefore, made to meet the requirements of the foaming situation.

(i) For the effective foam formation, the blade should be placed as low as possible and accordingly the ratio E/D_b should be minimum ($\approx$ zero).

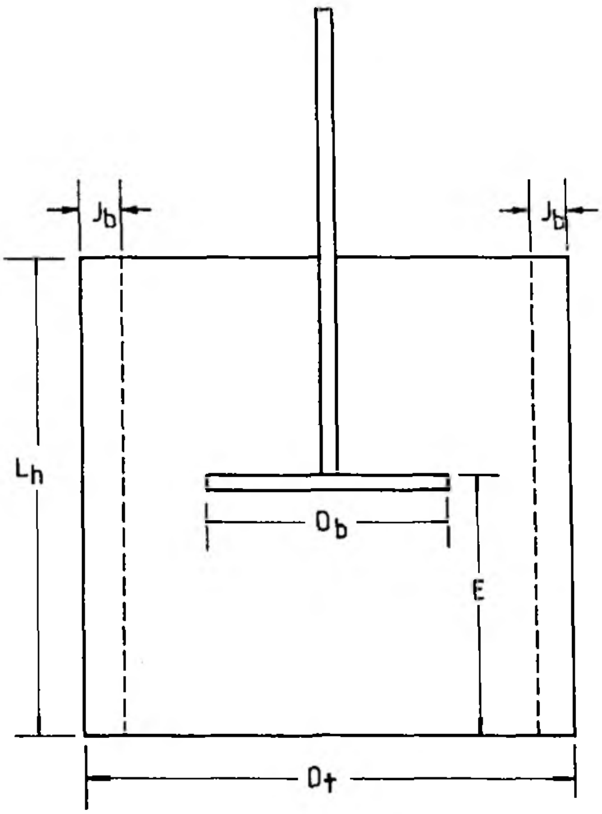


Fig. 3.3 Dimensions of a typical turbine agitator (McCabe *et al.*, 1976)

(ii) Due to foaming, the material volume expands and hence, the height of the vessel should be sufficiently large to accommodate the foamed material. Assuming 150% volume expansion upon foaming the ratio of L_h/D_t was taken as 2.5.

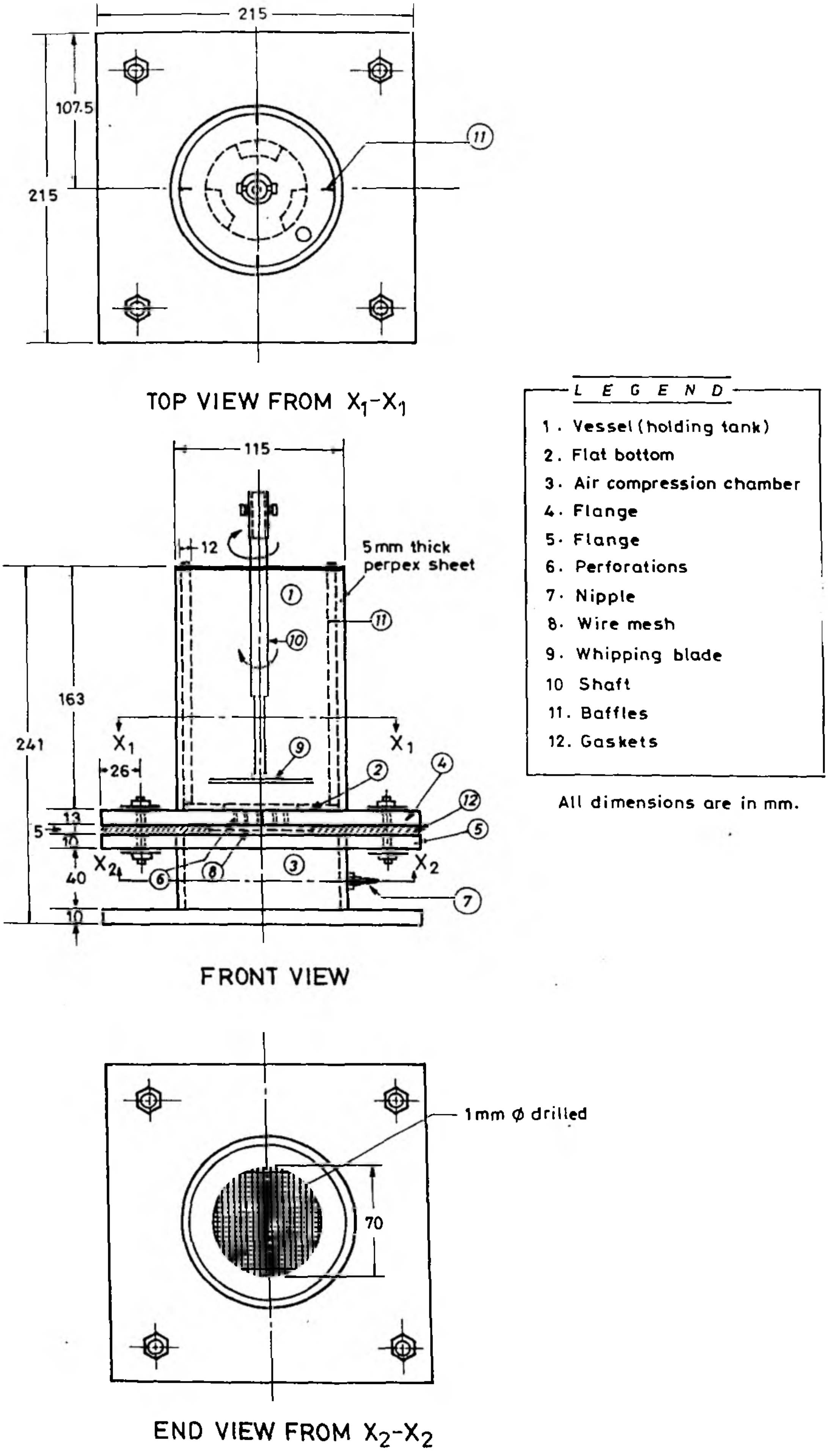
3.6.2 Fabrication of foaming device

The developed foaming device is shown in **Fig. 3.4**. It consisted of two sections, a cylindrical vessel or holding tank (1) with flat bottom (2) and an air compression chamber (3) of equal diameter as that of the vessel. The flat bottom of the vessel was extended 30 mm outside around the periphery to serve as a flange (4). An equal size of flange (5) was also provided on top of the compression chamber. The two sections were joined together through the flanges with the help of nuts and bolts. Perforations (6) of diameter 1.0 mm each were drilled on the bottom plate of the vessel around periphery of 37 mm radius for air spurging. A brass nipple (7) of 5 mm diameter and 35 mm length was provided in the air chamber to connect the unit to an air compressor. In between the two flanges a fine (100 μm) wire mesh (8) made of stainless steel was placed along with rubber gaskets on its top and bottom sides. The screen prevented the material (to be whipped) from passing down the air chamber and at the same time allowed the compressed air to pass through. Four measuring scales, equally spaced, were provided on the circumference of the vessel to measure the height/depth of material in the vessel. **Fig. 3.5** shows the pictorial view of different components of the foaming device.

A whipping blade (9) made of stainless steel (1.6 mm thick) with three cutting edges was used to agitate the material in the vessel. The details of the whipping blade is shown in **Fig. 3.6**. The blade was placed centrally in the vessel and connected to an universal AC/DC electric motor (0.5 kW) through a stainless steel shaft of 12 mm diameter (10). In order to avoid vortex formation during whipping, four stainless steel baffles (11) were provided on the vessel wall. A variable transformer was connected to the motor to control speed. A stroboscope was used to measure the rotational speed of the whipping blade. A pre-calibrated rotameter was used for monitoring compressed air flow rate.

3.6.3 Production of foam

Measured quantity of tomato concentrate sample/sugar sample solution was taken into the vessel of the foaming device, a pre-determined quantity of foaming agent, dispersed in water (suspension) was added into it and mixed thoroughly with the help of the whipping blade for about 1 min. The initial height/depth of this mixture was recorded. Compressed



TOP VIEW FROM X_1-X_1

FRONT VIEW

END VIEW FROM X_2-X_2

All dimensions are in mm.

Fig. 3.4 Details of the developed foaming devire

Ⓐ Holding tank
Ⓑ Compression chamber
Ⓒ Screen mounted on gasket
Ⓓ Whipping blade with shaft
Ⓔ Baffles

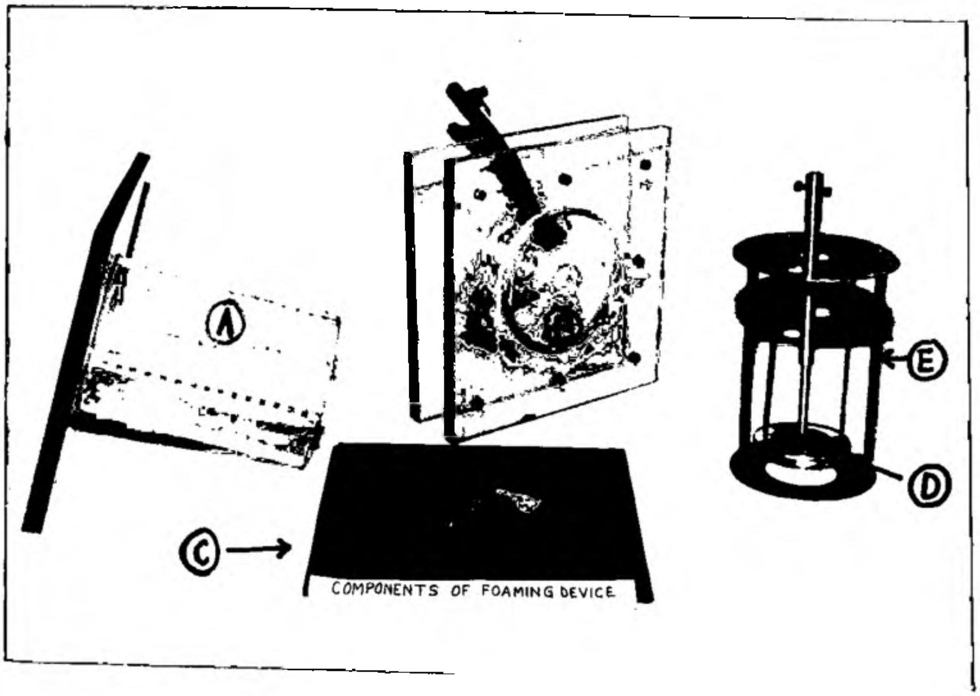
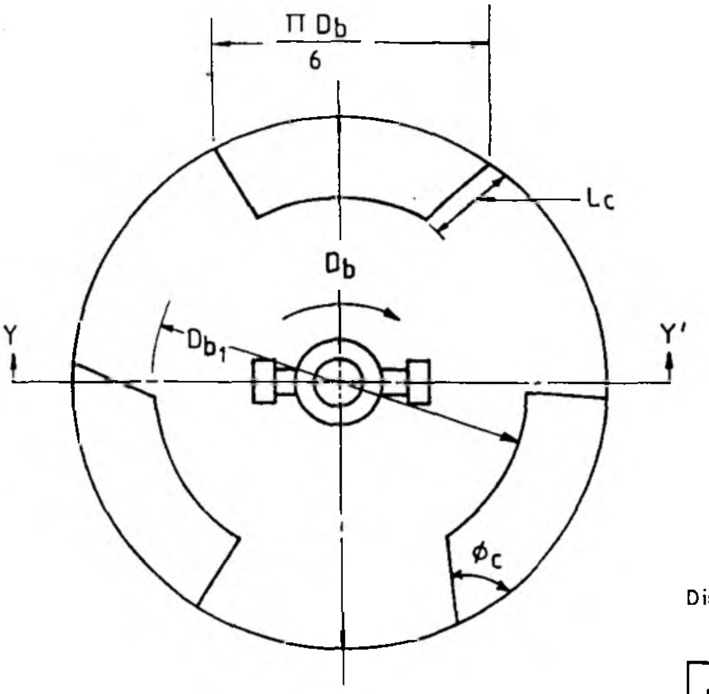


Fig. 3.5 Components of the foaming device



TOP VIEW

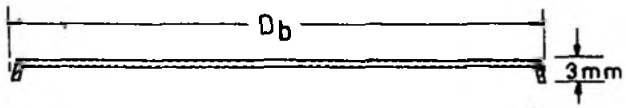
D_b = Diameter of whipping blade

L_c = Cutting edge length

ϕ_c = Cutting angle

Dimensions for different whipping blade

D_b (mm)	D_{b_1} (mm)	$\frac{D_b}{D_{b_1}}$	ϕ_c (Deg.)	L_c (mm)
41	27.4	1.5	75	6.80
52	34.8	1.5	75	8.60
60	40.0	1.5	75	10.0
68	45.4	1.5	75	11.3
79	52.8	1.5	75	13.1



SECTIONAL VIEW ALONG Y-Y'

Fig.3.6 Details of the whipping blade

air was then allowed to pass through the bottom of the vessel at a controlled rate and the blade was rotated at a desired speed. The air flow and the rotation of whipping blade were stopped simultaneously after a desired time period and the height of the foamed material in the vessel was recorded. Experiments were done at room temperature which varied between 25-29°C. A pictorial view of the experimental set-up is shown on **Fig. 3.7**.

The whipping blade was removed soon after the foaming and the foamed material as well as any drained out liquid was rapidly transferred into a measuring cylinder of 500 ml capacity. Any air pockets remaining in the vessel were removed by keeping the vessel upside down and giving two quick downward strokes on the bottom of the vessel.

The foaming properties, *viz.*, foam expansion (overrun) and foam stability were determined using the standard procedures as described by Patel *et al.* (1988), Chandak and Chivate (1972), Lah *et al.* (1980) and Halling (1981).

Foam expansion : The per cent foam expansion (FE) was calculated from the height/depth of material in the vessel before and after whipping (Lah *et al.*, 1980).

$$\%FE = \frac{Height\ of\ material\ after\ foaming - Initial\ height\ of\ material}{Initial\ height\ of\ material} \times 100$$

Foam stability : The foam was allowed to stand for 60 min at room temperature (25-29°C) after which the volumes of the drained out liquid and that of the foam were read directly on the measuring cylinder (**Fig. 3.8**). The per cent foam stability (FS) was calculated as follows (Patel *et al.*, 1988).

$$\%FS = \frac{Foam\ volume\ at\ 60\ \mathrm{min}}{Initial\ voloume\ of\ foam\ including\ the\ liquid\ volume\ without\ foam} \times 100$$

3.6.4 Experimental plan and statistical analysis

The foaming experiments were carried out in two parts. In the first part, performance evaluation of the developed foaming device and the optimization of machine and operating parameters were done using a 62°B sugar solution containing 1 per cent glycerol monostearate as foam inducer. In the second part, the foaming properties of tomato

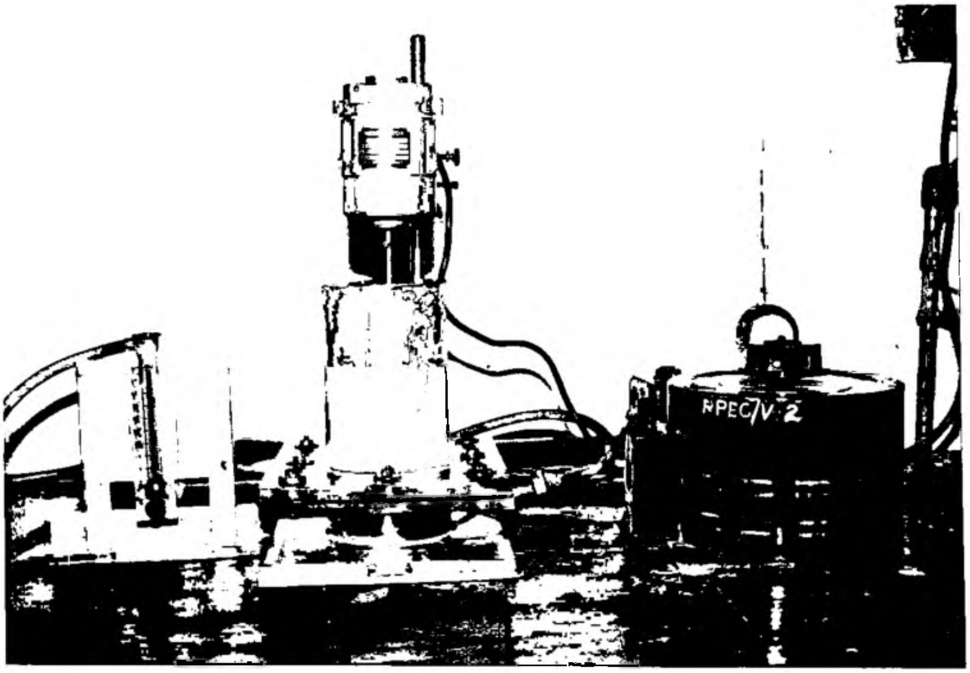


Fig. 3.7 Pictorial view of experimental set-up for foaming

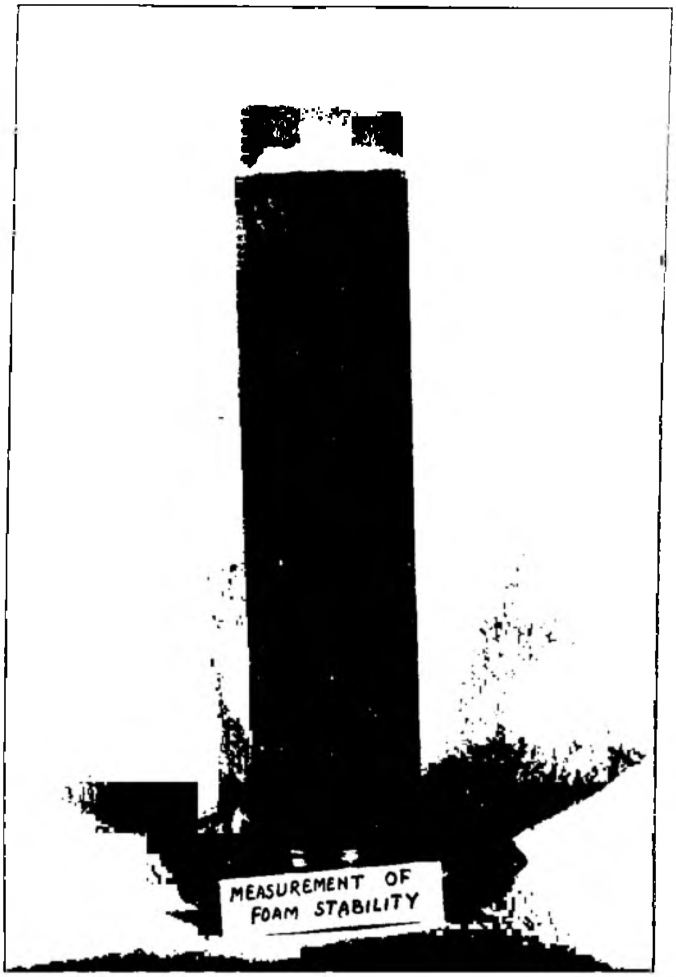


Fig. 3.8 Measurement of foam stability

concentrate were studied in order to find out a suitable foaming agent. Response surface methodology (RSM) was used to study the system followed by optimization of the machine and operating parameters (Myers, 1971).

The foaming process was considered to be affected by five independent variables (regressors or factors), ϵ_i, *viz.*, whipping speed W_S; whipping time W_θ; rate of air spurging A_r; diameter of whipping blade, D_b and the height of liquid to be foamed L_h. All these variables were closely controlled during experiments. The dependent variable, referred as system response η *i.e.* per cent FE was measured experimentally. A mathematical function f was assumed for describing the relationship between response, η and factors, ϵ_i, such as

$$\eta = f\,(\epsilon_1, \epsilon_2, \ldots, \epsilon_5) \qquad \ldots (3.9)$$

The exact mathematical representation of the function (f) is either unknown or extremely complex. However, a second order polynomial equation of the following form was assumed to relate the response, η and the factors, ϵ_i.

$$\eta = \beta_o + \sum_{i=1}^{5} \beta_i X_i + \sum_{i=1}^{5} \beta_{ii} X_{ii}^2 + \sum_{i=1}^{4} \sum_{j=i+1}^{5} \beta_{ij}\, X_i\, X_j \qquad \ldots (3.10)$$

where, β_o, β_i, β_{ii}, β_{ij}, are regression coefficients and X_i are the coded independent variables linearly related to W_S, W_θ, A_r, D_b, and L_h. The coding of ϵ_i into X_i was performed by the following equation

$$X_i = \frac{(\epsilon_i - \bar{\epsilon}_i)}{d_i} \qquad \ldots (3.11)$$

where, ϵ_i is the actual value of the factor in original units; $\bar{\epsilon}_i$ is mean of high and low levels of the factor ϵ_i; and d_i is interval (spacing) of variation of factor ϵ_i. After the coding, the experimental region extended from - 2.378 to + 2.378 of the X_i, which allowed a general design to be used in particular application.

In order to determine the effects of individual factors on foam expansion of sugar solution, an experimental design from the family of central composite rotatable design (CCRD) was used (Mullen and Ennis, 1979). **Table 3.2** shows the experimental design of the independent variables expressed in coded forms. The design requires 52 experiments with 32 (2^5) factorial points, 10 extra points to form a central composite design with α, the fourth root of the factorial points *i.e*, 2.378, and 10 centre points for replication. It fulfills the requirements for multi-factor response surface designs (Box and Hunter, 1957; Myers, 1971) and reduces the overall error *i.e.* variance or sampling error and bias error (Box and Draper, 1959). Furthermore, the design is specific for investigations with second order polynomials (**Eqn. 3.10**). It is rotatable and provides a reasonably constant variance of response in the five-dimensional space. To avoid bias, the total of 52 runs were performed in a random order for estimation of the constants of **Eqn. (3.10)**. The ranges of the 5 variables were chosen through preliminary trial experiments. The independent (ϵ_i) and the coded (X_i) variables and their levels are presented in **Table 3.3**. For example, the maximum blade diameter of 79 mm was chosen, because a blade having diameter slightly higher than this would not possibly rotate easily. Five blades of different diameters, as detailed in **Fig. 3.6**, were used as per the demand of the experimental design. These blades are shown in **Fig. 3.9**. Similarly, the ranges of the other variables were decided. The values of each independent parameter presented in **Table 3.3** were controlled within ± 10 rev min^{-1} for the whipping speed, ± 10 s for whipping time, ± 0.25 l min^{-1} for air flow rate, ± 1 mm for blade diameter, and ± 1 mm for liquid depth. Response surfaces were obtained using computer software written in Fortran.

Determination of optimum combination of independent variables, *viz*., whipping speed, whipping time, air flow rate, blade diameter and liquid depth involved calculation of stationary points and exploration of the nature (shape) of the surface around these points. At the stationary point the slope of the response surface is zero in all directions (Box and Draper, 1987). Canonical analysis, which allows rotation of the axes to remove all cross-product terms, was used to find the stationary point of the response surface using the method described by Draper (1963); Myers (1971) and Khuri and Cornell (1987).

The characteristics of the stationary points were evaluated by writing the fitted response surface (**Eqn. 3.10**) in canonical form as :

$$FE = FE_o + \sum_{i=1}^{5} \lambda_i W_i^2 \qquad \text{... (3.12)}$$

where, FE_0 is the foam expansion at the stationary point, λ_i are the characteristic roots of the symmetric matrix (elements of which are estimated as coefficients of second order terms), while W_i are the canonical variables (linear combinations of the original variables X_i).

Table 3.2 **Coded levels of independent variables foa a five-variable CCRD**

Experiment No.	Coded levels of the independent variables				
	X_1	X_2	X_3	X_4	X_5
1	1	1	1	1	1
2	1	1	1	1	-1
3	1	1	1	-1	1
4	1	1	1	-1	-1
5	1	1	-1	1	1
6	1	1	-1	1	-1
7	1	1	-1	-1	1
8	1	1	-1	-1	-1
9	1	-1	1	1	1
10	1	-1	1	1	-1
11	1	-1	1	-1	1
12	1	-1	1	-1	-1
13	1	-1	-1	1	1
14	1	-1	-1	1	-1
15	1	-1	-1	-1	1
16	1	-1	-1	-1	-1
17	-1	1	1	1	1
18	-1	1	1	1	-1
19	-1	1	1	-1	1
20	-1	1	1	-1	-1
21	-1	1	-1	1	1
22	-1	1	-1	1	-1
23	-1	1	-1	-1	1
24	-1	1	-1	-1	-1
25	-1	-1	1	1	1
26	-1	-1	1	1	-1
27	-1	-1	1	-1	1
28	-1	-1	1	-1	-1
29	-1	-1	-1	1	1
30	-1	-1	-1	1	-1
31	-1	-1	-1	-1	1
32	-1	-1	-1	-1	-1
33	-2.378	0	0	0	0
34	2.378	0	0	0	0
35	0	-2.378	0	0	0
36	0	2.378	0	0	0
37	0	0	-2.378	0	0
38	0	0	2.378	0	0
39	0	0	0	-2.378	0
40	0	0	0	2.378	0
41	0	0	0	0	-2.378
42	0	0	0	0	2.378
43	0	0	0	0	0
44	0	0	0	0	0
45	0	0	0	0	0
46	0	0	0	0	0
47	0	0	0	0	0
48	0	0	0	0	0
49	0	0	0	0	0
50	0	0	0	0	0
51	0	0	0	0	0
52	0	0	0	0	0

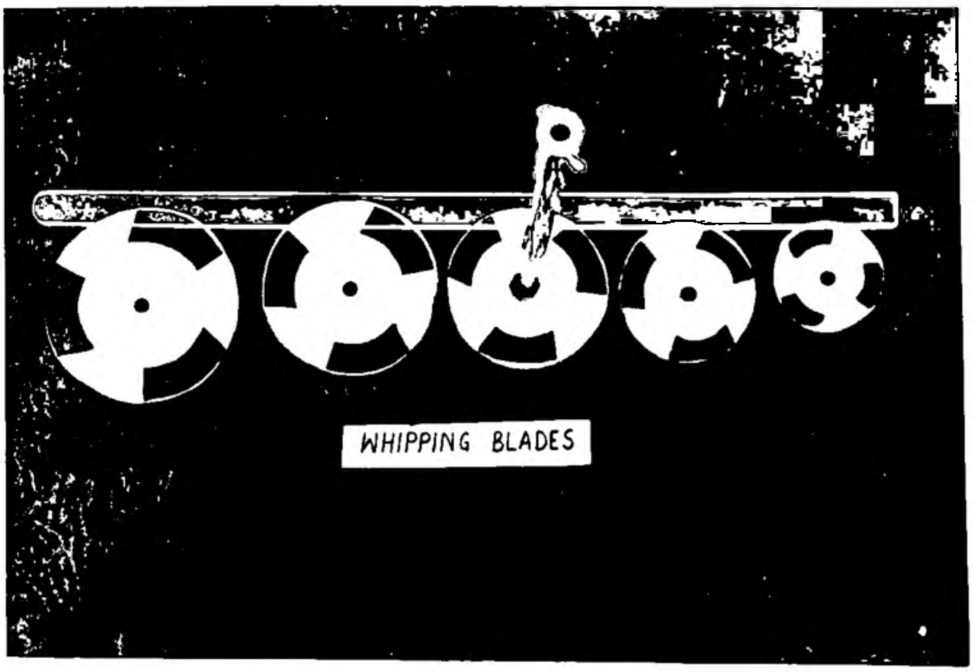


Fig. 3.9 Whipping blades of difernent size

The sign of λ_i determines whether the stationary point is maximum (all '-ve'), minimum (all '+ve') or saddle point (mixed *i.e.* some are positive and others are negative).

Table 3.3 Coded and actual values of independent variables included in CCRD used in foaming experiment on sugar solution

Independent variables	Codes	Levels					Interval of variation
		-2.378	-1	0	1	2.378	
Whipping speed, rev $\min^{-1}$	X_1	580	765	900	1035	1220	135
Whipping time, min	X_2	1	3.0	4.5	6.0	8.0	1.5
Air flow rate, l $\min^{-1}$	X_3	6.0	11.5	15.5	19.5	25.0	4.0
Blade diameter, mm	X_4	41	52	60	68	79	8.0
Liquid depth/height, mm	X_5	20	37.5	50	62.5	80	12.5

3.6.5 Selection of foaming agent

Experiments were conducted to investigate the effect of different chemicals (foam inducers and stabilizers) on foaming properties of tomato concentrate with a view to providing the basis for selection of a suitable foaming agent as well as its optimal concentration. A wide range of the concentration (20 to 32°B) of tomato juice has been indicated to be suitable for foaming in the literature (Ginnette *et al.*, 1963; Hart *et al.*, 1963; Chandak and Chivate, 1972). Results of the preliminary investigations as described later (Sec. 4.6.3) indicated that the tomato concentrate having 27% total solids (25°B) provided better foam expansion and foam stability. Accordingly, tomato concentrate of 25°B was used for the selection of foaming agent.

Four chemicals *viz.*, glycerol monostearate (GMS), pectin, carboxy methylcellulose (CMC), and combination of GMS and pectin (1:1) belonging to surfactant and stabilizer groups were used as foaming additives. They were evaluated for their effectiveness as foaming agent for tomato concentrate. Stock suspensions/solutions (10% w/v) of these chemicals were prepared in warm (65-70°C) distilled water and cooled. Calculated quantities of this solution/suspension were added to the tomato concentrate so as to achieve additive concentration in the range of 0.5-2.5%. Capability of individual additives was assessed by degree of foam formation in tomato concentrate and its stability at room temperature.

A two-factor factorial design which included 20 experiments was used. The treatment combinations were tested in a random order and each experiment was replicated twice. The performance of a surfactant/stabilizer as foaming agent was measured by the two responses *i.e.* foam expansion (FE) and foam stability (FS). The foaming device was operated at the optimum conditions as obtained using sugar solution (62°B) containing 1% GMS.

3.6.6 Prediction of foam expansion of tomato concentrate

Since Eqn. (3.10) does not take into consideration the concentration of foaming agent (F, % TS), the ratio, R_F was calculated from :

$$R_F = \frac{(FE_{Ta})_F}{(FE_{Sa})_{F=1\%GMS}} \qquad \text{... (3.13)}$$

where, $(FE_{Ta})_F$ is the actual foam expansion of tomato concentrate with any concentration of foaming agent and $(FE_{Sa})_{F\,=\,1\%\,GMS}$ is the actual foam expansion of sugar solution containing 1% GMS.

A functional relationship of the type $R_F = p + q\,F$ was developed as described by Hove and Das (1995) for milk fat concentration. The theoretically predicted value for foam expansion FE_{Tpred} was then calculated from :

$$(FE_{Tpred})_F = (p+qF)\ (FE_{Spred})_{F=1\%GMS} \qquad \text{... (3.14)}$$

where, $(FE_{Tpred})_F$ is the predicted foam expansion of tomato concentrate with any concentration of foaming additive, $(FE_{Spred})_{F\,=\,1\%\,GMS}$ is the predicted foam expansion of sugar solution containing 1% GMS, F is the concentration of foaming agent in tomato concentrate and p and q are the constants.

3.7 Drying of Foam

The foamed tomato concentrate samples (moisture content 303-314%, db) obtained from the foaming device at its optimized levels of operating conditions were subjected to air-drying at varying levels of drying air conditions. A dryer having provisions to vary air temperature and velocity was used for the purpose.

3.7.1 Experimental set-up

The schematic diagram of the experimental set-up used in drying studies is shown in Fig. 3.10 and its pictorial view in Fig. 3.11. It consisted of two units, *viz.*, a dryer (1) and a dehumidifier (2) connected together through a duct (3) having facilities to regulate the ratio of ambient and dehumidified air sucked by the dryer. The dryer consisted of an air blower (4), a heating unit (5), a plenum chamber (7), a drying chamber (9), power supply arrangement and the control panel. The dehumidifier was used to vary the relative humidity of the air.

Air blowing unit : The centrifugal blower (4) blows air through a stainless steel wire mesh and the air passes through an insulated heating chamber. The maximum air handling capacity of the blower was 4.5 m^3 min^{-1}. It was driven by a 0.5 hp single phase universal motor. The capacity of the blower could be varied by varying the input voltage to the motor with the help of an AC transformer. Air velocity was regulated either by controlling the input voltage to the motor or by controlling the inlet opening of the blower.

Air heating unit : This unit (5) consisted of a rectangular chamber (420 × 200 × 200 mm) made of aluminum sheet (1.60 mm thick) having arrangements for fixing two (1.5 kW each) finned strip electric heaters (6), connected in parallel to an AC power source. The heating chamber was insulated by asbestos sheet and glass wool. The heating unit was connected to the plenum chamber through a duct.

Plenum chamber : An insulated plenum chamber (7) was provided between the heating unit and the drying chamber. In order to facilitate uniform distribution of air in the drying chamber, baffles (8) were installed at the inlet of the chamber. A thermocouple (*J-type*), connected to a temperature controller, was placed after the heating unit. It maintained the air temperature in the drying unit.

Drying unit : The drying unit (9) consisted of a rectangular chamber having arrangements for placing five trays. The inlet and exhaust sides of the chamber were provided with perforated stainless steel sheet (10) for maintaining uniform velocity of the air in the chamber. A door made of perspex sheet (4 mm) fixed by hinges and rubber gasket for loading and unloading of the trays was provided in front of the chamber.

①	DRYER
②	DEHUMIDIFIER
③	DUCT
④	AIR BLOWER
⑤	AIR HEATING CHAMBER
⑥	HEATERS
⑦	PLENUM CHAMBER
⑧	BAFFLES
⑨	DRYING CHAMBER
⑩	PERFORATED WALL (SS)
⑪	DRYING AIR EXHAUST
⑫	INSULATION (ASBESTOS ROPE)
⑬	ROTATING DESICCANT BED
⑭	ROTATING SHAFT
⑮	MOTOR
⑯	DRIVING CHAIN & PULLEY
⑰	DEHUMIDIFICATION COMPARTMENT
⑱	REACTIVATION COMPARTMENT
⑲	PROCESSED AIR INLET
⑳	PROCESSED AIR OUTLET
㉑	REACTIVATION AIR INLET
㉒	REACTIVATION AIR OUTLET
㉓	DIVIDER
㉔	HEATERS

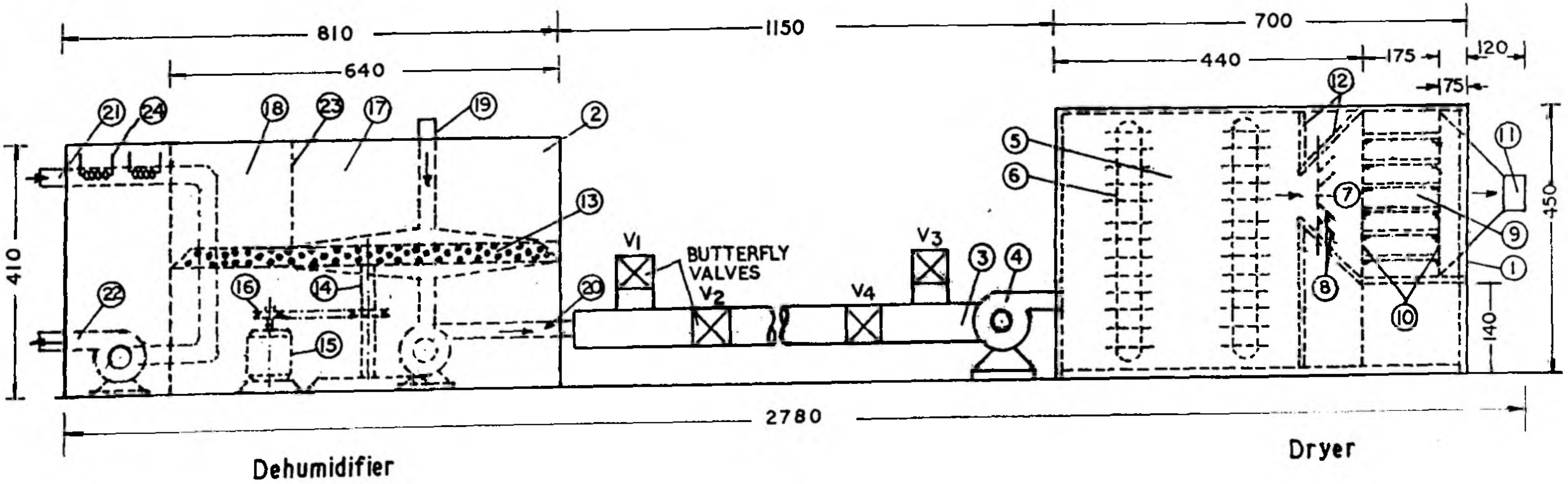


Fig.3·10 Schematic diagram of the drying unit

All dimensions are in mm

ⒶDryer
ⒷDehumidifier
ⒸDuct
ⒹTemperature controller
ⒺTemperature indicator
ⒻVariable transformer
ⒼDry-wet bulb thermometer

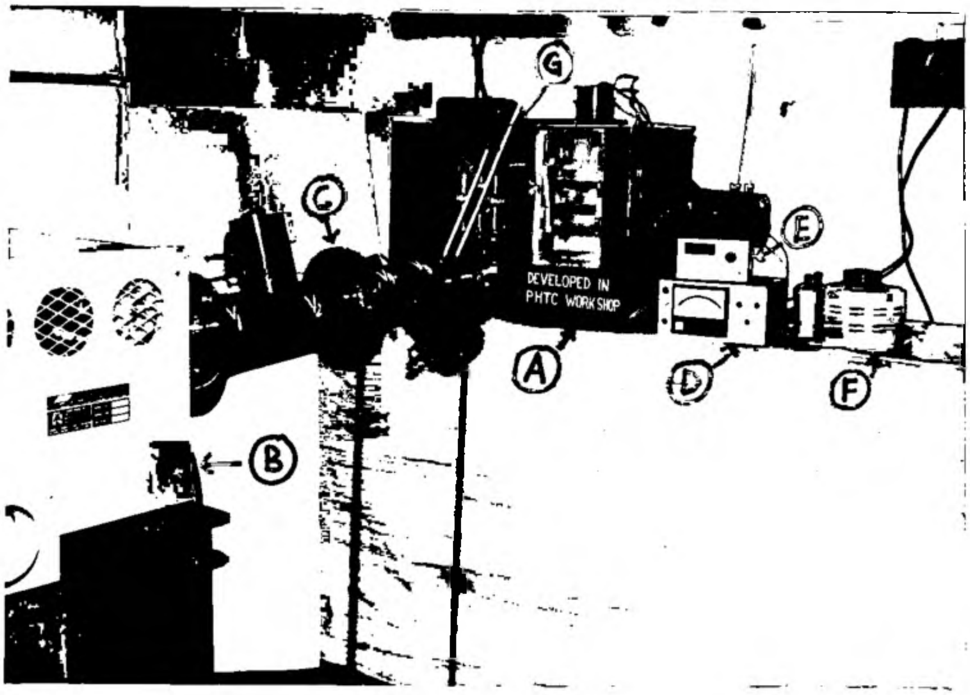


Fig. 3.11 Pictorial view of the experimental set-up for drying

Dehumidifying unit : The dehumidifying (2) unit consisted of a desiccant bed (13) rotated by a shaft (14) through a motor (15). The rotating bed had two compartments, one at the dehumidification side (17) and the other at its reactivation side (18). The ambient air after dehumidification was blown out through the processed air outlet (20). The desiccant bed was being continuously regenerated with the help of heated air. The processed air outlet port (20) of the dehumidifier was connected to the inlet port of the dryer through the duct (3). In order to vary the relative humidity of the inlet air to the dryer, the ratio of dehumidified and ambient air was regulated with the help of four butterfly valves (V_1, V_2, V_3 and V_4) provided on the duct.

When the ambient air was to be introduced to the dryer, valve V_4 was kept fully open and the valves V_1 and V_2 were closed. To draw dehumidified air, valve V_4, V_2 and V_3 were adjusted to match the blower capacity. Mixing of the dehumidified and ambient air was possible by controlling the opening of the valves V_1, V_2, V_3 and V_4. All the valves were partially opened and adjusted in such a way that a desired ratio of the two air could be maintained at an intermediate level of relative humidity of the ambient and processed air. The different temperature and relative humidity conditions of the air maintained in the dryer with and without the use of dehumidifier is shown in **Table 3.4**.

Measuring instruments and techniques : Two mercury-in-glass thermometers were inserted at the inlet and exhaust end of the dryer for measuring the dry bulb and wet bulb temperatures of incoming and outgoing air to the dryer. These two temperatures were used to determine the relative humidity of inlet and exhaust air. Relative humidity of the drying air, calculated by using a psychrometric chart was also verified with the help of a hair hygrometer. Two thermocouples for measuring the product and air temperature were placed in the drying chamber and connected to a digital temperature indicator.

The air velocity at the product surface in the drying chamber was measured by using a pre-calibrated anemometer. Three circular holes of 20 mm diameter each provided on the front door panel of the dryer were used for inserting the sensing probe of anemometer. During the drying operation these holes were kept closed by using rubber corks.

Table 3.4 Different air temperatures and relative humidities (RH) maintained inside the dryer

Air type	Initial codition		Air condition after heating		
	Temperature, °C	Relative Humidity, %	Temperature, °C		
			45	55	65
			Relative humidity, %		
Ambient	31	85	40	25	15
Dehumidified	42	30	26	16	10
Mixed (ambient + dehumidified)	40	45	35	21	13

3.7.2 Levels of input variables

The foam-mat drying process is normally influenced by the number of variables, such as foam density, foam thickness (tray loading rate) as well as the temperature, velocity and humidity of the drying air. In the present investigation the levels of these variables were either taken from the literature or decided on the basis of the results of preliminary experiments.

The foam density maintained during experimentation was in the range of 590 to 620 kg m^{-3}. A foam thickness of 3.1 mm had been suggested by earlier workers for drying of several foods and other products (Morgan *et al.*, 1959; Morgan *et al.*, 1961a; Ginnette *et al.*, 1963 and Komanowsky *et al.*, 1964). In the present study a foam thickness of 3 mm was maintained. The levels of relative humidity of the drying air were selected on the basis of the ambient air condition and the capability of the dehumidifier. The other two variables, *viz.*, temperature and the velocity of the drying air, were fixed on the basis of the observations made during the preliminary experiments. In order to find out the upper limit of these two variables, the stability of the foam was considered. During drying, it was essential that the foam reduce its thickness gradually. Air at very high temperature and velocity resulted in collapse of the foam. The maximum levels of air temperature and velocity at which the foam remained stable were 65°C and 2.0 m s^{-1}, respectively. Accordingly three temperatures (45, 55 and 65°C) and three velocities (1.0, 1.5 and 2.0 ms^{-1}) were chosen for the experiments.

3.7.3 Experimental technique and procedure

The dryer was operated for some time to stabilize the air conditions at the desired level. The observed variations of the set values in the dryer were ± 1°C, ± 1.5% and ± 10% for temperature, relative humidity, and air velocity, respectively. The foamed tomato concentrate was spread (1.8 kg m^{-2} foam) on each tray to a thickness of 3 mm over an area of 100 × 100 mm (Fig. 3.12). In order to prevent sticking and facilitate easy removal of the material after drying, the trays were lined with 90 μm thick polyethylene sheet. Once the desired air conditions were attained in the dryer, three trays with the sample were loaded into the drying chamber. The clearance between the trays was kept at 50 mm. The door of the dryer was properly closed to prevent air leakage.

To monitor the weight loss during drying the trays were taken out of the dryer at regular intervals, weighed by using an electronic balance and quickly replaced inside the dryer. It was assumed that the brief interruptions (less than 30 s) did not interfere with the drying process. The intervals maintained were 5 min for the first 20 min, 10 min for the following hour, 20 min for the next hour and 30 min for the rest of the drying period. The experiments were continued till the dried product attained constant weight. The product temperature during the experiments was recorded at regular intervals. Moisture content (%, db) of the product at different stages of the drying process was calculated and that of the final product was determined by drying in a vacuum oven at 70°C and 450 mm Hg pressure. All the experiments were replicated thrice.

3.7.4 Analysis of dehydrated tomato juice

Immediately after drying, samples (5-10 g) of dehydrated tomato juice were collected in self sealing polyethylene (90 μm) bags and placed inside a desiccator kept under dark until analyses. These samples were anlysed for their chemical constituents, *viz.*, sugars, acidity, ascorbic acid and lycopene contents within 5-6 h after drying.

3.7.5 Conditioning and Grinding

The dried samples immediately after termination of the air drying operation were placed alongwith the trays in a desiccator containing calcium chloride as desiccant and stored in a refrigerator maintained at 10 ± 1°C temperature. Within about 1.5 h the samples attained thermal equilibrium with the environment. The samples were then immediately

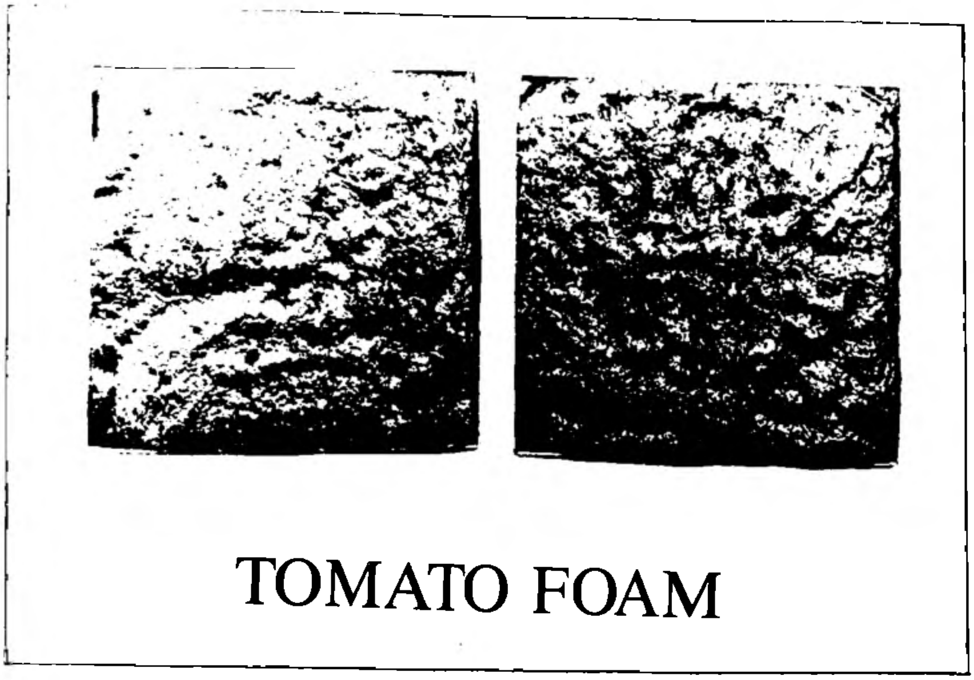


Fig. 3.12 Tomato foam spread on trays

ground in a domestic kitchen grinder in about one minute. The powdered product, thusobtained, was collected and used for analytical and storage studies.

3.7.6 Experimental design and statistical analysis

A three-factor factorial design with three levels of each variable was used. The three independent variables (factors) were drying air temperature (T_d), air velocity (V_a) and relative humidity (Rh_d) of the drying air. The complete design included 27 experiments. **Table 3.5** shows the experimental plan alongwith the actual and coded values (**Eqn. 3.11**) of the parameters used. The treatment combinations were tested in random order. Response surface methodology (RSM) was used to estimate the effect of process variables on drying rate and quality of the dried product.

3.7.5 Estimation of Moisture Diffusivity

Moisture diffusivity (D) represents the overall transport property of the moisture in the material. Diffusion-controlled mass transfer is assumed when the vapour or liquid flow conforms to Fick's law of diffusion (Porter *et al.*, 1984). The unsteady-state-diffusion process can be represented as:

$$\frac{\delta c}{\delta \theta} = D_{AB} \left[\frac{\delta^2 c}{dr} \right] \qquad \dots (3.15)$$

where,

c = concentration of moisture A at a distance r in a two component system of A and B,

θ = diffusion time,

r = distance in the direction of diffusion, and

D_{AB} = diffusivity of moisture A in B.

The moisture content, M of a material in the form of a thin slab during the falling-rate drying can be derived from (**Eqn. 3.15**) when the surface of the material is assumed to have attained the equilibrium moisture M_e with the environment and the initial moisture distribution in the slab is uniform at M_c. Under these conditions, the following equation is obtained (Porter *et al.*, 1984).

Table 3.5 Experimental design showing actual and coded values of the variables used for foam-mat drying of tomato concentrate

Expt. No.	Temperature, °C		Relative humidity, %		Velocity, m s^{-1}	
	Actual	Coded	Actual	Coded	Actual	Coded
1	45	-1	40	1	1.0	-1
2	45	-1	35	0.667	1.0	-1
3	45	-1	26	0.067	1.0	-1
4	45	-1	40	1	1.5	0
5	45	-1	35	0.667	1.5	0
6	45	-1	26	0.067	1.5	0
7	45	-1	40	1	2.0	1
8	45	-1	35	0.667	2.0	1
9	45	-1	26	0.067	2.0	1
10	55	0	25	0	1.0	-1
11	55	0	21	-0.267	1.0	-1
12	55	0	16	-0.6	1.0	-1
13	55	0	25	0	1.5	0
14	55	0	21	-0.267	1.5	0
15	55	0	16	-0.6	1.5	0
16	55	0	25	0	2.0	1
17	55	0	21	-0.267	2.0	1
18	55	0	16	-0.6	2.0	1
19	65	1	15	-0.667	1.0	-1
20	65	1	13	-0.8	1.0	-1
21	65	1	10	-1	1.0	-1
22	65	1	15	-0.667	1.5	0
23	65	1	13	-0.8	1.5	0
24	65	1	10	-1	1.5	0
25	65	1	15	-0.667	2.0	1
26	65	1	13	-0.8	2.0	1
27	65	1	10	-1	2.0	1

$$\frac{M - M_e}{M_c - M_e} = \frac{8}{\pi^2}\left[\sum_{n=0}^{n=\infty} \frac{1}{(2n+1)} e^{-[(2n+1)\pi/2]^2 D\theta/a^2}\right] \quad \text{... (3.16)}$$

where,

M = average moisture content at any time θ, % (db)
M_c = moisture content at the start of falling-rate period, % (db)
M_e = equilibrium moisture content, % (db)
D = moisture diffusivity, m^2/s
θ = time of drying in falling rate period, s, and
a = thickness of the slab, m

In the presence of constant drying rate period the value of M_c will be taken as the critical moisture content (M_c) of the material, whereas in its absence the initial moisture content (M_i) will be considered.

Equation (2) is based on the assumptions that D is constant; however, D is rarely constant but varies with moisture content, temperature, and humidity (Porter *et al.*, 1984). For long drying times and when $D\theta/a^2 > 0.2$, **Eqn. (3.16)** simplifies to a limiting form as:

$$\frac{M - M_e}{M_c - M_e} = \frac{8}{n^2}\left[e^{-D\theta(\pi/a)^2}\right] \quad \text{... (3.17)}$$

Eqn. (3.17) is further simplified to a straight line form as :

$$\ln\left|\frac{M - M_e}{M_c - M_e}\right| = \ln\left|\frac{8}{n^2}\right| - \frac{\pi^2}{a^2}D\theta \quad \text{... (3.18)}$$

By plotting $(M - M_e)/(M_i - M_e)$ on ordinate and θ on abscissa on a semilogarithmic graph paper, a straight line is obtained for values of $(M - M_e)/(M_i - M_e) < 8/\pi^2$. It may be noted that **Eqn. (3.18)** is applicable when the value of $\theta > 0.2\ a^2/D$.

From the known values of average moisture diffusivity and equilibrium moisture content the time required for drying foamed tomato concentrate mats can be calculated by rearranging the terms of **Eqn. (3.19)** as follows:

$$\theta = \frac{a^2}{D\pi^2}\left| \ln \frac{8}{n^2} - \ln \frac{(M - M_e)}{(M_i - M_e)} \right| \qquad \ldots (3.19)$$

3.8 Process Technology for Preparation of Dehydrated Tomato Juice Powder

Based on the results obtained at different stages of investigation *viz.*, juice extraction, concentration of juice, foaming of concentrate, air drying, cooling/conditioning and conversion into powder, a process technology for the preparation of dehydrated tomato juice powder was developed and a material balance was worked out. Experiments were conducted to prepare tomato powder using optimum process parameters. The experimental and theoritical data were compared. The powder obtained was analysed for various physico-chemical properties, like moisture content, ascorbic acid, lycopene, acidity, sugars and colour values, and the rehydration characteristics were determined using standard method.

3.9 Storage of Tomato Powder

Tomato powder was stored under accelerated condition of 38°C temperature and 90% RH in packets made of different flexible packaging materials. Three types of packaging materials, *viz.*, biaxially oriented polypropylene (BOPP), saran and metallised polyester/adhesive coextruded LD/LLD/HD, were used. The specifications like water vapour transmission rate (WVTR), oxygen transmission rate (OTR) and thickness of these packaging materials are given in **Table 3.6**.

Table 3.6 **Specifications of packaging materials used in the storage study of tomato powder**

Packaging material	Thickness (μm)	WVTR (g m^{-2} day^{-1} Pa^{-1})	OTR (cm^3 m^{-2} h^{-1} atm^{-1}) at 20°C
Biaxially oriented polypropylene (BOPP)	40	5.54×10^{-4}	56.00
Saran	100	2.85×10^{-4}	0.42
Metallised polyester/adhesive coextruded LD/LLD/HD (MPC)	112	nearly zero	nearly zero

WVTR = Water vapour transmission rate

OTR = Oxygen transmission rate measured as volume transmitted at normal temperature and pressure

Packets measuring 70 mm width were made from each of the above types of packaging materials using a heat sealing machine. A polyethylene tube (5 mm diameter and 75 mm long) was fixed at one corner of the packet close to the open end of the packet. Tomato powder (15 g) was filled into the packet and heat sealed immediately. The polyethylene tube was then connected to a vacuum pump, and the air inside the package was evacuated. The tube was then closed tightly with the help of a pinch-cock and the vacuum pump was disconnected. Sufficient care was taken to ensure that the powder does not gain moisture from the surrounding atmosphere during packaging. The packet so prepared was then resealed just below the polyethylene tube which divided the packet into two parts. The portion with the polyethylene tube was cut off. The final dimensions of the packet came out to be 80 × 70 mm (effective surface area, 0.0112 m^2). A pictorial view of the three different types of packets containing tomato powder is shown in **Fig. 3.13**.

The packets containing the tomato powder were placed inside a desiccator which was maintained at 90±1% relative humidity using saturated solution of potassium nitrate (Rockland, 1960). In order to prevent the effect of light on the storability of tomato powder, the desiccator was painted black. The desiccator containing the packets was placed in an incubator maintained at 38±0.5°C.

During the storage period of 90 days, two packets from each group of the packaging materials were withdrawn at intervals of 5, 10, 15, 20, 30, 45, 60 and 90 days for evaluating physico-chemical as well as organoleptic properties of the powder. Moisture, ascorbic acid and lycopene contents of the powder were determined using standard methods (**Sec.3.10**). The colour values were measured after reconstituting the samples in warm water to a concentration nearly equal to that of original juice (5.5-6.0°B).

Stored powder samples (3-4 g) were reconstituted to the single strength juice (5.5-6°B) using lukewarm water. The reconstituted juice in 100 ml glass beakers was evaluated by a panel of 10 trained judges comprising students and staff of the department of Agricultural and Food Engineering, IIT Kharagpur. Taste, smell/odor, colour, flavour and overall acceptability were judged using a nine-point hedonic scale (ISI, 1971b). Samples scoring 1 were rated as disliked very much, while those scoring 9 as liked very much. The score record sheet used is given in **Appendix - F-3** (Ranganna, 1995). Fresh juice was used to orient the panelists about the typical quality characteristics of fresh tomato. Since the purpose of the study was to find out the storage life of the powder, the sensory data pertaining to fresh juice were omitted. Data obtained were analysed statistically for their variance.

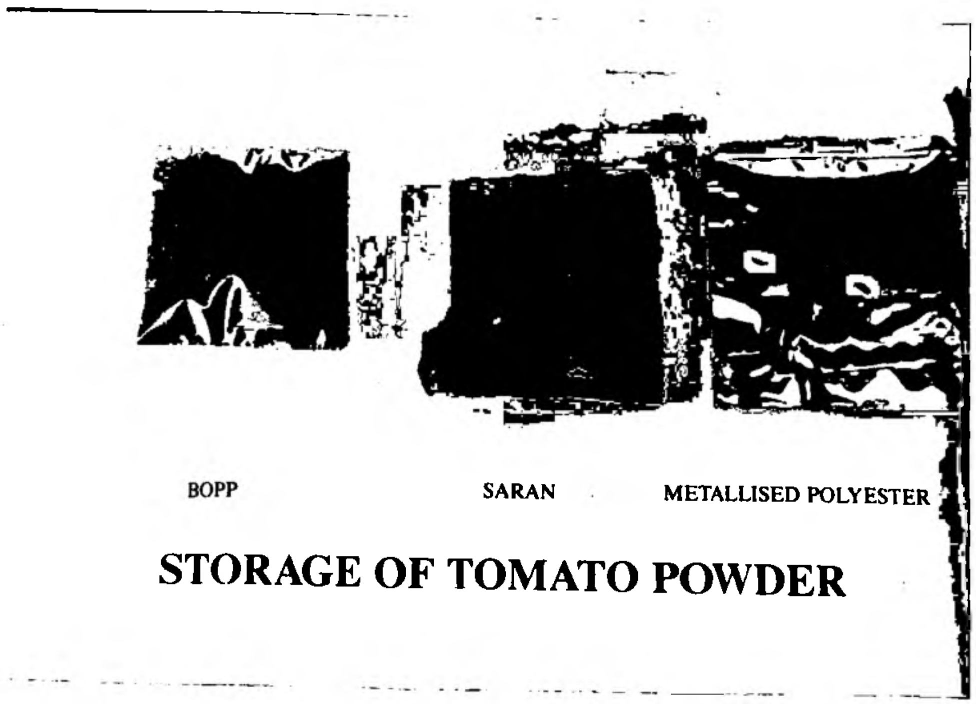


Fig. 3.13 Tomato powder packed in different packaging materials for storage

3.9.1 Moisture content of powder during storage

Moisture content of tomato powder during storage was predicted theoretically using the method described by Karel (1975c) which assumes the sorption isotherm to be a straight line (Eqn 3.21) within a small range of moisture content.

$$M = \sigma_1 a_w + \sigma_2 \qquad \ldots(3.20)$$

where, M is the moisture content in g water/g solids, a_w is the water activity and, σ_1 and σ_2 are the constants.

Moisture content, M of the powder after a storage period θ_S was calculated by Eqn. 3.22.

$$\ln\left[\frac{M_e - M_i}{M_e - M}\right] = \frac{K_p A p^o}{S_T \sigma_1} \qquad \ldots (3.21)$$

where, M_i, M are the moisture contents of powder at 0 and θ_S days; M_e is the equilibrium moisture content at storage condition in g water/g solids; K_p is the water vapour transmission rate of the packaging material in g m^{-2} day^{-1} Pa^{-1}; p^o is the water vapour pressure at storage condition in Pa; A is the packaging area in m^2; S_T is the weight of solids in tomato powder in g and σ_1 is a constant obtained freom linear approximation of sorption isotherm (Eqn. 3.21).

3.10 Analytical and other Methods

Standard analytical and other methods of analysis were used to determine various physico-chemical properties and quality attributes of whole tomato as well as its products (*viz.*, juice, concentrate and powder) at different stages of investigation. Reconstitution of the concentrate/powder nearly equal to single strength (5.5-6.0°B) was done by additing calculated quantity of distilled water to the known quantity of concentrate/powder and stirred well. For powder lukewarm water was used whereas reconstitution of concentrate was done with water at room temperature. The methods are briefly described in the following paragraphs.

3.10.1 Moisture content

Vacuum oven drying method as described by Ranganna (1995) was used to determine the moisture content. Samples (3-5 g) in triplicate were dried to an apparent dryness in a vacuum oven at 70°C at vacuum level not exceeding 450 mm Hg and subsequently the oven was maintained at 70°C and 100 mm Hg until the differences between two consecutive weighings were not more than 1 mg. The loss in weight was expressed as per cent on wet basis for the juice/concentrate and on dry basis for dehydrated juice (powder). Total solids (TS) content was calculated by subtracting the moisture content from 100.

3.10.2 Total soluble solids

Contents of total soluble solids (TSS) in fresh juice/concentrate/reconstituted juice samples were determined using a hand refractometer. A few of these observations were checked also by an Abbe refractometer.

3.10.3 Insoluble solids

A known weight of sample was diluted with hot distilled water and centrifuged. The supernatant liquid was filtered under suction in a Buchner funnel using previously dried (100°C for 2 h) and weighed filter paper (Whatman No. 1). The washing, centrifuging and filtration was repeated 4 to 5 times. The used filter paper was dried for 2 h at 100°C. Weight of the insoluble solids was obtained by subtracting the initial weight of the filter paper and was expressed as per cent of the total solids content of the sample (AOAC, 1984).

3.10.4 Colour

The colour of the juice, concentrate and dehydrated juice (powder) was directly measured by using a Lovibond Tintometer and expressed in red, yellow and blue units (Das, 1992; Reddy and Das, 1993). The colour of the juice was matched with a certain combination of red (R'), yellow (Y') and blue (B') coloured filters alongwith the suitable brightness. Samples of concentrated/dehydrated juice were diluted to 5.5°B (equivalent to original juice) with warm distilled water and the observations were taken as above. The apparent colour value, A' was given by

$$A' = (R' + Y' + B') \qquad \ldots(3.22)$$

where R', Y' and B' are the tintometer values of red, yellow and blue colours in Tintometer units (TU).

The colour, C' was calculated as

$$C' = A' \times Brightness \qquad \text{...(3.23)}$$

In order to study the colour development during the concentration process, the rate constant $k_{T'}$ was estimated from a straight line plot between ln C' and concentration time, θ_c (Reddy and Das, 1993). The effect of concentration temperature, T_c on the rate constant, $k_{T'}$ was represented by the Arrhenius type equation (Kessler, 1981).

$$K_T = A \exp\left[Ea/R\left(T_c + 273\right)\right] \qquad \text{...(3.24)}$$

where, Ea is the activation energy, kJ kg^{-1} $mole^{-1}$; R is the universal gas constant (8.314 kJ kg^{-1} $mole^{-1}$ $°K^{-1}$); T_c is the concentration temperature, °C; and A is a constant. The value of Ea was obtained from the slope of the straight line plot between ln $k_{T'}$ and $1/(T_c+273)$. The effect of temperature on $k_{T'}$ is also represented by Q_{10}, the value of which was determined from **Eqn. (3.23)**.

$$Q_{10} = 10^{10/z} \qquad \text{... (3.25)}$$

where, z is obtained from a straight line plot of log $(2.303/k_{T'})$ and T_c. The slope of the line is (- 1/z).

3.10.5 Density

The density of tomato juice and concentrate was determined by using a specific gravity bottle (50 ml) as described by Ranganna (1995).

3.10.6 pH and acidity

The pH of the juice and concentrate samples was determined with the help of a digital pH meter capable of giving 0.01 least count following the method described in AOAC (1984).

Acidity of the juice/concentrate/powder (dehydrated juice) was determined by the method described by Ranganna (1995).

Known weight of sample was mixed with freshly boiled and cooled distilled water, filtered through Whatman No. 4 filter paper and diluted to a known volume. The filtrate was titrated with 0.1 N sodium hydroxide using phenolphthalein as indicator and the acidity was calculated using the following formula:

$$\text{Acidity as anhydrous citric acid (\%)} = \frac{Titre \times Normality\ of\ alkali \times 64 \times Volume\ made\ up \times 100}{Volume\ of\ filtrate\ taken\ for\ titration \times Weight\ of\ sample \times 1000}$$

(where 64 is the equivalent weight of citric acid)

3.10.7 Ascorbic acid

Ascorbic acid was determined by the 2,6-dichlorophenol indophenol dye titration method (AOAC, 1984). Five to seven grams of juice/concentrate (2 g in case of powder) was dissolved in 100 ml of 3% metaphosphoric acid. Known quantity of this solution was titrated with the standard dye solution and ascorbic acid as mg/100 g of the sample was calculated as follows:

$$\text{Ascorbic acid (mg/100 g of sample)} = \frac{Titre\ value \times Dye\ factor \times Volume\ made\ up \times 100}{Aliquot\ of\ extract\ taken\ for\ titration \times Weight\ or\ volume\ of\ sample}$$

Dye factor is mg of ascorbic acid per ml of dye. This was estimated by standardizing the dye before titration with standard acid solution (AOAC, 1984).

3.10.8 Lycopene

Optical density of petroleum ether extract of the total carotenoids present in samples was measured at 503 nm with the help of a spectrophotometer and the lycopene content was calculated using the following formula for an optical density (OD) of 1.00 = 3.1206 μg of lycopene per ml (Ranganna, 1995).

$$\text{Lycopene (mg/100 g of sample)} = \frac{3.1206 \times OD\ of\ sample \times Volume\ made\ up \times Dilution \times 100}{Weight\ of\ sample \times 1000}$$

3.10.9 Sugars

Contents of sugars in the juice/concentrate and powder (dehydrated juice) samples were estimated by determining the volume of clarified solutions required to completely reduce the measured volume of Fehling solution (A+B, 1:1) using the Lane and Eynon method described by Ranganna (1995). Total sugars were calculated as invert sugars after inversion. The formulae used were as follows:

$$\%\ \text{Reducing sugars} = \frac{\text{mg of invert sugar} \times \text{Dilution} \times 100}{\text{Titre value} \times \text{Weight or volume of the sample} \times 1000}$$

% Total sugars = Per cent reducing sugars making use of the titre inverted sugars value obtained in the determination of total sugars after inversion.

% Sucrose = (% Total invert sugars - % Reducing sugars originally present) × 0.95

% Total sugars = (% Reducing sugars + % Sucrose)

3.10.10 Ash

Partially dried juice/concentrate samples were kept in a muffle furnace at 500°C for 6 h; whereas the dehydrated juice sample was directly kept at the above mentioned temperature for the same time. The difference in weight was estimated as the total ash content of the sample (Ranganna, 1995).

3.10.11 Protein

The protein content of tomato was determined following the microkjeldahl method described by Ranganna (1995). Tomato samples (10-15 g) were digested with concentrated sulphuric acid using copper sulphate and potassium sulphate mixture as oxidation catalysts. The digests were then distilled in the micro Kjeldahl distillation apparatus using 40% sodium hydroxide solution. Liberated ammonia was collected in 2% boric acid solution and titrated against 0.1 N hydrocholoric acid. Nitrogen content in the samples was calculated by the formula given below. The protein content was found out by multiplying with nitrogen to protein conversion factor of 6.25 for plant materials.

$$\text{Nitrogen, }\% = \frac{\left[\begin{matrix}\text{Simple}\\ \text{titre}\end{matrix} - \begin{matrix}\text{Blank}\\ \text{titre}\end{matrix}\right] \times \begin{matrix}\text{Normality of}\\ \text{hydrochloric acid}\end{matrix} \times 14 \times \begin{matrix}\text{Volume made up}\\ \text{of the digest}\end{matrix} \times 100}{\text{Aliquot of the sample} \times \text{Weight of the sample taken} \times 1000}$$

Protein, % = Nitrogen per cent × 6.25

3.10.12 Fat

The fat content in the samples were determined using Sochlet continuous extraction method (Ranganna, 1995). Five to seven grams of samples were extracted with hexane for 8-10 h and per cent fat was calculated.

3.10.13 Solubility

The determination of the solubility of the powder was carried out by adding 5 g material to 125 ml distilled lukewarm water at 45°C (Al-Kahtani and Hassan, 1990). The mixture was agitated with a magnetic stirrer at position 5 (maximum). The time required for material to dissolve completely was recorded.

CHAPTER - IV

RESULTS AND DISCUSSIONS

This chapter deals with the results obtained during different stages of the study and inferences drawn thereof. Results have been compared with the published work and deviations from general trends are explained wherever possible.

4.1 Physico-chemical Properties of Tomato

Data on some important physical properties of tomato fruits (cv. *Pusa Ruby*) used in this study are presented in **Table 4.1**.

Table 4.1 Physical properties of tomato fruits (cv. *Pusa Ruby*)

Characteristics	Minimum	Maximum	Mean*	Standard deviation
Weight, g per fruit	40.05	108.15	70.10	14.87
Size, mm (Equivalent diameter)	42.92	59.00	50.00	3.71
Sphericity	0.787	0.955	0.91	0.042
True density, kg m^{-3}	948.00	998.00	981.00	14.00
Skin, %	2.70	4.60	3.50	0.50
Seed, %	6.33	8.23	7.47	0.48

* Average of 7 replications

Weight of the fruits varied from 40.05 to 108.15 g and equivalent diameter from 42.96 to 59 mm, the averages being 70.1 g and 50 mm per fruit, respectively. The values for weight and equivalent diameter were found to be smaller than the values reported by Satwadhar *et al.* (1988) and higher than those reported by Gowda *et al.* (1994) for the same variety of tomatoes. From the average values of weight and equivalent diameter the fruits used in the present study could be graded as of medium size (Madaiah *et al.*, 1986; Satwadhar *et al.* 1988). The sphericity of the fruits ranged between 0.787 and 0.955 with an average value of 0.91, approaching close to 1. This suggested nearly round shape of the fruits (Mohesenin, 1970). Many researchers (Kaur, *et al.*, 1975; Sethi and Anand, 1982) have earlier designated *Pusa Ruby* as a round shaped variety. Fruit shape is a characteristic of the tomato cultivars (Kasrawi *et al.*, 1981). The true density of the fruits varied between 948 and 998 kg m^{-3} with the average value being 981 kg m^{-3}. True density was found to be in the same range as reported by Satwadhar *et al.* (1988) for many other varieties of tomato. The average values of the skin and seed content were found to be 3.5 and 7.47 per cent respectively on the basis of whole tomato. The combined weight of skin and seed was slightly higher than the values reported by Shibli *et al.* (1996) for four different varieties of tomatoes.

The values of some important physico-chemical constituents of tomato used in the study are presented in **Table 4.2**.

Table 4.2 Some important physico-chemical constituents of tomato fruit (cv. *Pusa Ruby*)

Constituents	Mean*	Standard deviation
Total solids, %	7.22	0.51
Total soluble solids, °B	5.5	0.91
pH (whole juice)	4.23	0.11
Acidity, % (citric acid)	0.6	0.035
Fat, %	0.15	0.015
Protein, %	1.16	0.067
Ash, %	0.59	0.027
Ascorbic acid, mg/100 g	21.54	1.12
Lycopene, mg/100 g	4.45	0.34
Sugars		
Reducing sugars, %	2.65	0.21
Total sugars, %	3.90	0.22

* Average of 7 replications

The total solids (TS) content varied from 6.45 to 8.34 % (mean, 7.22%) which was close to the value reported by Kaur *et al.* (1975 and 1976), but was higher than those reported by Sethi and Anand (1982) for the same variety. Out of 7.22% TS, about 1% was due to skin and seed (0.31 and 0.653% respectively). This was in agreement with the values reported by Narkivoraj and Ranganna (1976). The pH of the juice was found to vary from 4.00 to 4.23 and acidity ranged between 0.55 to 0.66% citric acid, the average values being 4.23 and 0.60% citric acid, respectively which were comparable to earlier reports in the literature (Sethi and Anand, 1982; Nanjunda Swami *et al.*, 1983).

Average values of proteins, fat and ash contents were found to be 1.16, 0.15 and 0.59%, respectively. The values of fat and ash contents were comparable with the values reported by Shibli *et al.* (1996) for four different varieties of tomatoes, whereas the value of proteins was a little lower than those reported by Shibli *et al.* (1996).

The average value of ascorbic acid being 21.54 mg/100 g of fruit was comparable with those reported by Singh *et al.* (1983). The values for the ascorbic acid content in tomato fruits found in the present study were, however, higher than those reported by Gowda *et al.* (1994) and lower than those of Radhakrishnaiah Setty *et al.* (1987) for the same variety. The lycopene content varied between 3.90 to 4.88 mg/100 g, the average being 4.45 mg/100 g of the fruit which was comparable with the value reported by Radhakrishanaiah Setty *et al.* (1987) for the same variety. Similar values of lycopene content were also reported earlier for many other varieties of tomato (Balasubramanian, 1984; Madaiah *et al.*, 1986; Saini and Singh, 1994). Total sugars content in tomato varied between 3.60 to 4.15% (mean, 3.90%). Of these, approximately 68% was found to be reducing sugars. The values of reducing sugars were found to differ with the values reported by Singh *et al.* (1983), however, it represented almost 50% of the total soluble solids of the tomatoes, which was in agreement with the values reported by Goose and Binsted (1964).

The recorded difference in some of the attributes from those reported in the literature might be due to the variations in factors such as agronomic practices, and agroclimatic regions, *etc.*

4.2 Tomato Juice

Table 4.3 shows some important physico-chemical properties and quality attributes of the cold-break extracted juice (CBEJ) and hot-break extracted juice (HBEJ).

It can be seen from the table that there was not much difference in total soluble solids, pH, density and sugars contents of the juices prepared by the cold and hot-break methods. The total yield of the juice was found to be higher by 5.20% in the hot-break than in the cold-break method.

The recovery of total solids on the basis of total solids of whole tomato was also higher in the hot-break method (86.6%) as compared to that of the cold-break method (79.6%). This was perhaps due to the heat treatment given to tomatoes prior to juice extraction. Bhasin and Bains (1987) had reported an increase of 2.5 to 8% juice yield in the hot-break method as compared to cold-break method while evaluating two varieties of tomato.

Table 4.3 **Some important physico-chemical characteristics and quality attributes of tomato juice extracted by cold-break and hot-break methods**

Attributes/characteristics	CBEJ*	HBEJ*
Yield, %	81.00	86.20
Total solids, %	5.75	6.25
Total soluble solids, °B	5.50	5.50
Density, kg m^{-3}	1032.00	1025.00
Colour, TU	47.00	52.20
Insoluble solids, %	0.26	0.72
pH	4.10	4.25
Acidity, % (citric acid)	0.60	0.56
Ascorbic acid, mg/100 g	22.55	20.95
Lycopene, mg/100 g	3.22	4.10
Sugars		
Reducing sugars, %	2.60	2.62
Total sugars, %	3.80	3.82
Protein, %	-	0.55
Ash, %	0.45	0.50

* Average of 7 replications CBEJ - Cold-break extracted juice

TU Tintometer unit HBEJ - Hot-break extracted juice

Higher value of total solids in HBEJ was mostly contributed by the insoluble solids indicating that the loss of insoluble solids through the skin and seeds was more in case of CBEJ. Higher values of total solids content in HBEJ may be due to the transfer of pectic substances (pectins) from seed and skin into juice because of heating (Lal *et al.,* 1990).

The lycopene content of HBEJ (4.10 mg/100 g) was also found to be more than that of CBEJ (3.22 mg/100 g). Of the 4.45 mg/100 g (average) of total lycopene in whole tomato the HBEJ contained about 92%, whereas it was only 72.3% in CBEJ. The higher value of lycopene content in HBEJ may be because of the release of the pigment from the skin due to the heat treatment (Lal *et al.*, 1990). Bhasin and Bains (1987) reported nearly equal values of lycopene content in both HBEJ and CBEJ. Similarly, the colour value (tintometer units) of the HBEJ was found to be more than that of the CBEJ. On the other hand, ascorbic acid content of HBEJ was found to be slightly lower by 1.5% as compared to that of the CBEJ. The acidity also decreased slightly in HBEJ. In addition, protein content of 0.55 % was estimated in HBEJ, whereas in CBEJ, it was found to be in traces.

The results indicated superiority of the hot-break method of juice extraction over the cold-break one in terms of juice yield, total solids, lycopene and protein contents. In an earlier study (Kjaegaard, 1974) hot-break extracted juice had been found better for preparation of powder as the powder prepared from the cold-break extracted juice had less desirable characteristics on reconstitution . The hot-break extracted juice was, therefore, used for subsequent studies on concentration and dehydration.

4.3 Concentration of Tomato Juice

Experimental values pertaining to some important physico-chemical changes in `hot-break' tomato juice during vacuum concentration is given in **Appendix A (Table A-1)**. Statistical analysis of the experimental data (**Table A-1**) is presented in **Table 4.4**.

4.3.1 Effect of process variables on physico-chemical properties

Regression analysis was done for each of the response variables after coding the values of the independent variables, *viz.*, concentration time (θ_c) and temperature (T_c) between -1 and 1 using **Eqn. (3.11)**. The effect of process variables on different physico-chemical properties, *viz.*, total soluble solids, total solids, pH, acidity, ascorbic acid, lycopene, inversion of sugars and change in colour of tomato concentrate is discussed in the following paragraphs.

Total soluble solids

The effect of temperature and time on total soluble solids (TSS) of tomato juice during concentration is shown in **Fig. 4.1**. The increase in TSS followed a linear relationship for greater part of the time except at the end of the cycle where its rate of increase was very low. At 45°C the juice could be concentrated upto 25°B only, whereas it was possible to concentrate upto 33.5°B at 75°C.

Table 4.4 Analysis of variance for different physico-chemical properties of tomato concentrate

Source of variation	Degrees of freedom	Statistics	Mean sum of squares and F_{cal}						
			TSS	pH	Acidity	Ascorbic acid	Lycopene	Reducing sugars	Colour
Concentration time, θ_C (X_1)	1	MSS	882.4	$0.,3\times10^{-2}$	0.01	0.2	0.03	362.6	224.9
		F_{cal}	536.6**	27.8**	4.51*	240.8**	123.1**	254.9**	1666.2**
Concentration temperature, T_C (X_2)	1	MSS	649.4	0.14×10^{-1}	0.17×10^{-3}	0.1	0.1	304.6	119.8
		F_{cal}	422.3**	11.7**	0.1^{NS}	140.8**	267.5**	214.1**	888.0**
X_1^2	1	MSS	3.1	0.72×10^{-2}	0.1	0.01	0.9×10^{-3}	41.18	0.1
		F_{cal}	1.9^{NS}	6.2	38.9**	25.5**	4.7*	29.0**	1.0^{NS}
X_2^2	1	MSS	10.5	0.14×10^{-2}	0.84×10^{-3}	0.02	0.68×10^{-2}	7.5	0.1
		F_{cal}	6.4*	5.3*	0.4^{NS}	39.6**	34.4**	5.3*	1.0^{NS}
$X_1\times X_2$	1	MSS	239	0.62×10^{-2}	0.1	0.02	0.02	96	51.6
		F_{cal}	145.4**	1.2^{NS}	0.5^{NS}	42.2**	78.0**	67.5**	382.5**
Error	33	MSS	1.65	0.12×10^{-2}	0.23×10^{-2}	5.2×10^{-4}	0.20×10^{-5}	1.42	0.14
Total	38								

** Significant at 1% level
* Significant at 5% level
^{NS} Non significant

The time required to achieve juice concentration of 25°B at 45°C and 33.5°B at 75°C were 240 min and 75 min, respectively. Beyond these periods, the rate of increase in concentration was very small. Moreover, the material started sticking to the vessel surface and could not be agitated easily.

The statistical analysis of data indicated that both concentration temperature and concentration time significantly affected the TSS at 1% level. The linear multiple regression equation in terms of coded variables (Eqn. **4.1**) shows the relationship between the response TSS and the independent variables. From the coefficients of the independent variables, *viz.*, concentration time (X_1) and concentration temperature (X_2) it is clear that the contribution due to X_1 was more pronounced than that due to X_2. The coefficient of determination ($r^2 = 0.79$) of **Eqn. (4.1)** being low, the experimental data were refitted to a second-order polynomial equation (Eqn. 4.2) which significantly improved the coefficient of determination ($r^2 = 0.98$). After decoding the variables in terms of actual values using **Eqn. (3.11)**, the **Eqn. (4.2)** can be used for prediction of TSS in the concentrate.

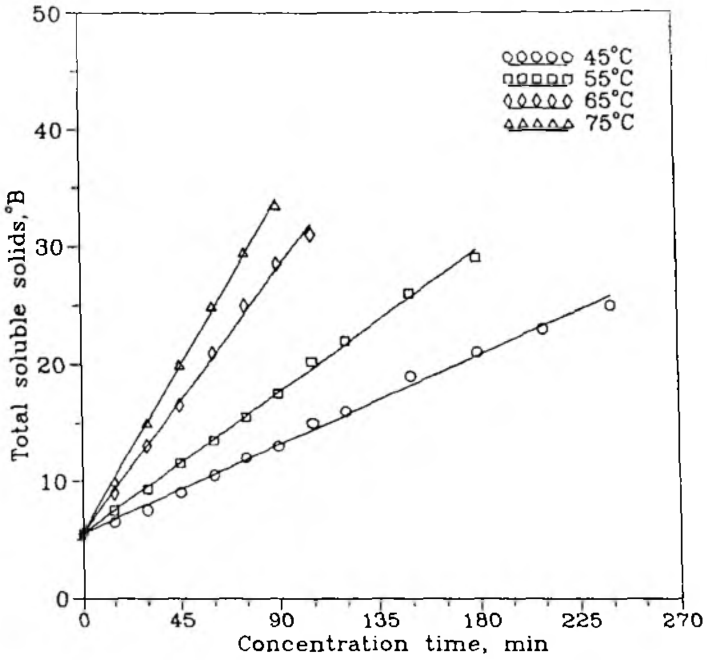


Fig. 4.1 Variation in concentraion of tomato juice with concentration time at different temperatures

$$TSS = 23.51 + 14.69X_1 + 6.85X_2 \quad (r^2=0.79) \qquad \ldots (4.1)$$

$$TSS = 27.8 + 21.49\,X_1 + 13.25\,X_2 + 11.99\,X_1X_2 + 1.25\,X_2^2 \quad (r^2=0.98) \qquad \ldots (4.2)$$

where, TSS is total soluble solids in °B, and X_1 and X_2 are the coded values of the concentration time and temperature, respectively.

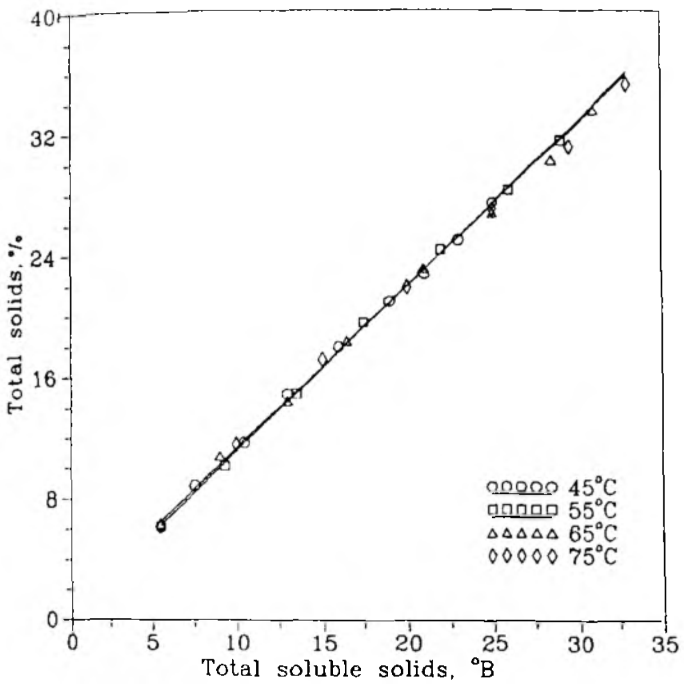


Fig. 4.2 Relationship between total soluble solids (°B) and total soilds (%) of tomato concentrate

The relationship between total soluble solids (TSS) and total solids (TS) is shown in **Fig. 4.2**. It is clear from the figure that the TSS and TS in tomato juice/concentrate were linearly related to each other. Further, the relationship between TSS and TS at any time was found to be independent of concentration temperature and time. A good coefficient of determination (r^2 =0.99) existed between TSS and TS (**Eqn. 4.3**).

$$TS = 0.794 + 1.052\,TSS \quad (r^2 = 0.99) \qquad \ldots (4.3)$$

where TS is the total solids in per cent and TSS is the total soluble solids in °B.

pH and acidity

The pH of tomato juice concentrates ranged from 4.20 to 4.30. A slight increase in the pH was observed during early stages of the concentration process followed by constant pH with increase in concentration at all the temperatures.

The acidity of the juice (9% as citric acid, total solids basis) decreased slightly with concentration. The average decrease in acidity was found to be 3.5% in concentrated juice on moisture free basis. According to Bauman (1979) the slight decrease in acidity may be due to the loss of volatile acids. The pH and acidity of the tomato juice concentrate were found to be independent of process variables, *viz.*, time and temperature. The observations pertaining to pH and acidity were in agreement with the results of Sandhu and Bhatia (1985) and Wani *et al.* (1990) who also obtained the similar results while studying the preparation of fruit juice concentrates.

Ascorbic acid

The effect of process time and temperature on retention of ascorbic acid (AA) during concentration of tomato juice is shown in **Fig. 4.3**. Destruction of ascorbic acid was influenced by both temperature and time of processing. At 65 and 75°C it followed a linear relationship for the greater part of the concentration cycle, while at 45 and 55°C the relationship was non-linear. The destruction rate of ascorbic acid increased with increase in temperature. The analysis of variance showed that both the variables had significant (1% level) effect on the retention of AA (**Table 4.1**). The table also shows that the quadratic and interaction effect were significant at 1% level. **Eqn. (4.4)** shows a linear relationship for concentration time and temperature on retention of AA. The coefficients of the variables in the equation shows that concentration time (X_1) had more contribution than temperature (X_2) on destruction of AA. Further, the negative sign of both the variables suggested that the retention of AA decreased with the increase in concentration time and temperature.

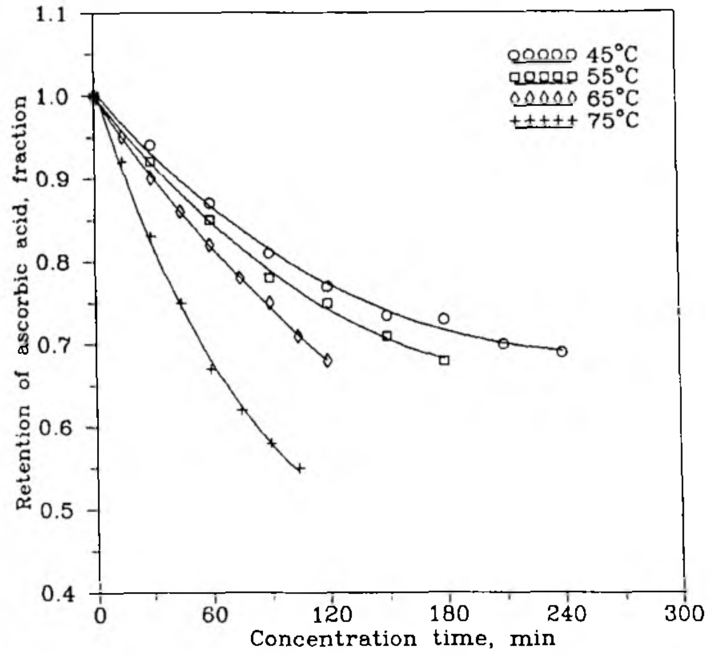


Fig. 4.3 Retention of ascorbic acid during concentration of tomato juice at different time-temperature combinations

$$Aa_{ret} = 0.72 - 0.215\,X_1 - 0.074\,X_2 \quad (r^2=0.77) \qquad \ldots \text{(4.4)}$$

where Aa_{ret} is the retention of ascorbic acid in per cent and X_1 and X_2 are the concentration time and temperature, respectively.

Since the coefficient of determination (r^2 = 0.77) of linear relationship in **Eqn. (4.4)** was low, the observed data were refitted to a second-order polynomial regression equation

(Eqn. 4.5). High value of coefficient of determination (r^2 = 0.97) in **Eqn. (4.5)** indicated adequate fitting of the data and can be used for predication of ascorbic acid retention (Aa_{ret}) within the experimental limits after decoding the variables.

$$Aa_{ret} = 0.69 - 0.26X_1 - 0.135X_2 + 0.08X_1^2 - 0.114X_1X_2 - 0.055X_2^2 \qquad \ldots (4.5)$$
$$(r^2 = 0.97)$$

where Aa_{ret}, X_1 and X_2 are the same as explained in **Eqn. (4.4)**.

Lycopene

Figure 4.4 shows the retention of lycopene with varying process time and temperature during concentration of tomato juice. It is evident from the figure that the lycopene content of tomato juice decreased with the increase in concentration time as well as temperature. The maximum retention of lycopene at maximum possible concentration of juice within the experimental limits was found to be 95% at 45°C, 91% at 55°C, 86% at 65°C and 78% at 75°C, respectively. The corresponding time requirement and maximum possible concentration of juice were 240 min and 25°B; 180 min and 29°B; 105 min and 31°B; and 90 min and 33.5°B, respectively.

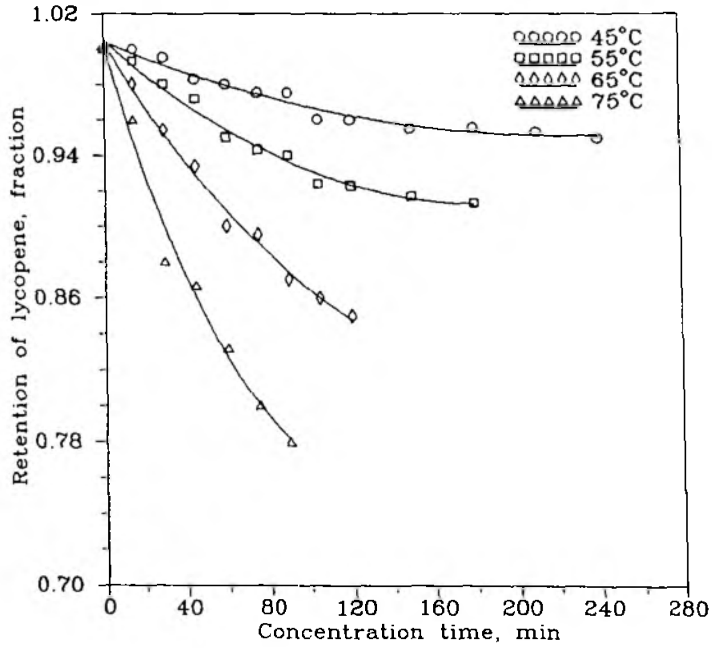


Fig. 4.4 Retention of lycopene during concentration of tomato juice at different time-temperature combinations

The analysis of variance (**Table 4.1**) showed that both time and temperature had significant effect on retention of lycopene at 1% level. In addition, the quadratic as well as interaction effects were also found to be highly significant. In order to understand the relative effect of these variables on retention of lycopene during concentration of tomato juice, a linear relationship (Eqn. 4.6) was developed.

$$Ly_{ret} = 0.9035 - 0.063X_1 - 0.063X_2 \quad (r^2 = 0.66) \qquad \ldots \textbf{(4.6)}$$

where, Ly_{ret} is the retention of lycopene in per cent; X_1 and X_2 are the coded values of the concentration time and temperature, respectively.

The coefficients of the process variables, *viz.*, the concentration time (X_1) and temperature (X_2) were found to be equal with linear **(Eqn. 4.6)** as well as polynomial relationship **(Eqn. 4.7)** suggesting that both the factors contributed equally to the retention of lycopene. Negative sign of the coefficients indicated that retention of lycopene decreased with increase in their levels. The coefficient of determination (r^2 = 0.66) of **Eqn. (4.6)** being poor, a second order relationship **(Eqn. 4.7)** with r^2 = 0.95 can be used satisfactorily for prediction of lycopene retention.

$$Ly_{ret} = 0.88 - 0.113X_1 - 0.115X_2 + 0.021X_1^2 - 0.096X_1X_2 - 0.032X_2^2 \quad (r^2 = 0.95) \qquad \ldots \textbf{(4.7)}$$

where Ly_{ret}, X_1 and X_2 are the same as explained above in **Eqn. (4.6)**.

Sugars

There was an increase in the reducing sugars content of samples during concentration and the per cent increase depended upon both the process time and temperature. The increase in reducing sugars content was perhaps because of the heat-induced conversion of non-reducing into reducing sugars due to inversion during the concentration process. Similar observations were also reported earlier by Wani *et al.* (1990). Molwane and Gunjal (1985) had also reported an increase in reducing sugars while preparing tomato

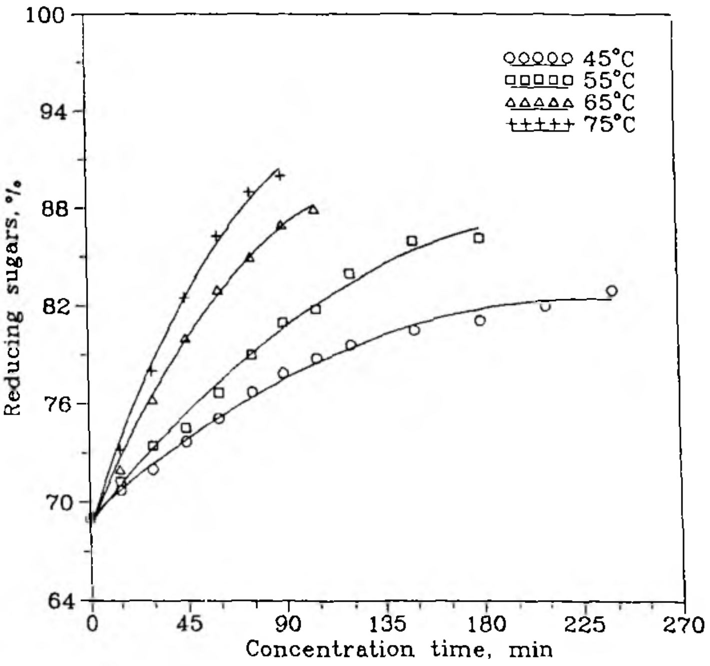


Fig. 4.5 Increase in reducing sugars content in tomato juice with time during concentration at different temperatures

concentrates using either hot-break or cold-break extracted juices. **Fig. 4.5** shows the increase in reducing sugars in tomato juice with time during concentration at different temperatures. It is evident from the figure that the increase in reducing sugars initially followed a linear relationship with concentration time and exhibited non-linearity during later stages of concentration at all the temperatures under investigation. The values of reducing sugars contents in concentrates were found to be 83, 86.2, 88 and 90% at 45, 55, 65 and 75°C, respectively for the corresponding maximum possible concentration of 25, 29, 31 and 33.5°B, respectively.

The variance test (**Table 4.1**) revealed that both the variables had significant effect on increase in reducing sugars at 1% level. The multiple linear regression **Eqn. (4.8)** in terms of coded variables indicated that concentration time (X_1) had more contribution on inversion of sugars as compared to temperature (X_2). Coefficient of determination ($r^2 = 0.72$) of **Eqn. (4.8)** being poor, and the quadratic and interaction effect were found to be significant, a second order regression **Eqn. (4.9)** with $r^2 = 0.97$ was developed for the prediction of reducing sugars.

$$RS = 83.68 + 10.68X_1 + 4.86X_2 \quad (r^2 = 0.72) \qquad \textbf{... (4.8)}$$

$$RS = 87.2 + 13.76X_1 + 8.77X_2 - 4.45X_1^2 + 7.59X_1X_2 + 1.1X_2^2 \quad (r^2 = 0.97) \qquad \textbf{... (4.9)}$$

where, RS is the reducing sugars content in per cent on the basis of total sugars and X_1 and X_2 are the coded values of the concentration time and temperature, respectively.

Colour

The extent of colour change in tomato juice during concentration process was quantified by measuring the colour of the concentrate. A semi-log plot of colour, C' *versus* concentration time was compared at four temperatures. Linear regression analysis showed that the value of r^2 ranged from 0.98 to 0.99. The linear plots (**Fig. 4.6**) indicated that the change in colour during concentration process could be described as first order reaction kinetics without introducing significant error.

Therefore the following equation was used to describe the change in colour during concentration of tomato juice, measured in tintometer units, as a function of process time.

$C' = C'_0 \exp(k_{T'}/\theta_C)$ ... (4.10)

where C' is the colour of juice at time θ_C, $C'o$ is the colour of concentrate at time 0; $k_{T'}$ is the reaction rate constant in min^{-1} at concentration temperature T_c and θ_C is the concentration or process time in min.

Reaction kinetics parameters for colour change in tomato juice during concentration are presented in **Table 4.5**. The reaction rate constant, $k_{T'}$ increased with the increase in temperature. The table also gives the value of activation energy, E_a, z and Q_{10} which were 487.5 kJ kg^{-1} $mole^{-1}$, 63.09°C and 1.44, respectively.

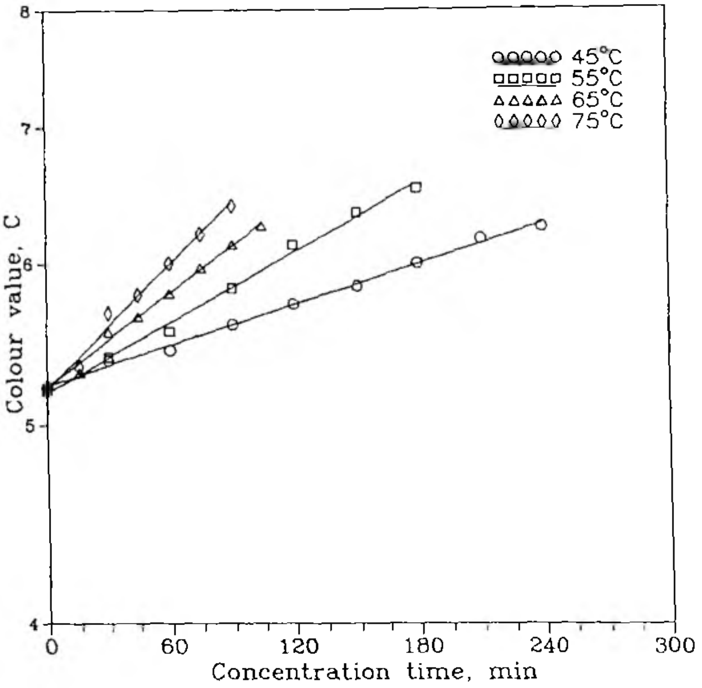


Fig. 4.6 Changes in colour value of tomato juice with concentration time at different temperatures

Table 4.5 Reaction kinetics parameters for colour change in tomato juice during concentration

Kinetics parameters		
Reaction rate constant, $k_{T'}$ (min^{-1})		
45°C	....	7.5932×10^{-4}
55°C	....	1.3122×10^{-3}
65°C	....	1.7517×10^{-3}
75°C	....	2.3268×10^{-3}
Activation energy, Ea (kJ kg^{-1} $mole^{-1}$)	....	487.50
Z value (°C)	....	63.09
Q_{10}	....	1.44

Optimization of process variables

Since ascorbic acid (AA) is considered to be the most heat labile component in the products of plant origin (Johnson *et al.*, 1995; Labuza and Riboh, 1982), its maximum retention in the concentrate was taken as criteria for optimization of the concentration process variables. It was assumed that the process parameters retaining maximum AA will also preserve the other components maximally.

In the present investigation, tomato juice (5.5°B) was concentrated for foam-mat drying operation to follow. From the preliminary experiments on production of foam described elsewhere (**Sec. 4.6.3**) it was found that the solids content in tomato juice played an important role on its foaming characteristics. Samples containing 25°B TSS (26.5-27% TS) gave the best results on foaming of tomato concentrate. Accordingly this concentration was taken as the criterion for optimization of the concentration temperature.

Time requirement and retention of ascorbic acid (Aa_{ret}) for concentrating tomato juice upto 25 and 30°B at different temperatures were calculated using **Eqn. (4.2)** and **Eqn. (4.5)**. Calculated values for the retention of ascorbic acid were plotted against concentration temperature (**Fig. 4.7**).

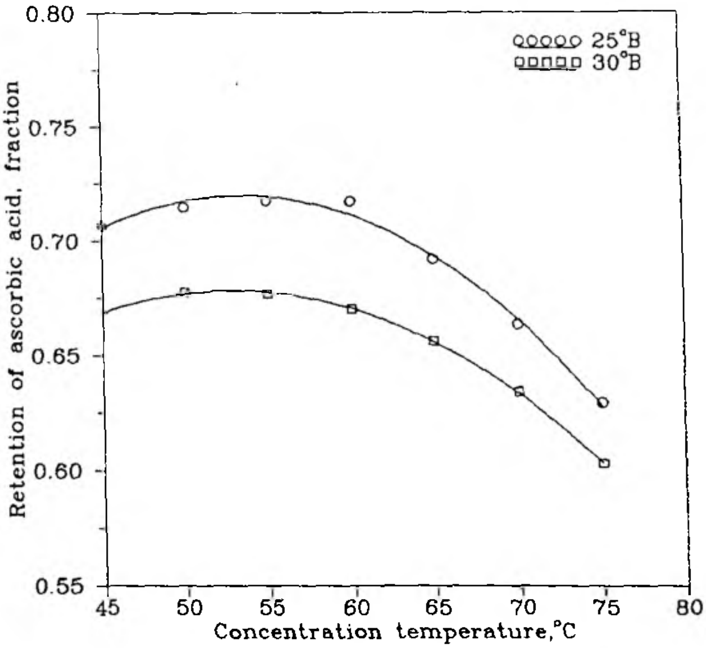


Fig. 4.7 Retention of ascorbic acid in 25° and 30°B tomato concentrates prepared at different concentration temperatures

It can be seen form **Fig. 4.7** that the retention of ascorbic acid did not vary appreciably with increase in processing temperature from 45 to 60°C. The average values of ascorbic acid retention within this temperature range were found to be 72 and 67.5% for 25 and 30°B concentration, respectively. Increase in temperature beyond 60°C, however, drastically reduced the retention of ascorbic acid in the concentrate.

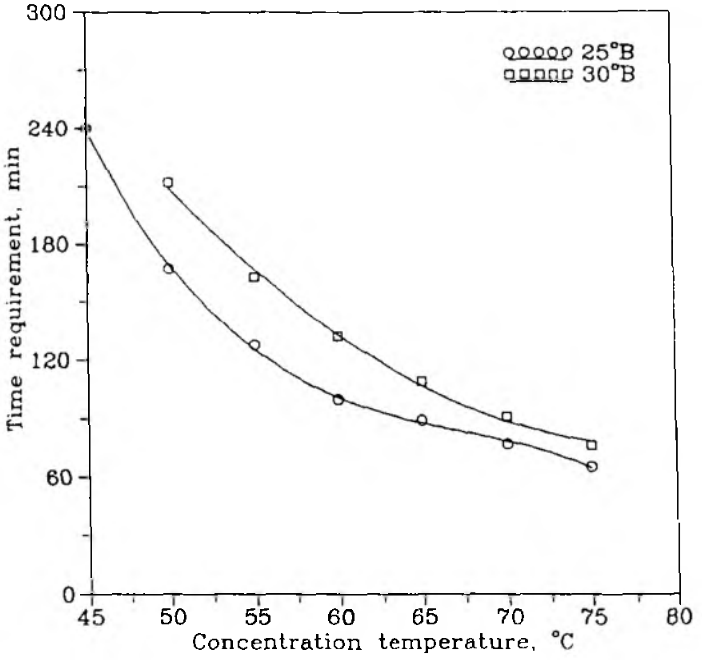


Fig. 4.8 Effect of temperature on the processing time required to concentrate the juice upto 25°B and 30°B

Figure 4.8 shows the effect of temperature on time required to concentrate the tomato juice upto 25 and 30°B. For the case of 25°B concentration, it can be seen from the figure that increase in concentration temperature from 45 to 50°C, 55°C and 60°C caused substantial reduction in concentration time (30, 47 and 58%, respectively) compared to that at 45°C. An increase in temperature beyond 60°C, however, did not appreciably reduce the concentration time. The corresponding decrease in time was found to be 63, 68 and 73% for each successive increase of 5°C concentration temperature. Similarly, for 30°B also substantial decrease in concentration time was noticed only upto 60°C (**Fig. 4.8**). From the above analysis it is clear that the concentration of tomato juice at 60°C was found to be the best from the view of AA retention as well as process time requirement within the experimental limits. Hence, 60°C temperature was used for the preparation of tomato concentrate for further experiments.

Experiments, in triplicate, were conducted to verify the optimal values of process variables, for obtaining tomato concentrate of 25 and 30°B TSS. The process temperature was set at 60°C and the juice samples were concentrated for calculated time period of 99 and 132 min, respectively. The predicted and experimental values for TSS, retention of AA (**Eqn. 4.5**) and Lycopene (**Eqn. 4.7**) are presented in **Table 4.6** which compared well.

Table 4.6 Predicted and experimental values of ascorbic acid, lycopene retention and concentration of juice obtained after concentrating for the required time period

Desired concentration, °B	Process time calculated, min	Concentration obtained, °B	Retention			
			Ascorbic acid		Lycopene	
			Predicated	Experimental	Predicted	Experimental
25	99	24.5	72	70	90	93
30	132	29.0	67	65	87	91

4.4 Boiling-point Rise of Tomato Juice

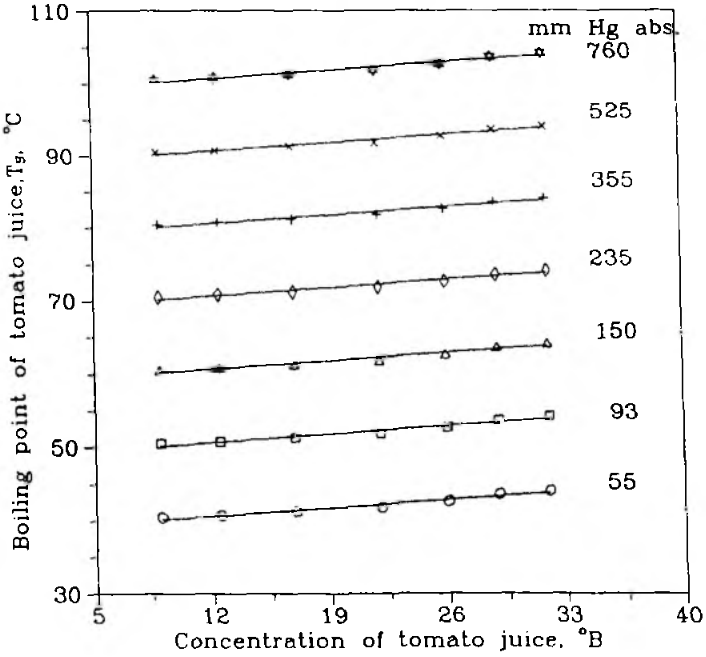


Fig . 4.9 Variation in boiling point of tomato juice with concentration at different pressures

Experimental data on boiling points of hot-break extracted tomato juice at different concentrations and pressures can be seen in **Table B-1 (Appendix - B)**. **Fig. 4.9** shows the change in boiling points of tomato juice with concentrations at different pressures. The boiling point of tomato juice at all pressures increased linearly with the increase in concentration of juice. The boiling-point rise of 9.5 and 32°B tomato juice at atmospheric pressure were found to be 0.4 and 4.15°C, respectively. The corresponding values of boiling-point rise at 55 mm Hg pressure were found to range between 0.4 and 4.05°C, respectively. The boiling-point rise of the tomato juice was found to be more than the reported values of the same for sucrose solution (Honig,1953) at the same concentrations. This was due, propably to the presence of organic acids and other solutes in the juice. The values of BPR

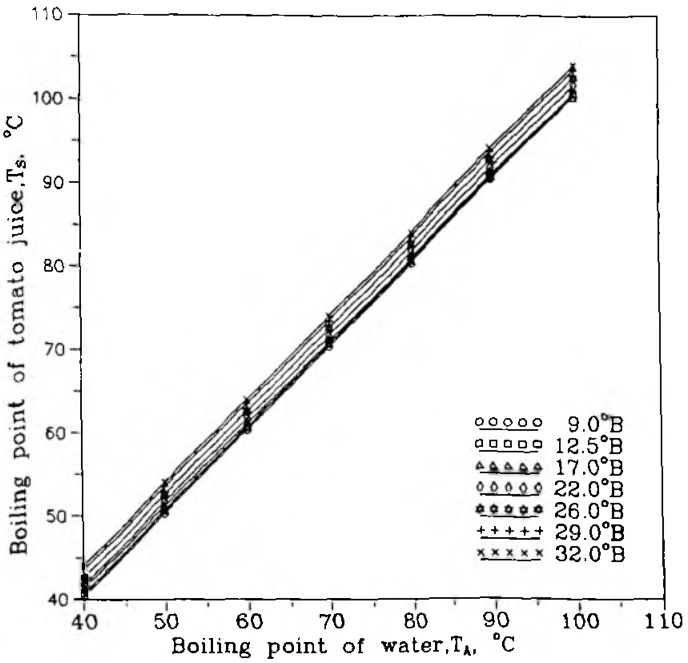


Fig. 4.10 *Duhring's* plot for tomato juice at various concentration

in tomato juice in the present study were also found to be higher than those reported by Varshney and Barhate (1978) for pineapple and lemon juices and by Moresi and Spinosi (1980) for orange juice but were comparable with those for mango juice (Varshney and Barhate, 1978) at the same concentration. **Fig. 4.10** presents the *Duhring's* plot of the tomato juice at different concentrations. It can be seen that the boiling points of tomato juice, T_S, at various concentrations increased linearly with the boiling point of water, T_A, as stated by *Duhring's rule* (McCabe *et al.*, 1993). At a constant concentration of the juice, relationship between T_S and T_A will, therefore, be

$$T_S = m_o + m_1 T_A \qquad \text{... (4.11)}$$

where, m_o and m_1 are empirically determined constants. These parameters for each of the experimental concentrations of tomato juice were obtained by using the method of least squares and are given in **Table 4.7**. The values of the coefficients of determination were found to be 1 at each concentration. The values of m_1 for different concentrations of juice are close to 1, indicating that the resulting plots for different concentrations are roughly parallel. This suggested that the boiling-point rise, ΔT_b, at each concentration of juice was independent of T_A but was related to the soluble solids content of the juice.

The boiling-point rise ΔT_b will therefore be

$$\Delta T_b = T_S - T_A \approx m_o \qquad \text{... (4.12)}$$

Table 4.7 **Values of Constants m_0 and m_1 in Eqn. (4.11) for tomato juice at different concentrations**

Concentration, °B	m_0 , °C	m_1
9.0	0.3786	1.0005
12.5	0.7750	0.9996
17.0	1.7714	0.9900
22.0	1.8107	0.9995
26.0	2.6286	1.0010
29.0	3.5500	1.0007
32.0	4.0643	1.0009

The values of ΔT_b as obtained by subtracting the boiling point of water from the observed boiling point of juice were plotted as a function of boiling point of water (**Fig. 4.11**). It may be seen that the plots for different concentrations are straight line and parallel. This indicated that the boiling-point rise was not affected by the pressure at which it was measured. The analysis of variance (**Table B-2, Appendix - B**) revealed that concentration of the juice had significant effect on its boiling-point rise, whereas the effect of vacuum level was non-significant. Our results of pressure independence are in disagreement with published data for apple (Crapiste and Lozano, 1988) and Thai tangerine juices (Ilangantileke *et al.*, 1992) which was due probably to the difference in measuring technique and composition of the juice. The pressure independence of boiling-point rise for many fruit juices was, however, reported by Varshney and Barhate (1978) and Moresi and Spinosi (1980; 1984a and 1984b).

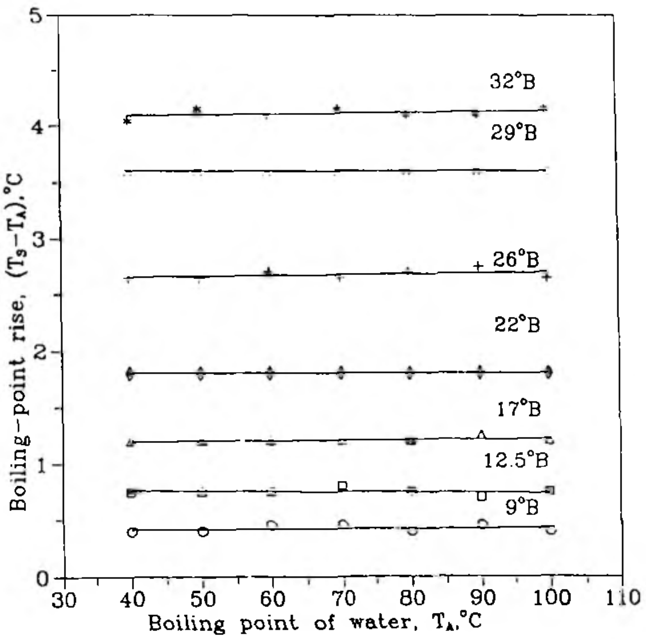


Fig. 4.11 Boiling-point rise, ΔT_b, of tomato juice of varying concentration vs boiling point of pure water, T_A

The observed mean values of ΔT_b for tomato juice at different concentrations alongwith their standard deviations are presented in **Table 4.8. Fig. 4.12** shows the BPR of tomato juice as a function of its concentration.

The experimental values of ΔT_b were correlated with concentration of tomato juice and a non-linear regression model (**Eqn. 4.13**) was derived.

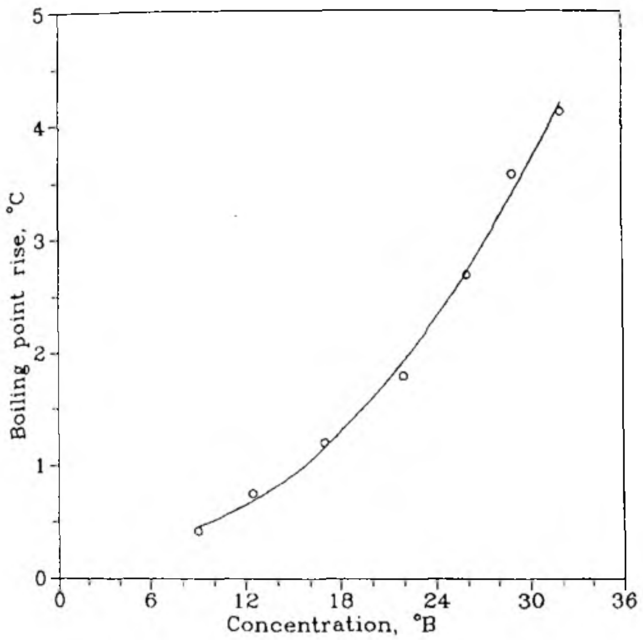


Fig. 4.12 Boiling-point rise of tomato juice as a function of its concentration

$$\Delta T_b = 0.45 - 0.0438\, x + 0.005\, x^2 \quad (r^2=0.99) \qquad \ldots (4.13)$$

where ΔT_b and x are the boiling-point rise of tomato juice in °C and concentration of tomato juice in °B, respectively.

Table 4.8 Mean values of boiling-point rise in tomato juice as a function of concentration

Concentration, °B	Boiling-point rise, °C	Standard deviation, °C
9.0	0.421	0.025
12.5	0.750	0.028
17.0	1.207	0.018
22.0	1.786	0.035
26.0	2.679	0.037
29.0	3.571	0.045
32.0	4.114	0.035

High value of coefficient of determination ($r^2 = 0.99$) indicated good agreement between predicted and experimental values and provided an easy estimation of the boiling-point rise of tomato juice.

Eqn. (4.13) was used for predicting the boiling-point rise of tomato juice at different concentrations and the vacuum level was adjusted accordingly during the concentration process so as to maintain the juice under boiling condition throughout the process.

4.5 Desorption Isotherms of Tomato Concentrate

The desorption isotherms of tomato concentrate (25°B) at 20, 30, 40, 50 and 60°C temperatures are presented in **Fig. 4.13.** Experimental values of a_w and the EMC data have been given in **Appendix - C (Table C-1).** It is evident from the figure that the relationship between a_w and EMC data is S-shaped at all the temperatures and the EMC increased with an increase in a_w at any temperature, while it decreased with the increase in temperature at the same a_w. Demertzis *et al.* (1989) reported that at higher temperatures, the kinetic energy of the water molecules was high and water absorbance at a given water activity was low. The desorption isotherms of tomato concentrate (**Fig. 4.13**) were found to exhibit short LI - I, intermediate LI - II and long LI - III which is a characteristics feature of sugar - rich products like dried fruits (Ayranci *et al.*, 1990; Tsami *et al.*, 1990). It may be observed from **Fig. 4.13** that the slopes of the isotherms in the 0.2-0.45 a_w range are low, indicating that tomato concentrate absorbs moisture slowly in this range.

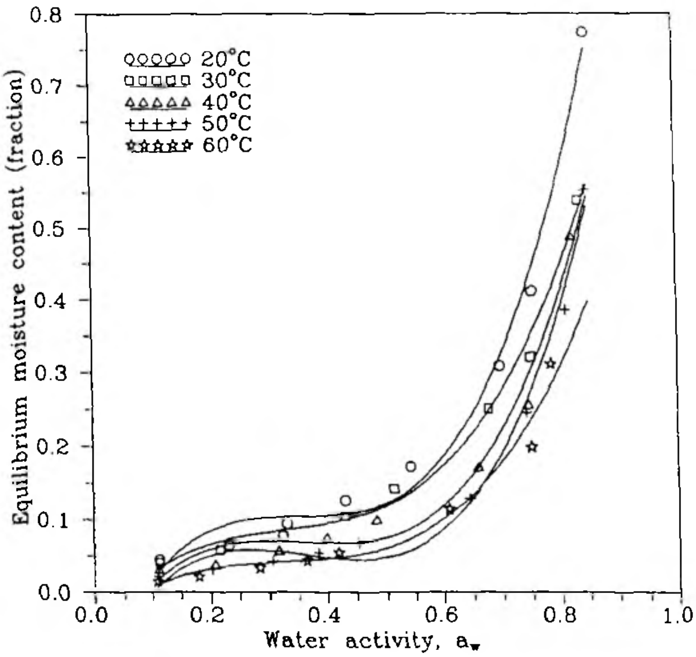


Fig. 4.13 Desorption isotherms for tomato concentrate (25°B) at different temperatures

The a_w-EMC data were fitted to the GAB and BET models. All the experimental data were used for fitting into the GAB model, while only those for $a_w < 0.55$ was used for the BET model.

The constants of the GAB and BET equations and the values of coefficient of determination (r^2), relative percent deviation (Eqn. 3.7) and standard error (Eqn. 3.8) for both the models are given in **Table 4.9**.

Table 4.9 Estimated parameters for GAB and BET models of desorption isotherms of 25°B tomato concentrate at different temperatures

Parameters	Temperature, °C				
	20	30	40	50	60
GAB Model					
Mo_g	0.079	0.068	0.048	0.037	0.035
C_g	6.173	7.107	7.697	6.838	4.053
k	1.070	1.063	1.101	1.131	1.153
Coefficient of determination (r^2)	0.97	0.96	0.94	0.99	0.980
Standard error of estimate (SE)	0.041	0.044	0.016	0.043	0.035
Mean relative per cent deviation (P_d)	5.20	5.41	5.82	4.45	5.35
BET Model					
Mo_b	0.090	0.075	0.058	0.043	0.038
C_b	5.099	5.931	5.520	5.687	4.149
Coefficient of determination (r^2)	0.96	0.95	0.91	0.98	0.97
Standard error of estimate (SE)	0.006	0.008	0.007	0.004	0.005
Mean relative per cent deviation (P_d)	5.14	5.82	8.57	3.71	6.43

It may be observed from the table that the values of r^2 ranged between 0.94 and 0.99 and between 0.91 and 0.98 for GAB and BET models respectively at different temperatures (20-60°C), indicating adequate fitting of experimental data to both the models. The BET equation had the smaller values of standard error (SE) of moisture estimate (0.0025 to 0.0084) as compared to that for the GAB equation (0.016 to 0.044). The higher values of SE by GAB may be due to the higher range of a_w applied in fitting the equation. However, the mean relative percentage deviation, P_d (3.71 to 8.57) was more in case of BET equation than the (4.46 to 5.82) GAB equation. According to Lamauro *et al.* (1985) an equation with a P_d value equal to or less than 5 is considered to be a good fit. Hence, either of the equations may be used to represent a_w-EMC data for tomato concentrate at 20-60°C temperature range.

The estimated parameters for both BET and GAB models have also been presented in **Table 4.9**. Values of constant k for the GAB equation varied between 1.0626 and 1.1530 suggesting that the sorption was infinite at $a_w < 1.0$. According to Chirife *et al.* (1992), a value of k > 1.0 is physically unsound. But the tomato concentrate was rich in sugars and for a similar product (dried apricots) Samaniego-Esguerra *et al.* (1991) have reported k values of 0.94-1.02 when the transformed polynomial regression was used. These values, however, differed slightly when indirect non-linear or direct linear regression methods were used. The Mo value decreased with increasing temperature within the experimental limits. Our findings are in agreement with those of Iglesias and Chirife (1976) who reported similar results for many foods and food systems. The decrease in Mo values may be due to a reduction in the total number of active sites for water binding as a result of physical and/or chemical changes in the product induced by temperature (Iglesias and Chirife, 1976; Mazza and LeMaguer, 1978). Increasing temperatures may also activate and make them less stable and break

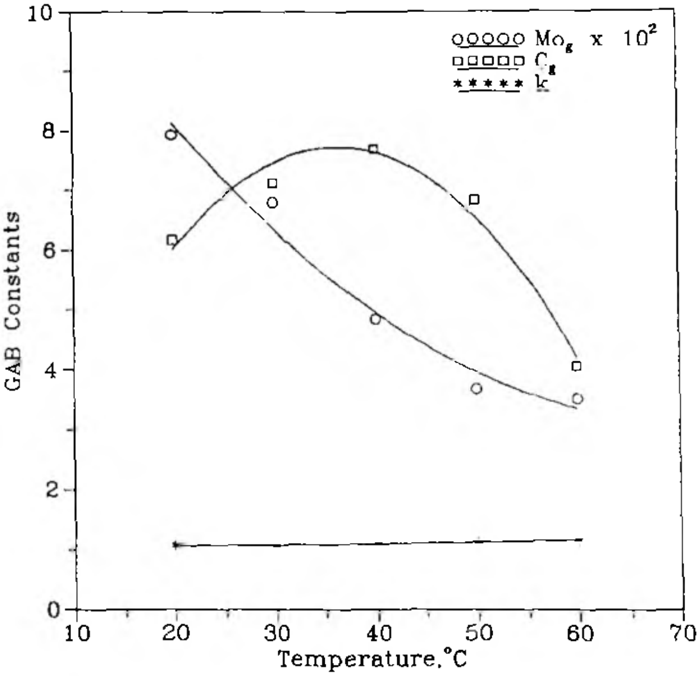


Fig. 4.14 Variation of GAB constants, Mo_g, C_g and k with temperature

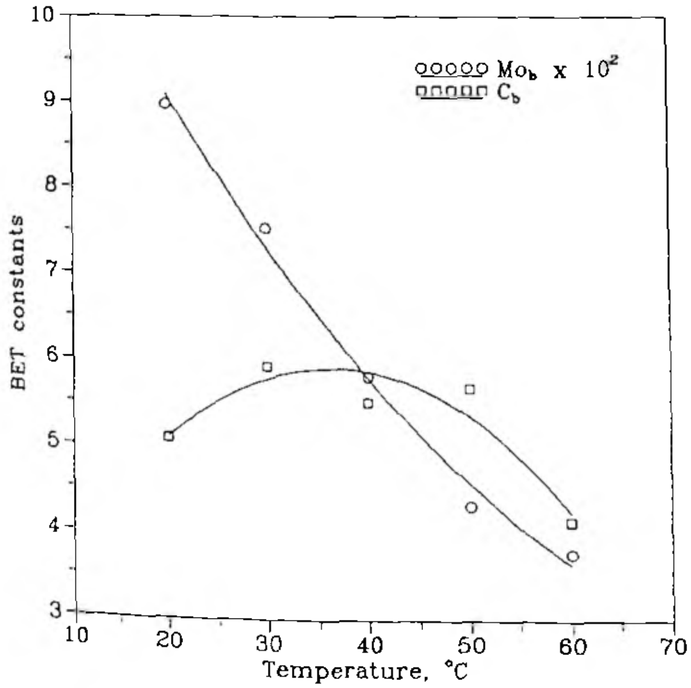


Fig. 4.15 Variation of BET constants, Mo_b and C_b with temperature

away from the water-binding sites of the food material, resulting in lower value of Mo. Further, according to Demertzis *et al.* (1989) the monolayer moisture contents obtained by GAB and BET models were not exactly the same. However, in the present study, t-test indicated that the Mo values calculated by GAB and BET models were similar ($t_{cal} = 0.651$) at 5% level of significance for each temperature.

The temperature dependence of the constants of GAB (Mo_g, C_g and k) and BET (Mo_b and C_b) equations may be observed in **Fig. 4.14 and 4.15**. The values of Mo obtained by GAB and BET models decreased from 7.93 to 3.51% and from 8.98 to 3.78% respectively with the increase in temperature from 20 to 60°C. If a dry tomato powder is to be stored, it must be done at low moisture content. The highest value of C of GAB and BET equations at 40°C shows that the energy of moisture binding is the highest at this temperature, *i.e.*, the amount of heat energy required to remove water will be the highest if it is done at this temperature. The regression equations for each of these parameters of the models alongwith their coefficient of determination are presented in **Table 4.10.** Higher values of coefficient of determination for GAB parameters (0.98 to 0.99) than those of BET parameters (0.87 to 0.98) suggest better prediction of values by the GAB model. The GAB model was, therefore, used to predict the values of equilibrium moisture content in further studies.

Table 4.10 Temperature dependent regression equations for GAB and BET model parameters for tomato concentrate

Model	Regression equation	r^2
GAB	$Mo_g = 0.1287 - 0.2762\times10^{-2}\ T + 0.1957\times10^{-4}\ T^2$	0.98
	$C_g =- 0.7071 + 0.4626 - 0.6346\times10^{-2}\ T^2$	0.97
	$k = 1.339 - 13.86\ T^{-1} + 169.4\ T^{-2}$	0.99
BET	$Mo_b = 0.1354 - 0.251\times10^{-2}\ T + 1434\times10^{-4}\ T^2$	0.98
	$C_b = 1.973 + 0.2164\ T - 0.2973\times10^{-2}\ T^2$	0.88

4.6 Foaming of Tomato Concentrate

Investigations were carried out on performance evaluation of the foaming device, determination of optimum operating and machine parameters for maximum foam expansion and on the effect of foaming additives on foaming properties of tomato concentrate.

4.6.1 Performance evaluation of the foaming device

The performance of the developed foaming device was evaluated using sugar solution (62°B) containing 1% glycerol monosteatrate (GMS) as foam inducer. Foam expansion in sugar solution was taken as the measure for evaluation of the device. Experiments were conducted in accordance with the **Table 3.2** and the observed foam expansion values (%FE) are presented in **Table 4.11**. The device worked satisfactorily with the sugar solution. Foam expansion in the sugar solution varied between 80 and 152% within the ranges of operating and machine parameters. A large variation in the observed FE data with variation in the experimental conditions indicated that the operating and machine parameters as well as their levels had marked effect on the foam expansion (FE).

A second-order polynomial model (**Eqn. 3.10**) was fitted with the experimental data and tested for adequacy through analysis of variance. **Eqn. (4.14)** shows the predicted value of foam expansion (FE_{Spred}) as a function of whipping speed X_1, whipping time X_2, air flow rate X_3, blade diameter X_4 and liquid depth X_5 expressed in coded form. This equation was obtained using the step-down regression method where factors with F-value less than one were rejected as described by Snedecor and Cochran (1967). High value of the coefficient of determination ($r^2 = 0.95$) obtained for the response variable indicated that the developed model for foam expansion (FE) accounted for and adequately explained 95% of the total variation.

$$
\begin{aligned}
FE_{Spred} = \; & 151.75 + 2.33X_2 - 11.63X_3 + 3.983X_4 - 4.47X_5 - 9.1X_1^2 + 2.77X_1X_2 \\
& + 5.32X_1X_3 + 8.5X_1X_4 - 3.65X_1X_5 - 10.63X_2^2 + 4.1X_2X_4 - 1.7X_4X_5 \\
& - 5.74X_3^2 + 1.41X_3X_4 + 1.79X_3X_5 - 5.6X_4^2 + 2X_4X_5 - 10.42X_5^2 \qquad \ldots (4.14) \\
& (r^2 = 0.95)
\end{aligned}
$$

Table 4.11 Observed foam expansion in 62 °B sugar solution under varying operating conditions of foaming device

Expt. No.	Levels of the independent variables					Observed foam expansion, %
	Whipping speed, rev min^{-1}	Whipping time, min	Air flow rate, l min^{-1}	Blade diameter, mm	Liquid depth, mm	
1	1035	6	19.5	68	62.5	143.50
2	1035	6	19.5	68	37.5	135.22
3	1035	6	19.5	52	62.5	120.00
4	1035	6	19.5	52	37.5	124.60
5	1035	6	11.5	68	62.5	100.00
6	1035	6	11.5	68	37.5	92.00
7	1035	6	11.5	52	62.5	84.33
8	1035	6	11.5	52	37.5	95.45
9	1035	3	19.5	68	62.5	148.00
10	1035	3	19.5	68	37.5	133.00
11	1035	3	19.5	52	62.5	121.33
12	1035	3	19.5	52	37.5	118.00
13	1035	3	11.5	68	62.5	96.00
14	1035	3	11.5	68	37.5	90.20
15	1035	3	11.5	52	62.5	89.00
16	1035	3	11.5	52	37.5	95.00
17	765	6	19.5	68	62.5	121.00
18	765	6	19.5	68	37.5	103.00
19	765	6	19.5	52	62.5	125.00
20	765	6	19.5	52	37.5	108.00
21	765	6	11.5	68	62.5	94.67
22	765	6	11.5	68	37.5	86.00
23	765	6	11.5	52	62.5	102.00
24	765	6	11.5	52	37.5	96.20
25	765	3	19.5	68	62.5	110.33
26	765	3	19.5	68	37.5	88.00
27	765	3	19.5	52	62.5	157.33
28	765	3	19.5	52	37.5	131.00
29	765	3	11.5	68	62.5	104.00
30	765	3	11.5	68	37.5	80.00
31	765	3	11.5	52	62.5	131.33
32	765	3	11.5	52	37.5	1118.00
33	580	4.5	15.5	60	50	100.00
34	1220	4.5	15.5	60	50	83.44
35	900	1	15.5	60	50	102.00
36	900	8	15.5	60	50	136.00
37	900	4.5	6	60	50	133.00
38	900	4.5	25	60	50	103.33
39	900	4.5	15.5	41	50	86.00
40	900	4.5	15.5	79	50	95.00
41	900	4.5	15.5	60	20	98.33
42	900	4.5	15.5	60	80	100.00
43	900	4.5	15.5	60	50	152.00
44	900	4.5	15.5	60	50	151.00
45	900	4.5	15.5	60	50	152.00
46	900	4.5	15.5	60	50	149.00
47	900	4.5	15.5	60	50	152.00
48	900	4.5	15.5	60	50	152.00
49	900	4.5	15.5	60	50	152.00
50	900	4.5	15.5	60	50	152.00
51	900	4.5	15.5	60	50	152.00
52	900	4.5	15.5	60	50	152.00

Eqn. (4.15) shows the foam expansion (FE_{Spred}) in terms of real values of whipping speed W_S, whipping time W_θ, air flow rate A_f, blade diameter D_b and liquid depth L_h.

$$\begin{aligned} FE_{Spred} = \; & -164.83 + 0.33\, W_S + 7.8\, W_\theta - 5.1\, A_f + 8\, D_b + 64.84\, L_h \\ & - 5 \times 10^{-4}\, W_S^2 - 1.7\, W_\theta^2 - 0.36\, A_f^2 - 8.75\, D_b^2 - 6.67\, L_h^2 \\ & + 8.2 \times 10^{-3}\, W_S W_\theta + 9.85 \times 10^{-3}\, W_S A_f + 0.79\, W_S D_b - 0.022\, W_S L_h \\ & + 2.05\, W_\theta W_b - 0.544\, W_\theta L_h + 0.44\, A_f D_b + 0.354\, A_f L_h + 2\, D_b L_h \qquad \ldots (4.15) \\ & (r^2 = 0.95) \end{aligned}$$

The relationship between the coded and real values of the variables are:

$$X_1 = (W_s - 900)/135; \quad X_2 = (W_\theta - 4.5)/1.5; \quad X_3 = (A_f - 15.5)/4;$$
$$X_4 = (D_b - 60)/8 \; and \; X_5 = (L_h - 50)/12.5$$

The results of the analysis of variance (**Table 4.12**) of the coefficients of **Eqn. (4.14)** indicated that each factor except the whipping speed (X_1) had significant linear effect on foam expansion. Quadratic effects of all the variables including whipping speed were highly significant. In addition, interactions between whipping speed and all other variables, and between whipping time (X_2) and whipping blade diameter (X_4) also had significant effect on foam expension (FE). The terms which had non-significant effect on FE are not included here.

Table 4.12 Analysis of variance for regression coefficients of Eqn. (4.14)

Intercept (β_o), 151.75		
Linear terms	Quadratic terms	Interaction terms
β_2 = 2.33*	β_{11} = -9.1**	β_{12} = 2.77*
β_3 = - 11.63**	β_{22} = - 10.63**	β_{13} = 5.32**
β_4 = 3.98**	β_{33} = - 5.74**	β_{14} = 8.50**
β_5 = - 4.47**	β_{44} = - 5.59**	β_{15} = - 3.65**
	β_{55} = - 10.42**	β_{24} = 4.10**
% Variability explained	(r^2) = 0.95 %	

* Significant at 5 % level

** Significant at 1 % level

Effect of machine and operating parameters on foam expansion

The effect of individual variables and their interactions on the foam expansion can be explained with the help of **Eqn. (4.14)**. Inspection of the values of coefficients of linear terms suggested that air flow rate (X_3) contributed maximum to the foam formation followed by liquid depth (X_5), blade diameter (X_4) and whipping time (X_2) in that order. The presence of quadratic terms of all the variables in **Eqn. (4.14)** indicated curvilinear nature of the response surface (*i.e.* observed percent foam expansion).

Positive coefficients for whipping time (X_2) and blade diameter (X_4) in **Eqn. (4.14)** indicated that increase in the levels of these two variables increased the FE. However, the negative coefficients for their quadratic terms suggested that an excessive increase in their levels caused significant reduction in foam expansion. Similarly, high values of negative coefficients for linear and quadratic terms of air flow rate (X_3) and liquid depth (X_5) in the vessel indicated decrease in foam expansion with the increase in their levels.

Variations of foam expansion with whipping time (X_2) and air flow rate (X_3) can be seen in **Fig. 4.16a**. It is evident from the figure that the foam expansion increased with the increase in whipping time upto 0.4 (coded level) or 5.1 min (actual) beyond which it decreased. Our results are in agreement with the findings reported by Eldridge *et al.* (1963) and Kabirullah and Wills (1988). With the increase in whipping time, the foam bubbles gradually become smaller and increase the surface area of the foam. Excessive whipping, however, may cause breakage of air bubbles resulting in decrease in the foam expansion. It is also clear from **Fig. 4.16a**, that FE decreases with increase in air flow rate. An air flow rate of -0.45 (coded value) or 13.7 l min^{-1} (actual) yielded maximum foam volume. Increase in the air flow rate causes reduction in the contact time between air and liquid in the vicinity of the whipping blade making it insufficient to occlude the air cells.

Fig. 4.16b shows the effect of blade diameter (X_4) and liquid depth (X_5) on FE. The FE increased with the increase in blade diameter upto 0.22 (coded value) or 61.76 mm (actual) beyond which a further increase in blade diameter decreased the FE. This was possibly due to better agitation of the material with increased blade diameter which in turn increased the air incorporation. Excessive agitation due to increase in blade diameter beyond 0.22 (coded value) or 61.76 mm (actual) not only caused the breakage of air bubbles but also allowed a large volume of air to escape. **Fig. 4.16b** also shows that the foam expansion in sugar solution increased with the increase in liquid depth (X_5) upto -0.4 (coded value) or 45 mm (actual) beyond which it decreased. In whipping, mixing of the two phases

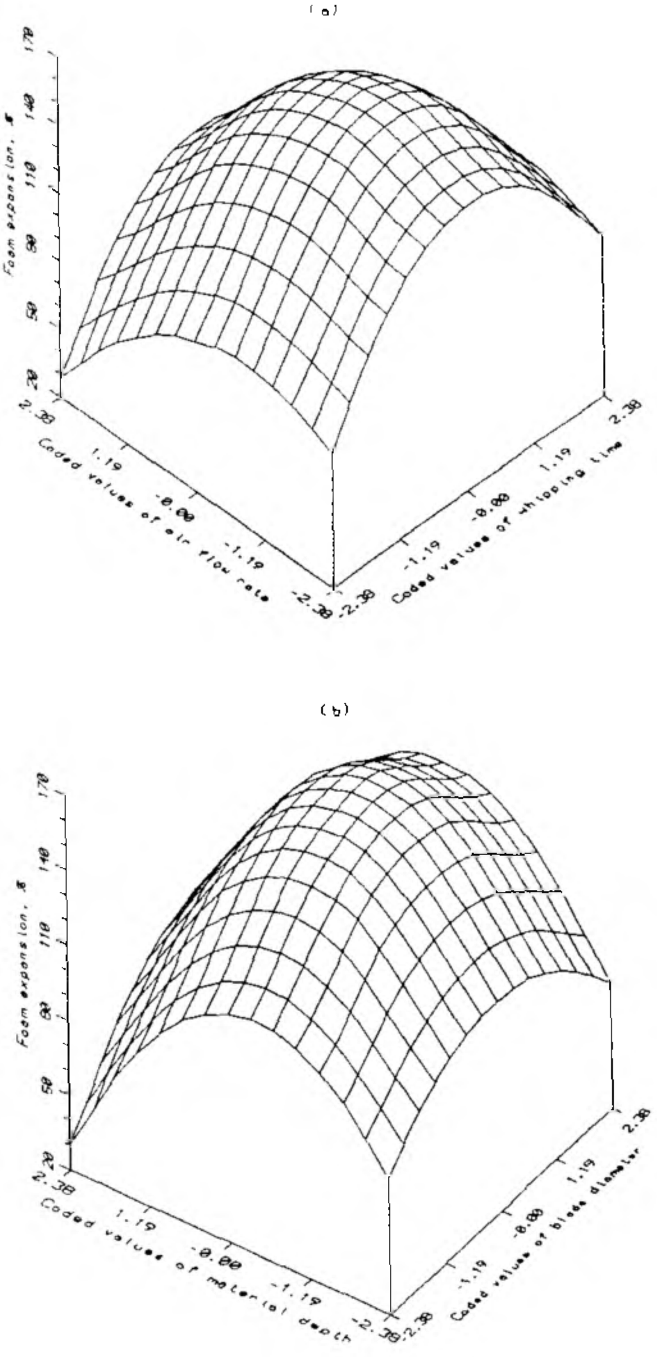


Fig. 4.16 Response surface of foam expansion (a) with varying air flow rate and whipping time (b) material height and blade diameter, other variables being kept at their central level

(air and liquid) takes place around the whipping blade. It is expected that for a given liquid depth the mixing of air into liquid depends on the residence time of the two phases in the immediate vicinity of the whipping blade. Moreover, as the liquid depth increased the effect of agitation decreased which in turn reduced the mixing of air into liquid and thereby resulted in a decreased FE.

Foam expansion during whipping is primarily a result of shearing which, in turn, is a function of whipping speed (rev min^{-1}). The absence of linear term of whipping speed (X_1) in **Eqn. (4.14)** indicated that the rate of shear upto some extent did not play a significant role in the foam expansion. On the other hand, the presence of negative coefficient of quadratic term (X_1^2) suggested that excessive shear rate decreased the FE. This was due to the fact that at very high shear rates, the time of contact between air bubbles and sugar solution during each revolution of the whipping blade may not be sufficient to occlude air cells at the liquid/air interface. Similar results were reported by Wang and Kinsella (1976) while studying the whipping properties of soy product. However, the interactions between whipping speed and other variables had significant effect on FE. This indicated that a certain shearing is essential to encapsulate the air bubbles.

Response contours for foam expansion (FE) were generated using predictive model (**Eqn. 4.14**). Two such plots (**Fig. 4.17a and 4.17b**) are presented here with whipping time and whipping speed, and whipping time and blade diameter, keeping other variables constant at their central values to show the interactions. **Fig. 4.17a** shows the interaction between whipping speed and whipping time which indicates that a definite whipping speed and whipping time are essential for maximum foam expansion. Maximum foam expansion was obtained between -0.45 and +0.45 (coded value) or between 840 and 960 rev min^{-1} of whipping speed, X_1 and the corresponding whipping time, X_2 requirement varied between -0.15 to 0.6 (coded value) or 4.3 to 5.4 min (actual). **Fig. 4.17b** shows the interaction between air flow rate and whipping time. The linear effect of the air flow rate was found to have negative effect (**Eqn. 4.14**) on FE; however, in combination with whipping time the effect on FE was found to be positive and significant indicating that their cumulative effect increased the FE. As indicated in **Fig. 4.17b**, increasing the levels of whipping time and blade diameter in the range of -0.2 to +1.2 (coded value) or 4.2 to 6.3 min (actual) and -0.4 to +0.4 (coded value) or 56.8 to 63.2 mm (actual), respectively resulted in maximum foam expansion, *i.e.*, 150%, however, any further increase or decrease in their levels caused reduction in FE.

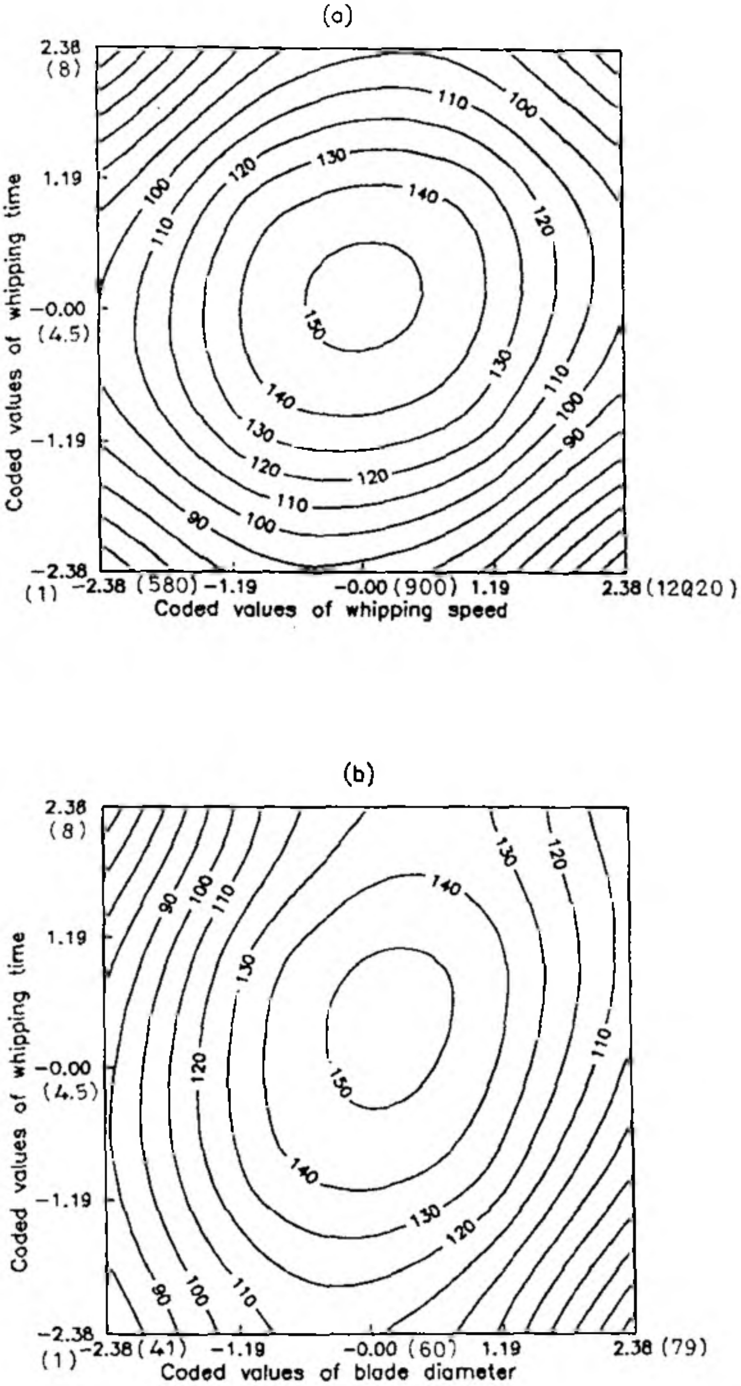


Fig. 4.17 Response contours of foam expansion at (a) varying whipping time and whipping speed and (b) varying whipping time and blade diameter, other variables being kept at their central level (figures in parenthesis represent actual values)

4.6.2 Operating and machine parameters for maximum foam expansion

To find out the conditions for maximum foam expansion, stationary point was calculated using the regression equation (**Eqn. 4.14**) and the procedure described by Draper (1963), Myers (1971) and Khuri and Cornell (1987). **Table 4.13** shows the values of stationary point in terms of coded and actual values.

Table 4.13 Predicted levels of operating variables yielding maximum foam expansion in 62°B sugar solution

Variables			Symbol		Stationary points	
			Coded	Actual	Coded	Actual
1	Whipping speed,	rev min^{-1}	X_1	W_S	- 0.46	840.00
2	Whipping time,	min	X_2	W_θ	- 0.02	4.47
3	Air flow rate,	l min^{-1}	X_3	A_f	- 1.30	10.30
4	Blade diameter,	mm	X_4	D_b	- 0.22	58.25

The canonical form of the predicted response equation for foam expansion based on the stationary points was obtained as follows:

$$FE = 158 - 1.03\,W_1^2 - 6.17\,W_2^2 - 8.81\,W_3^2 - 11.47\,W_4^2 - 13.99\,W_5^2 \qquad \ldots \textbf{(4.16)}$$

where $W_1, \ldots, W_5$ are the canonical variables which are linear functions of the coded variables $X_1, \ldots, X_5$.

All the characteristic roots (eigenvalues or coefficients) of **Eqn. (4.16)** have negative signs indicating that the stationary point existed indeed a maximum, which in turn suggested that movement away from this point would cause a decrease in response *i.e.*, a reduction in foam expansion.

High eigenvalues (λ_4 and λ_5) corresponding to W_4 and W_5 indicated paraboloid nature of the response surfaces, while their negative signs suggested negative slope around the stationary points (maximum in present case) in all the W directions. **Fig. 4.16a and 4.16b** show the response surface corresponding to the original variables. It can be seen that the response surfaces are paraboloid having downward openings indicating negative slopes about the maximum. Similarly, the smaller negative eigenvalues (λ_1, λ_2 and λ_3) corresponding to W_1, W_2 and W_3, respectively indicated that the response surfaces had a slight curvature also corresponding to the maximum [**Fig. 4.16a and 4.16b**]. This is another evidence that moving away from stationary point in any direction in the five dimensional space caused decrease in the FE.

4.6.3 Effect of additives on foaming properties of tomato concentrate

Samples of tomato concentrate in the range of 20 to 32°B were subjected to whipping. It was observed, during preliminary experiments, that whipping of the tomato concentrate without any chemical foaming agent produced very little foam which collapsed completely within 10 minutes at room temperature (25-29°C). When whipped with the added chemical foaming agent, an appreciable foam expansion was obtained, which remained stable over a period of time. This necessitated the use of a suitable foaming agent for the formation of stable foam.

Preliminary experiments exhibited that the tomato concentrate with solids content close to 25°B (26.5-27% TS) containing a chemical foaming agent gave the best results on foam expansion, and the foam was found to be quite stable for drying. Moving away on either side from this concentration level affected both the foam expansion as well as foam stability. In general, samples with less than 25°B solids contents required more amount of these chemical additives to acquire necessary stiffness. On the other hand, in the samples with solids content higher than 25°B the ability of foam expansion was reduced greatly. This behaviour was observed for all the four additives attempted. Hence, tomato concentrate of 25°B (27% TS) was used for preparation of foams and subsequent foam-mat drying. Ginnette *et al.* (1963); Hart *et al.* (1963) and Chandak and Chivate (1972) have suggested 30% solids content in tomato concentrate for conversion into stable foams to be used for foam-mat drying. The deviation in solid contents for production of suitable foams may be due to the varietal difference of tomato.

Selection of foaming agent

Different chemicals *viz.*, CMC, pectin, mixture of pectin and GMS (1:1) and GMS were evaluated as foaming agent for tomato concentrate. The effects of these chemicals and their concentration on foam expansion and foam stability of tomato concentrate (25°B) are presented in **Figs. 4.18 and 4.19.** Experimental data are given in **Appendix-D (Table D-1).** Both the foam expansion and foam stability depended on the type of foaming agent and its concentration in the tomato concentrate. Large variations in foam expansion were observed with different additives under study. It varied from 20 to 34%; 23 to 39%, 30 to 66% and 34 to 122% with CMC, pectin, pectin and GMS (1:1) and GMS respectively in the 0.5 to 2.5% concentration range of each additive. Similarly, large variations in foam stability with concentration of foaming agent were also observed. It varied from 65 to 100%; 63 to 99.5%; 55 to 99% and 49.5 to 98.8% with CMC, pectin, pectin and GMS (1:1) and GMS respectively for the same concentration range. The analysis of variance (**Table 4.14,**) indicated that both the foam expansion and foam stability were affected significantly (1% level) by the additive type and its concentration level.

From **Fig. 4.18** it can be seen that foam expansion increased with the increase in concentration of CMC and pectin from 0.5 to 1.5%. Beyond this range, a further increase in their concentration decreased foam expansion. With GMS and combination of GMS

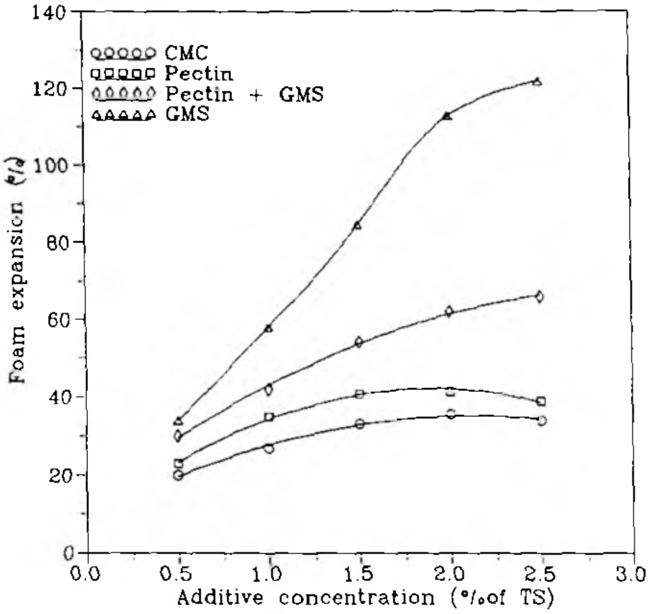


Fig. 4.18 Effect of concentration and type of foaming additive on foam expansion of tomato concentrate (25°B)

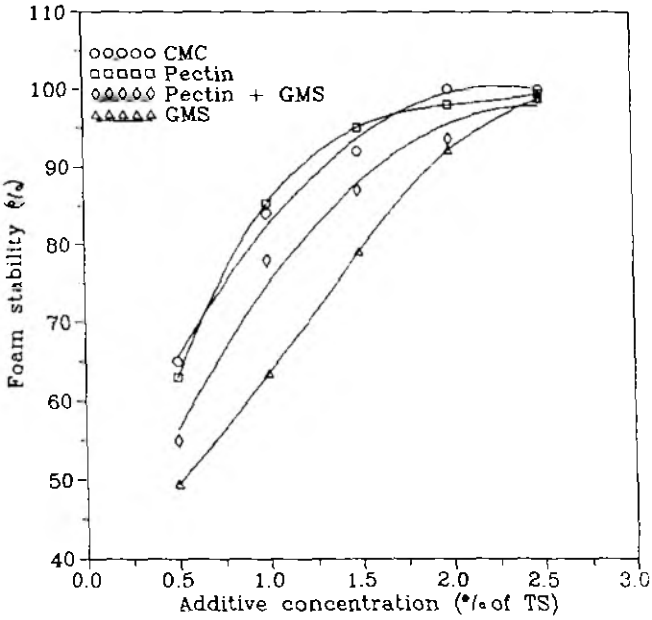


Fig. 4.19 Effect of concentration and type of foaming additive on foam stability of tomato concentrate (25°B)

and pectin (1:1), the increase in foam expansion continued over the entire range of experiment, *i.e.* from 0.5 to 2.5% concentration. The rate of increase in foam expansion, however, declined beyond 2% concentration level for both the additives. Kabirullaha and Wills (1988) and Lah *et al.* (1980) had also reported similar observations while studying the foaming properties of sunflower and soy protein, respectively. Attaining a stable value or decrease in rate of foam expansion beyond certain concentration of foaming additives might be due to increase in viscosity of the system.

Table 4.14 Analysis of variance for the effect of type and concentration of foaming additive on foam expansion (FE) and foam stability (FS) of tomato concentrate (25°B, 27% TS)

Source of variation	Degrees of freedom	Sum of squares		F_{cal}	
		FE	FS	FE	FS
Replication	1	2.04	0.38	0.15^{NS}	0.02^{NS}
Type of additive (AdT)	3	16576.32	930.31	401.52**	15.49**
Additive Concentration (AdC)	4	9805.66	8759.72	178.14**	109.39**
AdT × AdC	12	5291.65	363.26	32.05**	1.51^{NS}
Error	19	261.46	380.37		
Total	39	31937.13	10434.03		

**Significant at 1% level ^{NS}Non-significant

At too high additive concentration, the viscosity may be high enough to decrease air incorporation and thus decreases formation of air cells (Lah *et al.*, 1980). It can be seen from the **Fig. 4.18** that at any concentration of additives, maximum foam expansion was obtained with GMS followed by combination of GMS and pectin (1:1), pectin and CMC, in that order. This may be due to the fact that GMS is a surfactant, whereas pectin and CMC are thickening agents. Being a surface active agent, GMS sufficiently lowered the surface tension of the tomato concentrate and created an adequately thick surface to retain air cells. Combination of pectin and GMS, however, improved the foam expansion but was unable to form foams as high as pure GMS. The superiority of GMS over other edible foam inducers for several other fruit juice concentrates and aqueous food system have also been reported by Ginnette *et al.* (1963); Bates (1964); Cooke *et al.* (1976) and Nigam (1976).

Foam stability increased with the increase in additive concentration irrespective of the type of chemical (Fig. 4.19). In case of GMS, it followed linear relationship with concentration, while for the other three additives the relationship was non-linear. At 0.5% level of additive concentration, the difference in stability due to foaming agents was appreciable and the values were found to be 65, 63, 49.5 and 55% respectively for CMC, pectin, mixture of pectin and GMS and GMS. On the other hand, the difference in stability was not substantial at higher concentration level. The values of foam stability at 2.5% concentration with CMC, pectin, mixture of pectin and GMS and GMS were close to each other and found to be 100, 99.5, 98.8 and 99% respectively. Furthermore, the foam stability due to CMC and pectin was not appreciable over the entire range of concentration studied. Foam stability increased upon increasing the concentration of CMC, pectin and mixture of pectin and GMS upto 1% after which any further increase in their concentrations decreased the rate of increase in foam stability. On the other hand, foam stability increased linearly with GMS upto 2% concentration. Lower concentration (upto 1.5%) of GMS showed lower stability as compared to the other three additives. At 2.5% concentration of GMS the foam stability (98%) was, however, comparable to those of other three additives.

From the foam expansion and stability data, it can be seen that at 2% concentration, GMS resulted in much higher foam expansion (114%) as compared to other three additives, viz., pectin (41%), CMC (36%) and 1:1 combination of pectin and GMS (62%), whereas there was not much difference in foam stability by these chemicals (92% for GMS, as compared to 98, 100 and 94% by pectin, CMC and mixture of GMS+pectin respectively). The density of the foam produced by the use of 2% GMS suspension and at optimum operating conditions of the foaming device was found to be 510 kg m^{-3}. This was slightly higher than the value (400 kg m^{-3}) suggested by Hart *et al.* (1963) and Chandak and Chivate (1972) and slightly lower than the value (550 kg m^{-3}) suggested by Ginnette *et al.* (1963) for foam-mat drying of tomato concentrate. Since 2% GMS concentration gave the best results over the other three chemicals studied this was used for the production of foam out of 25°B tomato concentrate for foam-mat drying studies to follow.

4.6.4 Prediction of foam expansion in tomato concentrate

The values of actual foam expansion (FE_{Ta}) for tomato concentrate (25°B, 27% TS) using GMS as foaming agent at varying levels of concentration from 0.5 to 2.5%, were obtained under optimum conditions of foaming device, *i.e*, whipping speed, X_1 = 840 ± 5 rev min^{-1}; whipping time, X_2 = 4.5 min ± 10 s; air flow rate, X_3 = 10.3 ± 0.25 *l* min^{-1}; blade diameter, X_4 = 60 mm; and liquid depth, X_5 = 47 ± 1 mm. The results are presented in **Table 4.15**. The table also gives the values of R_F and the predicted values of the foam expansion, FE_{Tpred} calculated using **Eqn. (3.13)** and **Eqn. (3. 14)**, respectively.

The values of `R_F' (**Eqn. 3.13**) as the ratio of actual foam expansion of tomato concentrate with varying concentration of GMS to the actual foam expansion of sugar solution containing 1% GMS were calculated. Fig. 4.20 gives the plot of R_F and additive concentration, F, in the tomato concentrate. It may be observed from the figure that the values of R_F and F were linearly related. The equation obtained was :

$$R_F = 0.0852 + 0.298\,F \quad (r^2 = 0.95) \qquad \ldots \textbf{(4.17)}$$

where R_F is the ratio of actual foam expansion of tomato concentrate with any concentration of foaming agent to the actual foam expansion of sugar solution containing 1% GMS and F is the additive concentration in per cent.

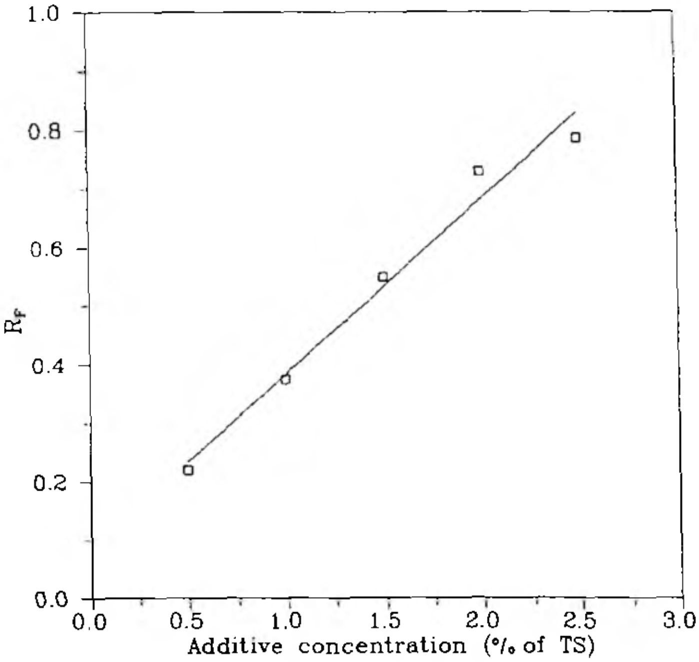


Fig. 4.20 Relationshipbetween R_F (Eqn. 4.17) and concentration, F of foaming additive (GMS) in tomato concentrate

The ratio (FE_{Ta} - FE_{Tpred})/FE_{Tpred} was calculated for all the values of F and it may be seen from **Table 4.15** that the actual foam expansion, FE_{Ta} differed by not more than 8.1% of the predicted value, FE_{Tpred}.

Table 4.15 Effect of additive concentration on actual and predicted foam expansion in tomato concentrate (25°B, 27% TS)

Additive concentration F, %	Foam expansion, %		R_F	$(FE_{Ta} - FE_{Tpred})/FE_{Tpred}$
	Actual (FE_{Ta})	Predicted (FE_{Tpred})		
0.5	34.00	37.00	0.219	- 0.081
1.0	58.00	60.55	0.374	- 0.042
1.5	84.50	84.09	0.545	0.004
2.0	113.50	107.63	0.732	0.055
2.5	122.00	131.17	0.787	- 0.070

4.7 Foam-mat Drying of Concentrated Tomato Juice

Investigations were carried out on (i) drying characteristics of foamed tomato concentrate (ii) estimation of effective moisture diffusivity (iii) quality of dehydrated product and (iv) optimization of drying parameters for foam-mat drying of concentrated tomato juice.

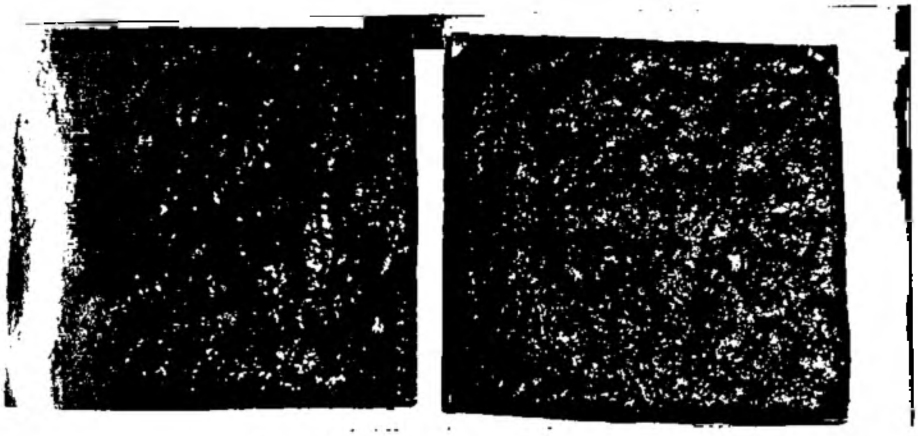
4.7.1 Drying characteristics of foamed tomato concentrate

The drying characteristics of foamed tomato concentrate in the form of a slab were studied under different drying conditions. The effect of drying process variables on the rate of moisture removal as well as the time required to the minimum moisture content were investigated. Twenty seven experiments were conducted in order mentioned in **Table 3.5** (Sec.3.7.6). The observations for each of the experiments are given in **Appendix-E** (Table E-1). The experimental parameters and final results are shown in **Table 4.16**. It was observed during drying that the removal of sufficient moisture caused the foam (cake) to collapse. **Fig. 4.21** shows the views of partially and finally dried slab of foamed tomato concentrate. In order to understand the effect of process variables on drying characteristics, experimental data were analysed and plots between moisture content (%, db) and drying time (min) were made. A few drying curves examplified by **Figs. 4.22 to 4.30** exhibit the change of moisture content of samples with time under different drying conditions.

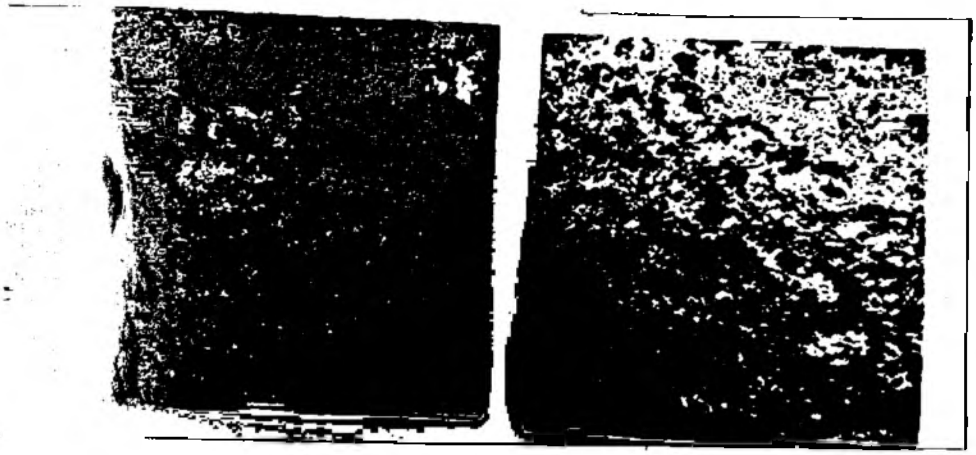
Table 4.16 **Final moisture content (% db) and drying time (min) for 3 mm thick tomato slab at different drying conditions**

Experiment No.	Drying air condition			Final moisture content, %, (db)	Drying time* corresponding to final moisture content, min
	Temperature, °C	Relative Humidity, %	Air velocity, m s^{-1}		
1	45	40	1.0	11.00	320
2	45	35	1.0	9.15	300
3	45	26	1.0	7.65	250
4	45	40	1.5	9.70	280
5	45	35	1.5	8.45	260
6	45	26	1.5	7.50	210
7	45	40	2.0	9.50	230
8	45	35	2.0	8.15	210
9	45	26	2.0	7.00	180
10	55	25	1.0	6.35	200
11	55	21	1.0	5.80	180
12	55	16	1.0	5.30	160
13	55	25	1.5	6.00	180
14	55	21	1.5	5.65	150
15	55	16	1.5	4.55	140
16	55	25	2.0	5.75	160
17	55	21	2.0	5.15	130
18	55	16	2.0	4.10	120
19	65	15	1.0	3.70	130
20	65	13	1.0	3.50	120
21	65	10	1.0	3.20	120
22	65	15	1.5	3.40	110
23	65	13	1.5	3.30	100
24	65	10	1.5	3.00	90
25	65	15	2.0	3.40	100
26	65	13	2.0	3.00	90
27	65	10	2.0	3.00	90

* The time at which the drying rate reached close to zero was taken as drying time and the corresponding moisture content as the final moisture content



(a) after 30 min drying



(b) after 50 min drying

(c) after final drying

Fig. 4.21 View of tomato foam during drying

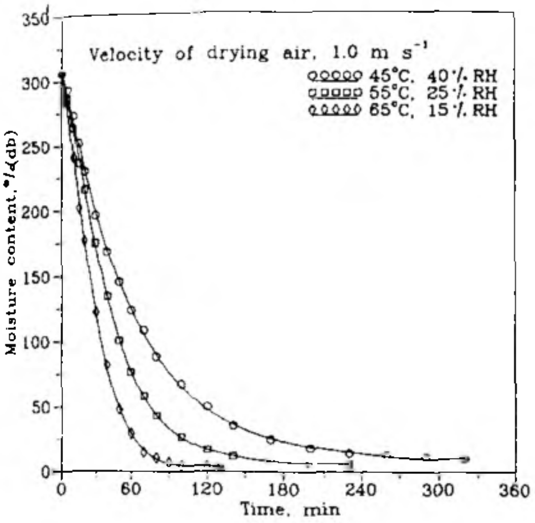


Fig. 4.22 Variation in moisture content of tomato foam with drying time at different air temperatures

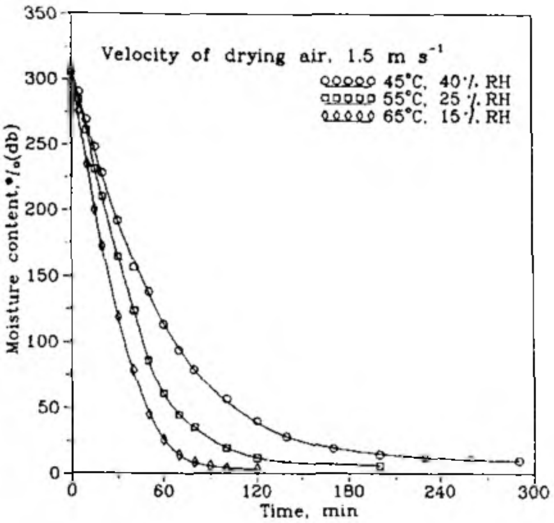


Fig. 4.23 Variation in moisture content of tomato foam with drying time at different air temperatures

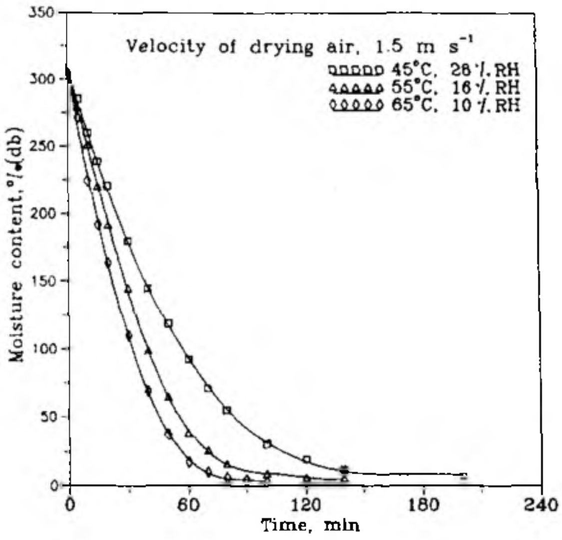


Fig. 4.24 Variation in moisture content of tomato foam with drying time at different air temperatures

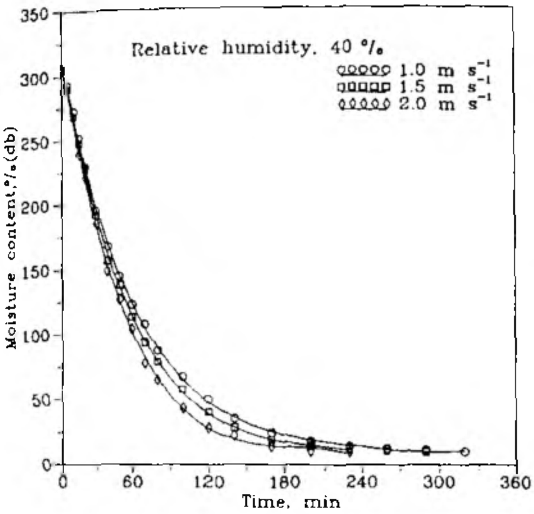


Fig. 4.25 Variation in moisture content with drying time at different velocities at 45°C

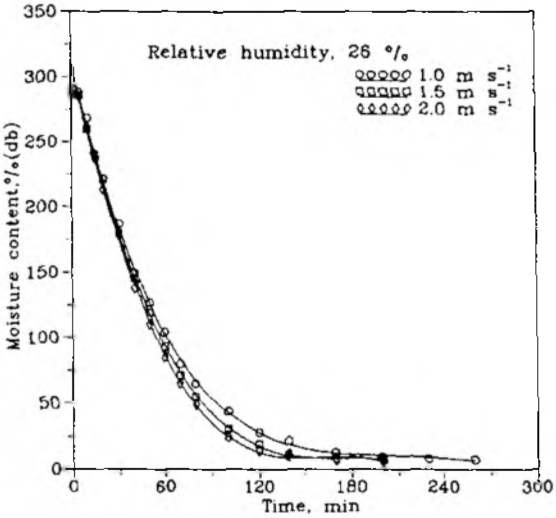


Fig. 4.26 Variation in moisture content with drying time at different velocities at 55°C

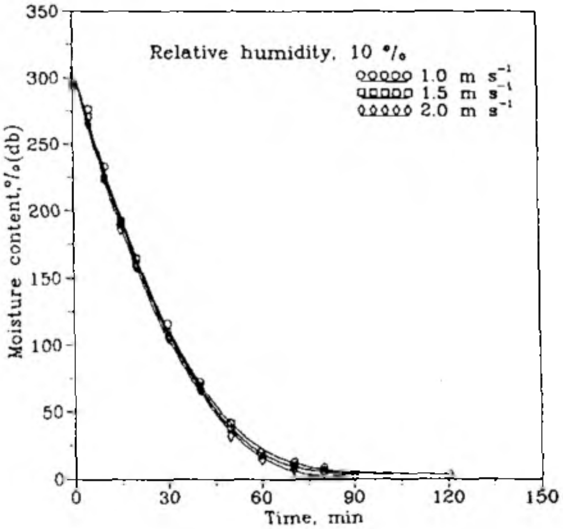


Fig. 4.27 Variation in moisture content with drying time at different velocities at 65°C

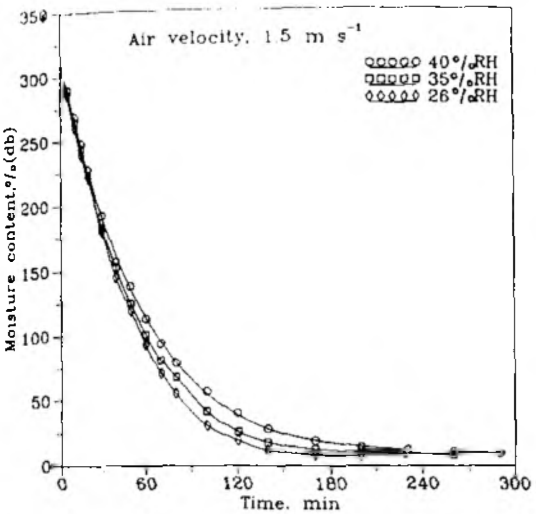


Fig. 4.28 Variation in moisture content with drying time for different relative humidities of air at 45°C

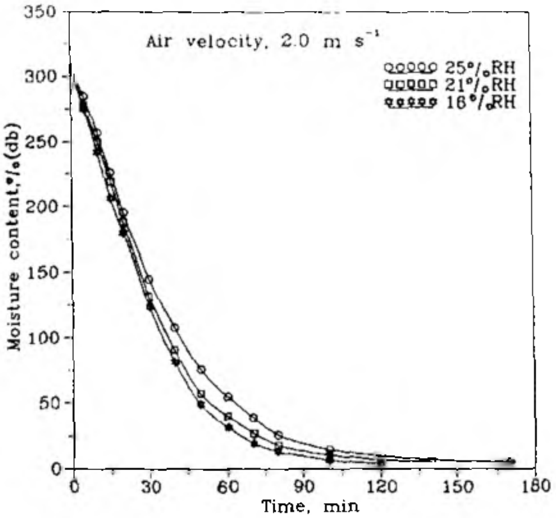


Fig. 4.29 Variation in moisture content with drying time for different relative humidities of air at 55°C

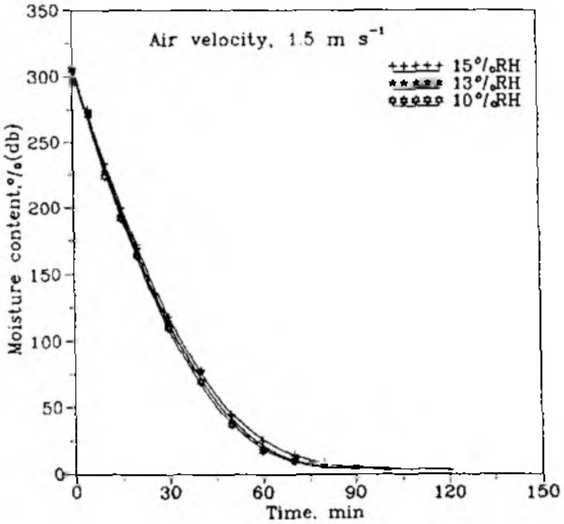


Fig. 4.30 Variation in moisture content with drying time for different relative humidities of air at 65°C

It can be observed from the **Figs. 4.22 to 4.30** that the moisture content of foamed tomato concentrate reduced exponentially with drying time. The curves obtained were similar to the drying curves reported by earlier researchers (Bissette *et al.*, 1963; Komanowsky *et al.*, 1964; Berry *et al.*, 1965a; Akintoye and Oguntunde, 1991 and Beristain *et al.*, 1993) for the foam-mat drying of foods and chemicals. The non-linearity of the drying curves indicated multiple stages of drying process which might have been caused owing to the periodic bursting of successive layers of foam bubbles as drying progressed. When a layer of bubbles bursts, the cake possibly attains an open porous structure resulting in acceleration of moisture diffusion from the uppermost layer.

A constant drying rate period might be present in the beginning of each experimental run, but it was perhaps too short to be noticed. Though the plots (**Figs. 4.22 to 4.30**) show constant slopes at initial stages of drying, the plot between drying rate versus drying time (not shown) did not show any constant rate period. The critical moisture content of fruits and vegetables are considerably higher than those of inorganic materials as reported by Sarvacos and Charm (1962) which may be ascribed to the colloidal and hydrophillic nature of the food materials. This causes the water molecules to be held tightly upon concentration and conversion into foam. As a consequence, during foam-mat drying of concentrated tomato juice, only the falling rate period was prevalent and the constant rate period was absent. This indicated a diffusion-controlled mechanism of drying. Many investigators (Chirife, 1971; Vaccarezza et al., 1974 and Karathanos *et al.*, 1990) have earlier observed that the immediate onset of the falling rate was a characteristic of aqueous food materials. Further, in all the cases, the drying rate was higher at the beginning of the process (**Figs. 4.22 to 4.30**) where moisture was easily evaporated by the drying air. As the tomato foams dry, shrinkage occurs, which perhaps restricted diffusion and caused decrease in the drying rate.

It may be seen from the **Fig. 4.22** that with the increase in air temperature, the drying rate increased which not only reduced the drying time but also dried the material to a lower moisture content than that at lower temperature (**Table 3.16**). The increase in drying rate with the increase in temperature was due to: (i) a rise in vapour pressure of water within the drying material resulting in faster migration of moisture from interior to the surface, and (ii) the decrease in relative humidity of drying air with increase in temperature enhancing the rate of moisture evaporation from the product surface. Similar effect was obtained with varying velocities and relative humidity of air (**Figs. 4.23 and 4.24**).

The slope of the drying curve increased with the increase in air velocity (**Figs. 4.25 to 4.27**). This indicated an increase in moisture removal rate with increase in air velocity.

This effect was observed for all the temperatures studied. Menon and Majumdar (1987) stated that during the falling rate period, an increase in air velocity could enhance heat transfer rate and speed up the drying process. Increasing the air velocity beyond 2.0 m s^{-1} (not shown), however, resulted in bursting and collapse of foam bubbles at a faster rate which adversely affected the moisture evaporation.

The effect of air velocity was found to be more prevalent at lower temperature as can be seen from **Figs. 4.25** and **4.26**. The net reduction in drying time due to increase in air velocity, however, decreased with the increase in air temperature **(Table 4.16)**. This can also be seen in **Fig. 4.27** where the effect of air velocity at 65°C air temperature is not as high as at 45 and 55°C. Similar observations were also reported by Cooke *et al.* (1976) for foam-mat drying of mango puree. It is also evident (**Figs. 4.25 to 4.27**) that during 30 to 50 min of the initial stage of drying, increase in air flow rate from 1.0 to 1.5 and 2.0 m s^{-1} did not affect the rate of moisture removal. The effect of air velocity appeared to be more pronounced in the final stages of drying where higher velocity helped in early attainment of the equilibrium condition. This is in contrast to the findings of Cooke *et al.* (1976) who reported non-significant effect of air velocity in the final stages of drying. According to Komanowsky *et al.* (1964), the foam-mat drying profiles are product dependent.

Figs. 4.28 to **4.30** show the influence of relative humidity on drying behaviour of foamed tomato concentrate. It is evident from the figures that at any air temperature and velocity, the slope of the drying curves appeared to be steepened with the decrease in relative humidity indicating increased rate of drying with the decrease in relative humidity. The effect of relative humidity on drying rate was seen to be more prevalent at drying air temperatures of 45 and 55°C, whereas at 65°C its value reduced to 10-15% showed small or negligible effect (**Fig. 4.30**). This behaviour was in agreement with the findings of several researchers who reported an insignificant effect of relative humidity below 15% (Diamante and Munro, 1991) and 20% (White *et al.*, 1973 and Chiang and Petersen, 1985) for the air drying of food materials including vegetables. Similar effect of relative humidity was observed at other three air velocities studied.

Effect of process variables on drying rate

It was noted from the experiments that at constant drying conditions, the moisture ratio [$MR = (M-M_e)/(M_i-M_e)$] of tomato foam was related exponentially to the drying time, θ_d (Figs. 4.31 to 4.33). Therefore, the Eqn. (4.18) could be used to analyze the drying processes.

$$\frac{M - M_e}{M_i - M_e} = a_d\, e^{-k_d\, \theta_d} \qquad \ldots (4.18)$$

where M is the moisture content of the sample (%, db) at time θ_d, M_e is the equilibrium moisture content, M_i is the initial moisture content and θ_d is the drying time. a_d and k_d are the constants where the later is known as drying rate constant.

The values of equilibrium moisture content, M_e required for the computation of moisture ratio in Eqn. (4.18) at different air conditions was obtained from the GAB model (Eqn. 3.1). These values along with the GAB constants (Mo_g, C_g and k) are presented in the Table 4.17.

Table 4.17 GAB constants and equilibrium moisture content (%, db) for different drying conditions

Drying air conditions		Values of GAB constants			EMC, M_e
Temperature, °C	Relative Humidity, %	Mo_g	C_g	k	(%, db)
45	40	0.044	7.248	1.115	6.79
45	35	0.044	7.248	1.115	5.95
45	26	0.044	7.248	1.115	4.64
55	25	0.036	5.533	1.143	3.46
55	21	0.036	5.533	1.143	3.02
55	16	0.036	5.533	1.143	2.44
65	15	0.032	2.554	1.166	1.36
65	13	0.032	2.554	1.166	1.18
65	10	0.032	2.554	1.166	0.91

Eqn. (4.18) was used to analyse the drying data of 27 experiments and the drying rate constant, k_d was determined. The experimental values of drying conditions and the values of drying constants, a_d and k_d are given in **Table 4.18**. It can be seen from the table that the value of k_d varies from 0.01507 to 0.05686 while the value of constant 'a_d' (Eqn. 4.18) did not vary appreciably with the variation in drying conditions. The correlation coefficient for each of the set of experimental values of MR and θ_d was found to be greater than 0.9.

4.7.2 Diffusivity analysis

When values of log (MR) were plotted with drying time, θ_d (**Eqn. 3.18**), assuming a constant value of diffusivity, a linear plot was expected, but deviations from linearity were observed. This occurred mainly at higher values of θ_d and at higher drying temperatures. A few such plots are presented in **Figs. 4.31**to **4.33**. The deviation from linearity of the **Eqn. (3.18)** was believed to be due to shrinkage of foam thickness, bursting of air bubbles and changes in material temperature during the process of drying. It may be also due to the change in actual temperature of the material during drying. This temperature remained below the dry bulb temperature of air throughout the experiment. Our observations are in confirmation with the results reported by Alzamora *et al.* (1980) who also have reported the temperature difference between product and drying air. This increased the slope of the drying curve and hence the effective diffusivity could be attributed to the increase in temperature.

In view of the limited information in literature on mechanism of food foam dehydration and due to complexity of the drying process, a lumped value of diffusivity, called effective diffusivity was calculated. The experimental drying curves (log MR *vs.* θ_d) were used to calculate the average value of diffusivity (D) using 7, 5, 3 or 1 term of the series solution (**Eqn. 3.16**). In all the cases, the D values obtained using only the first term were nearly equal to those obtained with 3, 5 or 7 terms. Therefore, the average diffusivity (D) *i.e.* effective diffusivity was calculated from the slope, k_d (drying rate constant) of linear analysis (**Eqn. 4.18**) using least square technique. The values of slope (k_d) for all the 27 experiments are given in **Table 4.18**.

Many workers including Marousis *et al.* (1989) and Karathonas *et al.* (1990) have reported that the diffusivity (D) may vary considerably with the moisture ratio, and consequently with the moisture content and this became evident in dying curves (log MR *vs* θ_d) being non-linear, while **Eqn. (4.18)** with constant diffusivity yields straight line curves

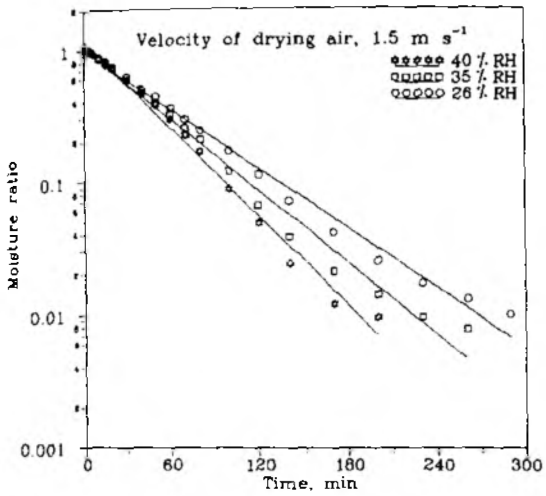


Fig. 4.31 Plot between moisture ratio and drying time for different relative humidities at 45°C air temperature and 1.5 m s^{-1} air velocity

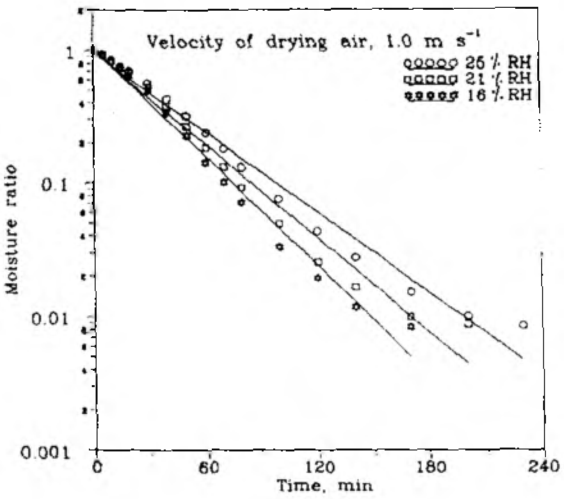


Fig. 4.32 Plot between moisture ratio and drying time for different relative humidities at 55°C air temperature and 1 m s^{-1} velocity

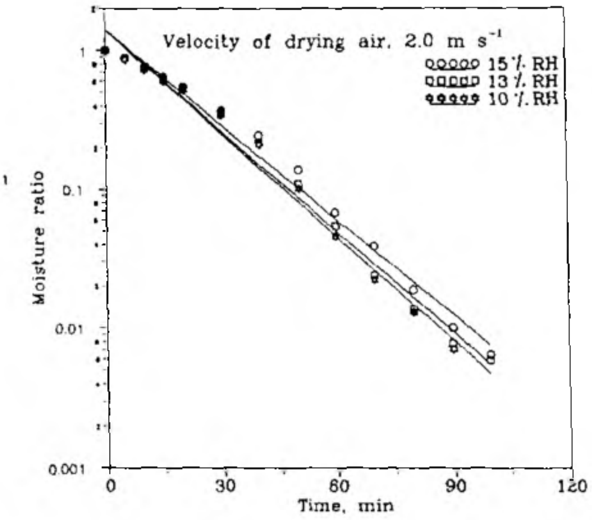


Fig. 4.33 Plot between moisture ratio and drying time for different relative humidities at 65°C air temperature and 2 m s^{-1} velocity

and therefore, the values of D were obtained from the slope of the drying curve.

Effect of process variables on diffusivity

The values of effective moisture diffusivity (D) calculated from the slope of the linear plots (**Fig. 4.31** to **4.33**) for a slab of 3 mm thick foamed tomato concentrate at different conditions of drying air are given in **Table 4.18**. The table shows that the value of diffusivity varied from 0.916×10^{-9} to 3.457×10^{-9} $m^2\ s^{-1}$. In order to understand the effect of each of the process variables and their contribution on the effective moisture diffusivity, regression analysis was done. The values of process variables were normalized (coded) between -1 and +1 using **Eqn (3.11)**.

The following first order regression model (**Eqn. 4.19**) with 0.96 coefficient of determination (r^2) was found to be adequate for describing the relationship of effective moisture diffusivity for foam-mat drying of tomato concentrate in terms of coded variables X_1, X_2 and X_3 listed in **Table 3.5**.

$$D_{pred} = 10^{-9}(2.0211 + 0.5243\ X_1 - 0.5025\ X_2 + 0.2936\ X_3) \quad (r^2=0.96) \qquad \textbf{... (4.19)}$$

The relationship between coded and actual values of the variables are:

$$X_1 = (T_d - 55)/10;\ X_2 = (Rh_d - 25)/15\ \mathit{and}\ X_3 = (V_a - 1.5)/0.5$$

where,D_{pred} is the estimated moisture diffusivity and, X_1, X_2 and X_3 represent coded values of the drying air temperature, relative humidity and air velocity, respectively.

Eqn. (4.19) can be expressed in terms of the natural values of variables by decoding the values of X_1, X_2 and X_3 using **Eqn. (3.11)**.

$$D_{pred} = 10^{-9}(-0.906 + 0.0524\ T_d - 0.0335\ Rh_d + 0.5872\ V_a) \qquad \textbf{... (4.20)}$$

where D_{pred} is the same as in **Eqn. (4.19)** and T_d, Rh_d and V_a are the drying air temperature in °C, relative humidity in per cent and air velocity in $m\ s^{-1}$, respectively.

Inspection of the magnitude of coefficients of the variables in **Eqn. (4.19)** revealed that the effect of drying air temperature (X_1) was the highest followed by relative humidity (X_2) and air velocity (X_3), in that order. Further, the positive coefficient of air temperature and velocity suggested that increasing the level of these two variables increased the

Table 4.18 Values of constants in Eqn. (4.18) with correlation coefficients and moisture diffusivity (D) for 3 mm thick tomato foam at different drying conditions

Experiment No.	Drying air conditions			Values of constants in Eqn. (4.18)		Correlation coefficient, r^2	Diffusivity $(D \times 10^9)$, $m^2\ s^{-1}$
	Temperature, °C	Relative Humidity, %	Velocity, $m\ s^{-1}$	a_d	k_d		
1	45	40	1.0	0.952	0.01507	0.99	0.916
2	45	35	1.0	1.002	0.01758	0.99	1.069
3	45	26	1.0	1.017	0.01977	0.99	1.202
4	45	40	1.5	0.980	0.01713	0.99	1.041
5	45	35	1.5	1.026	0.02082	0.98	1.229
6	45	26	1.5	1.172	0.02560	0.99	1.556
7	45	40	2.0	1.092	0.02172	0.99	1.320
8	45	35	2.0	1.116	0.02573	0.99	1.564
9	45	26	2.0	1.218	0.02886	0.96	1.755
10	55	25	1.0	0.982	0.02323	0.98	1.412
11	55	21	1.0	0.999	0.02711	0.97	1.648
12	55	16	1.0	1.064	0.03154	0.97	1.917
13	55	25	1.5	1.027	0.02695	0.98	1.638
14	55	21	1.5	1.093	0.03218	0.98	1.956
15	55	16	1.5	1.215	0.03819	0.99	2.322
16	55	25	2.0	1.136	0.03246	0.99	1.973
17	55	21	2.0	1.174	0.03769	0.99	2.291
18	55	16	2.0	1.306	0.04517	0.99	2.746
19	65	15	1.0	1.170	0.04302	0.98	2.615
20	65	13	1.0	1.203	0.04551	0.98	2.267
21	65	10	1.0	1.199	0.04641	0.98	2.821
22	65	15	1.5	1.280	0.04743	0.98	2.883
23	65	13	1.5	1.349	0.05172	0.98	3.144
24	65	10	1.5	1.339	0.05247	0.98	3.190
25	65	15	2.0	1.413	0.05228	0.98	3.178
26	65	13	2.0	1.402	0.05539	0.98	3.367
27	65	10	2.0	1.402	0.05686	0.98	3.457

diffusivity. On the other hand, the negative coefficient of the relative humidity indicated that increase in its level reduced diffusivity.

Analysis of variance (**Appendix-E, Table E-2**) for the regression equation (**Eqn. 4.19**) showed that the effective diffusivity was affected by all the three variables, *viz.*, air temperature, relative humidity and air velocity of the drying air at 1% level of significance.

It can also be seen from **Table 4.18** that keeping other variables constant, the effective diffusivity increased with the increase in temperature and with velocity, whereas it decreased with the increase in relative humidity. Increase in diffusivity with the increase in air temperature is obvious, as it increases the kinetic energy of the water molecules. Similarly, as the air velocity increases, the heat transfer rate increases, which in turn increases the diffusivity. At drying air condition of 45°C temperature and 40% relative humidity, the value of diffusivity increased by increasing the air velocity. The values of diffusivity were 0.916×10^{-9}, 1.041×10^{-9} and 1.320×10^{-9} m^2 s^{-1} for the air velocity of 1.0, 1.5 and 2.0 m s^{-1}, respectively. The effects of air velocity and relative humidity were found to be more pronounced at 45 and 55°C temperatures and negligible at 65°C temperature. One possible reason could be the increase in foam collapse with the increase in temperature and velocity of drying air. At higher temperature, since the material attains the air temperature more rapidly as compared to lower temperature, the positive influence of air velocity on the effective diffusion coefficient cannot be explained by the higher rate of heat transfer. However, an overall increase in effective moisture diffusivity was obtained with the increase in temperature.

A number of researchers have chosen to neglect the effect of air flow rates in the analysis of drying data and in diffusivity in particular, citing the conclusions of Henderson and Pabis (1962) that resistance to moisture movement at the surface is negligible compared to internal resistance for turbulent flows, which occur in most of the dryers. However, Islam and Flink (1982) pointed out that at air velocities of 2.5 m s^{-1} or less, the external mass transport resistance is significant and needs to be considered in the analysis of drying data. Diamante and Munro (1991) have reported the air velocity as one of the major variables to be considered in the air drying process. This study has also shown the effect of air velocity which was within the range of 1.0-2.0 m s^{-1}. The effect of air temperature on drying of biological materials is well documented in the literature (Igbeka, 1982; Hutchinson and Otten, 1983; Chiang and Peterson, 1985).

4.7.3 Effect of drying conditions on quality of product

The results of the preliminary experiments indicated that there was insignificant change in the total as well as reducing sugars, and total acids contents (dry matter basis) of tomato concentrate during its foam-mat drying process. On the other hand, excessive losses in vitamin C (ascorbic acid) and lycopene contents were noticed. The effect of drying conditions on retention of these two constituents was, therefore, studied in detail which were further used in the optimization of the drying process variables. Experimental data on ascorbic acid and lycopene content in the dried samples are presented in **Table 4.19**.

Table 4.19 shows that lycopene and ascorbic acid contents in the dried samples varied considerably with the variation in drying conditions. The retention of ascorbic acid varied from 53.5 to 72.2% and that of lycopene from 72 to 90%.

It can be seen from **Table 4.19** that the lycopene content in the samples dried at 45°C air temperature ranged between 79 and 87% depending upon the other process variables. A 10°C increase in air temperature from 45 to 55°C resulted in only a slight increase in the retention of lycopene (5-6%), probably due to the reduction in drying time. A further increase in temperature to 65°C caused reduction in its content by 12 to 13% as compared to that at 55°C. This indicated a pronounced effect of temperature at higher level which in turn accelerated the destruction rate of lycopene. Further, drying at 65°C not only reduced the drying time but also yielded a product with comparatively less moisture content. Pigments such as lycopene, being polyunsaturated hydrocarbon, degrade via a free radical oxidative mechanism which takes place at a higher rate in low moisture foods (Mishkin *et al.*, 1982). This behaviour was in contrast to that observed by Cooke *et al.* (1976) during the foam-mat drying of mango puree at 71-76°C with no significant reduction in its carotenoid contents. It can be seen from the **Table 4.19** that at a constant temperature and relative humidity of drying air, increasing the air velocity by 0.5 m s^{-1} increased the lycopene content by 3 to 4%, while an increase in relative humidity at constant velocity decreased the lycopene content by similar values for a constant temperature. This was due to the reduction in drying time and lycopene degradiation being an oxidative reaction, its magnitude depended on drying time.

The values of ascorbic acid content in the dried samples (**Table 4.19**) indicated an excessive loss and its retention was maximum at drying air temperature of 55°C. The per

Table 4.19 Effect of drying conditions on retention of per cent lycopene and ascorbic acid contents after drying to final moisture content and required drying time

Experiment No.	Drying air conditions			Drying time, min	Retention	
	Temperature, °C	Relative Humidity, %	Velocity, m s^{-1}		Lycopene, %	Ascorbic acid, %
1	45 (-1)	40 (1)	1.0 (-1)	320 (1)	79.00	53.50
2	45 (-1)	35 (0.667)	1.0 (-1)	300 (0.826)	80.95	54.00
3	45 (-1)	26 (0.067)	1.0 (-1)	250 (0.391)	84.35	58.30
4	45 (-1)	40 (1)	1.5 (0)	280 (0.652)	82.00	56.10
5	45 (-1)	35 (0.667)	1.5 (0)	260 (0.478)	84.00	58.70
6	45 (-1)	26 (0.067)	1.5 (0)	210 (0.044)	86.00	62.75
7	45 (-1)	40 (1)	2.0 (1)	230 (0.217)	85.10	62.55
8	45 (-1)	35 (0.667)	2.0 (1)	210 (0.044)	85.65	64.00
9	45 (-1)	26 (0.067)	2.0 (1)	180 (-0.217)	87.00	67.15
10	55 (0)	25 (0)	1.0 (-1)	200 (-0.044)	84.00	59.75
11	55 (0)	21 (-0.267)	1.0 (-1)	180 (-0.217)	85.00	63.50
12	55 (0)	16 (-0.6)	1.0 (-1)	160 (-0.391)	87.00	67.50
13	55 (0)	25 (0)	1.5 (0)	180 (-0.217)	85.00	63.50
14	55 (0)	21 (-0.267)	1.5 (0)	150 (-0.478)	87.35	68.20
15	55 (0)	16 (-0.6)	1.5 (0)	140 (-0.565)	88.00	72.80
16	55 (0)	25 (0)	2.0 (1)	160 (-0.391)	87.00	66.50
17	55 (0)	21 (-0.267)	2.0 (1)	130 (-0.652)	89.00	73.40
18	55 (0)	16 (-0.6)	2.0 (1)	120 (-0.739)	90.00	78.20
19	65 (1)	15 (-0.667)	1.0 (-1)	130 (-0.652)	72.00	59.80
20	65 (1)	13 (-0.8)	1.0 (-1)	120 (-0.739)	73.00	63.40
21	65 (1)	10 (-1)	1.0 (-1)	120 (-0.739)	73.00	63.40
22	65 (1)	15 (-0.667)	1.5 (0)	110 (-0.826)	75.00	65.50
23	65 (1)	13 (-0.8)	1.5 (0)	100 (-0.931)	75.00	70.60
24	65 (1)	10 (-1)	1.5 (0)	90 (-1)	78.00	71.70
25	65 (1)	15 (-0.667)	2.0 (1)	100 (-0.931)	75.00	71.20
26	65 (1)	13 (-0.8)	2.0 (1)	90 (-1)	77.00	70.85
27	65 (1)	16 (-1)	2.0 (1)	90 (-1)	77.00	72.20

cent retention of ascorbic acid was 53.5 to 67.15% at 45°C, 59.75 to 78.2% at 55°C and 59.80 to 72.2% at 65°C. The results are in good agreement with those of Cooke *et al.* (1976) who reported excessive loss of ascorbic acid during foam-mat drying of mango puree. Bissett *et al.* (1963) and Berry *et al.* (1965a), however, did not find any detectable loss of vitamin C in orange and grapefruit juice concentrates which were foam-mat dried at 71 to 88°C (160 to 190°F).

The higher values of ascorbic acid (AA) at higher temperature was due to the shorter drying time. Further, an excess increase in temperature adversely affected the retention of ascorbic acid as can be seen from **Table 4.19** where its value at 55°C was higher than that at 65°C even for the shorter drying time. Ascorbic acid has been reported to be more temperature sensitive at higher moisture contents (Mishikin *et al.*, 1982, 1983, 1984; Banga and Singh, 1994). In addition, during the early stages of the falling rate period, drying rate remains sufficiently high keeping the material temperature low and thereby counteracting the effects of high moisture on ascorbic acid degradiation. As the drying progresses, the temperature rises but the nutrient becomes more stable because of the low moisture contents.

It can also be seen from **Table 4.19** that the increase in air velocity increased the retention of ascorbic acid, whereas relative humidity had the reverse effect on its retention. With the increase in air velocity by 0.5 m s^{-1} at a particular air temperature, retention of ascorbic acid was increased by 1 to 7.5%, while an increase in relative humidity decreased the retention of ascorbic acid by similar value at constant air temperature and velocity. The possible reasons could be the shorter drying time and lower rate of oxygen diffusion into material than the moisture from the material.

In order to understand the effect of each of the process variables and their contribution on the retention of lycopene and ascorbic acid, regression analysis of the experimental data using step-down technique was done, where the factors with F-values less than one were rejected as described by Snedecor and Cochran (1967). The time required to dry the sample to the minimum possible moisture content was also converted into coded values using **Eqn. (3.11)** (**Sec 3.6.4**). The coded values corresponding to actual values of each variable are given in parantheses in **Table 4.19**. The following second-order polynomial regression equations **(Eqns. 4.21 and 4.22)** were found to have adequately described the relationship for retention of lycopene and ascorbic acid contents in the dried samples. High values of coefficient of determination (r^2), 0.99 and 0.98, were obtained for lycopene and ascorbic acid, respectively.

$$Ly_{ret} = 82.78 - 12.874\ X_1 \quad 11.74\ X_4 - 9.51\ X_1^2 \quad 7.93\ X_1\ X_4 \quad 3.152\ X_4^2 \qquad \ldots (4.21)$$
$$(r^2 = 0.99)$$

$$Aa_{ret} = 58.29 - 12.9\ X_1 - 22.68\ X_4 - 7.1\ X_1^2 - 8.1\ X_1X_4 + 3.61\ X_2X_4 \qquad \ldots (4.22)$$
$$(r^2 = 0.98)$$

where, Ly_{ret} and Aa_{ret} denote the per cent retention of lycopene and ascorbic acid respectively, and X_1, X_2 and X_4 represent drying air temperature, relative humidity and drying time in coded form, respectively.

Inspection of the coefficients of the variables in **Eqn. (4.21)** and **(4.22)** suggested that temperature (X_1) was the major factor contributing to destruction of lycopene and ascorbic acid followed by drying time (X_4). The negative coefficients of these variables (X_1 and X_4) in **Eqns. (4.21)** and **(4.22)** sussested that increase in their levels decreased the retention of lycopene and ascorbic acid. The negative values of their quardatic terms indicated that higher values of temperature and drying time further reduced the retention of lycopene and ascorbic acid. The presence of negative interaction terms between X_1 and X_4 indicated that increasae in temperature and drying time reduced the contents of lycopene and ascorbic acid. On the other hand, positive interaction between relative humidity (X_2) and drying time (X_4) indicated that increase in their levels increased the retention of ascorbic acid.

Results of the variance test **(Appendix-E, Table E-3)** indicated that temperature and drying time had significant effect at 1% level on retention of lycopene as well as ascorbic acid. Similarly, the quardatic effects of these two variables were also found to be significant at 1% level on destruction of lycopene, whereas temperature alone was found to have significant quardatic effect at the same level in case of ascorbic acid destruction. It is worth mentioning here that the relative humidity and velocity of the drying air had insignificant effect on the destruction of lycopene as well as ascorbic acid. In addition, an interaction effect between temperature and drying time was found to be significant at 1% level in case of lycopene retention, whereas the interections between temperature and drying time and between relative humidity and drying time each showed significant effect at 1% in case of ascorbic acid.

Eqns. (4.21 and 4.22) can be expessed in terms of natural values of variables after decoding the values of X_1, X_2, X_3 and X_4 using **Eqn. (3.11)**.

$$Ly_{ret} = -201 + 10.6\,T_d - 0.375\,\theta_d - 9.5\times10^{-2}\,T_d^2 - 2.38\times10^{-4}\theta_d^2 - 6.9\times10^{-3}\,T_d\,\theta_d \qquad \ldots\ (4.23)$$

$$Aa_{ret} = -111.7 + 7.9\,T_d + 0.135\,\theta_d - 7\times10^{-2}T_d^2 - 0.43\,Rh_d - 7\times10^{-3}T_d\theta_d + 2.1\times10^{-3}Rh_d\theta_d \qquad \ldots\ (4.24)$$

where Ly_{ret} and Aa_{ret} are the same as in **Eqns. (4.21 and 4.22)** and T_d, Rh_d, and θ_d are the air temperature in °C, relative humidity in per cent and drying time in min, respectively.

Conditioning and grinding of dried flakes

The dried product obtained in the form of flakes from the dryer were subjected to grinding using a kitchen grinder. It was observed during the experimentation that the dried flakes when cooled to room temperature could not be ground into a free flowing powder as it exhibited hygroscopicity and caking. Cooling of the flakes below room temperature under reduced level of relative humidity, however, helped overcome this problem. A further reduction of moisture content in the presence of a desiccant (calcium chloride) during conditioning was noted. Samples with moisture content less than 4% (db) and cooled to 15-20°C under reduced relative humidity (below 30%) and incubated for about 1.5 h could be converted into free flowing powders while those with moisture content more than 4% (db) could not be converted into powders even after cooling/conditioning owing to thermoplasticity of the material. This suggested the necessity for low moisture content and conditioning for preparation of tomato powder.

4.7.4 Optimization of process variables

Finding out the optimum values of drying process variables involved calculation of the stationary points (points of zero slope, or points where the first derivative is zero) and exploration of the nature (shape) of the surface around these points. The stationary points were calculated (**Table 4.20**) using the procedures described by Myers (1971) and Draper (1963). In both the cases of lycopene and ascorbic acid, the stationray points were found to be located outside the experimental region (-1 to +1). Therefore, it was necessary to move away from these points and locate the optimum inside the experimental region.

The canonical analysis for both the response variables based on the stationary points was done in accordance with the proedures adopted by Myers (1971) and Srivastav *et al.* (1994). In order to evaluate the characteristics of the stationary points, the fitted responses surfaces are written in canonical form using **Eqn. (3.12) (Sec. 3.6.4)** as:

$$Ly_{ret} = 114.34 + 0.17758W_1 - 0.50927W_2 - 6.11103W_3 - 29.75015W_4 \qquad \ldots\ (4.25)$$

$$Aa_{ret} \quad 56.678 + 3.59582\,W_1 + 0.59842\,W_2 \quad 1.85895\,W_3 \quad 27.36379\,W_4 \qquad \ldots (4.26)$$

where, Ly_{ret} and Aa_{ret} are the retention of lycopene and ascorbic acid respectively, and W_1, W_2, W_3 and W_4 are the eigenvectors or canonical variables (linear combinations of the original variables X_1, X_2, X_3 and X_4).

Table 4.20 **Predicted levels (coded) of process variables yielding optimum response of lycopene (Ly) and ascorbic acid (AA) retention in foam-mat drying of tomato concentrate**

Process variables	Symbol	Levels of optimum response/ stationary points (coded)	
		Lycopene, %	Ascorbic acid, %
Air temperature	X_1	-0.995	-0.964
Relative humidity of air	X_2	1.229	0.313
Air velocity	X_3	-5.217	-3.661
Drying time	X_4	1.290	0.976

The characteristics roots (eigenvalues or coefficients) of **Eqns. (4.25 and 4.26)** have mixed signs indicating that the stationary points existed in terms of saddle points, which in turn suggested that moving away from these points would cause an increased or decreased response, depending upon the direction of the movement (Myers, 1971; Khuri and Cornell, 1987). The location of the stationary points as well as the form of the canonical equations suggested that a situation of complicated ridge system existed for both the surface responses. Analysis of such ridge system is, however, not easily performed and is not always successful, especially when multi-response problems are investigated (Floros and Chinnan, 1987; 1988). Hence, a simpler approach (graphical solution) was chosen to further explore and explain the system. A series of contour plots of equal response as suggested by Myers (1971), Khuri and Cornell (1987) and Phirke *et al.* (1996) were generated which provided useful information.

The basic criteria considered in the optimization of process parameters was the moisture content of the end product. It was experienced that the dried samples with a moisture content more than 4.0% (db) were not suitable for their convertion into free-flowing powders. Accordingly, constraints were set such that the selected levels of processing variables would be the optimum for maximum retention of quality and a moisture content of 3.5% (slightly less than the upper limit) in the dehydrated samples.

The variables affecting the drying process are drying air temperature, relative humidity and velocity. The fourth variable, drying time depends on these three variables and therefore, was not considered. Moreover, with the known values of the three variables, the drying time can be estimated from **Eqn. (3.19)**.

A series of contour plots of equal responses for retention of lycopene and ascorbic acid, and final moisture content were generated with temperature and relative humidity (since both are related to each other) as the independent parameters keeping air velocity constant. One such set of plots corresponding to 2.0 m s^{-1} air velocity are presented in **Figs. 4.34** to 4.36. From **Figs. 4.34 and 4.35** it may be observed that the maximum possible retention of lycopene and ascorbic acid are 90 and 78% (concentrate basis) respectively. The coded levels of air temperature and relative humidity for the maximum value of these responses can be read as 0 and -0.81 and their respective actual values are 55°C and 13.75% respectively. From Fig. **4.36** it is observed that the response contour of 3.5% (db) moisture content was located far off from the point (0, -0.81). This point cannot be considered as the optimum one. Therefore, a compromise between quality attributes (*i.e.* lycopene and ascorbic acid retention) and moisture content in the dried product was necessary. Accordingly, the two responses (lycopene and ascorbic acid retention) were superimposed over the contour plot of moisture content (**Fig. 4.37**). It can be seen from **Fig. 4.37** that the values of lycopene and ascorbic acid retention corresponding to 3.5% moisture content were found to be 81 and 72% respectively which are close to the maximum possible retention (90 and 78% respectively). It is also evident from **Fig. 4.37** that several other combinations of temperature and relative humidity would also yield a product with 3.5% moisture content. However, the ranges of these two variables are considerably narrow, hence the ranges 62-65°C temperature and 10-22.5% relative humidity can be considered as the optimum.

Similar superimposed plots (**Figs. 4.38** and **4.39**) were also developed for the other experimental velocities (1.0 and 1.5 m s^{-1}) for comparison and the results are summarized in Tables 4.21 and 4.22. It may be seen from these tables that the range of temperature and relative humidity required to be maintained to dry the sample to the desired moisture content of 3.5 % (db) is nearly same, whereas the drying time varies significantly. With the increase in air velocity the drying time reduces and the retention of lycopene and ascorbic acid also increases. However, 2.0 m/s drying air velocity appeared to be the best as compared

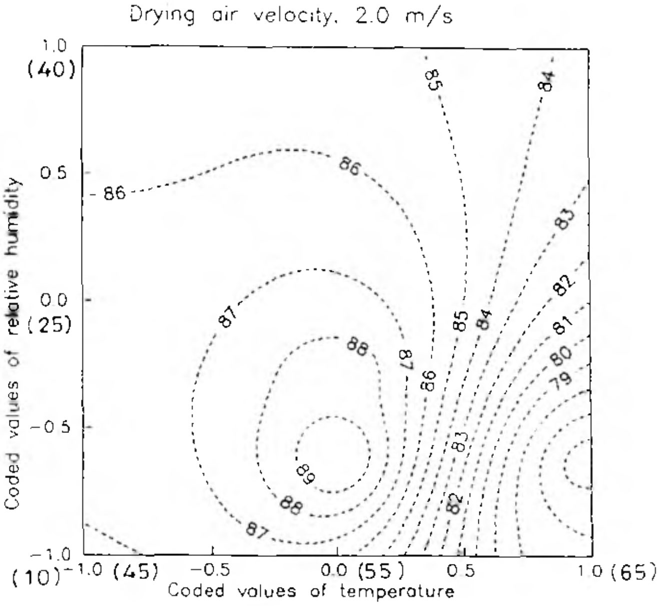


Fig. 4.34 Response contours for retention of lycopene in tomato powder dried under varying conditions of temperature and relative humidity at 2.0 m s^{-1} air velocity (figures in parentheses represent actual values)

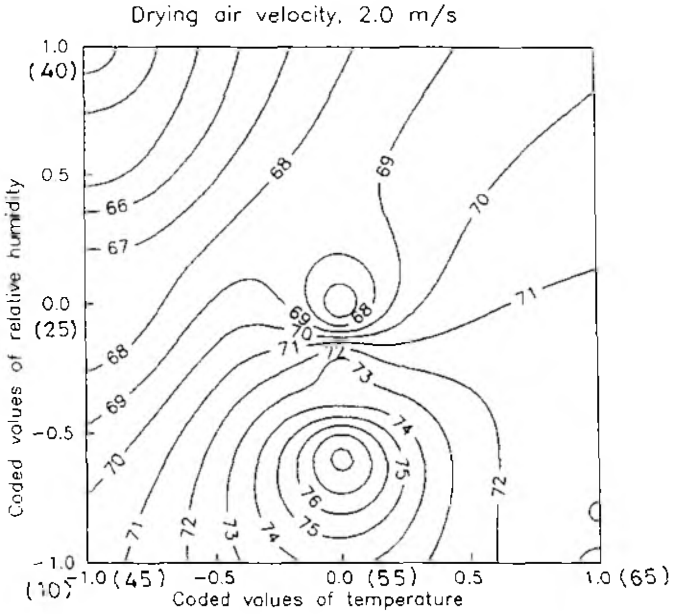


Fig. 4.35 Response contours for retention of ascorbic acid in tomato powder dried under varying conditions of temperature and relative humidity at 2.0 m s^{-1} air velocity (figures in parentheses represent actual values)

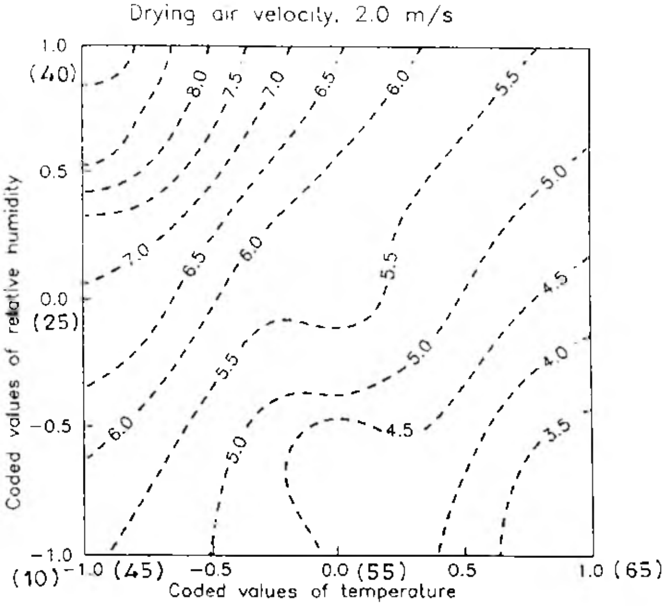


Fig. 4.36 Response contours for moisture content of tomato powder dried at different air temperatures and relative humidities at 2.0 m s^{-1} air velocity (figures in parentheses represent actual values)

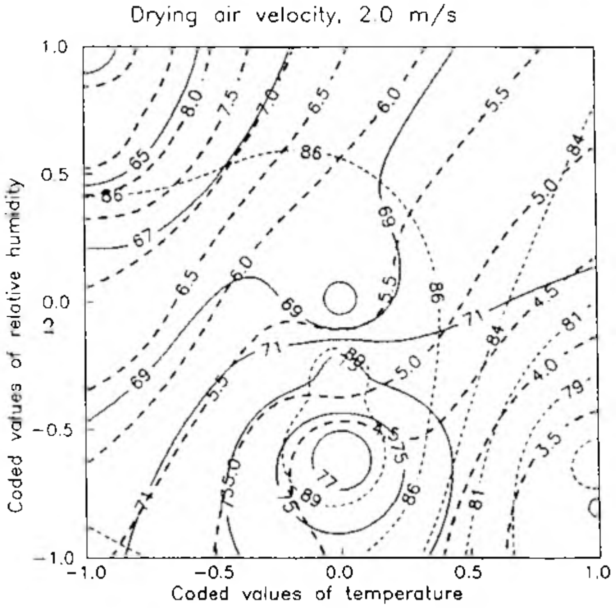


Fig. 4.37 Superimposed response contours for retention of lycopene and ascorbic acid over moisture content of tomato powder dried at varying air temperatures and relative humidities at 2.0 m s^{-1} air velocity

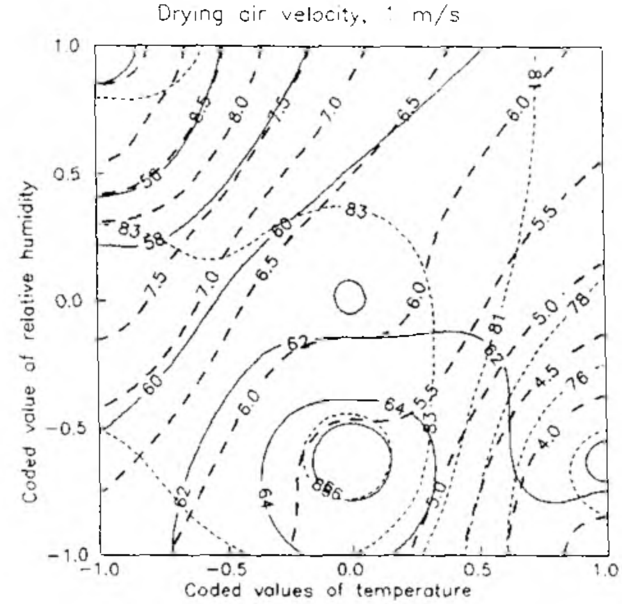


Fig. 4.38 Superimposed response contours for retention of lycopene and ascorbic acid over moisture content of tomato powder dried at varying air temperatures and relative humidities at 1.0 m s^{-1} air velocity

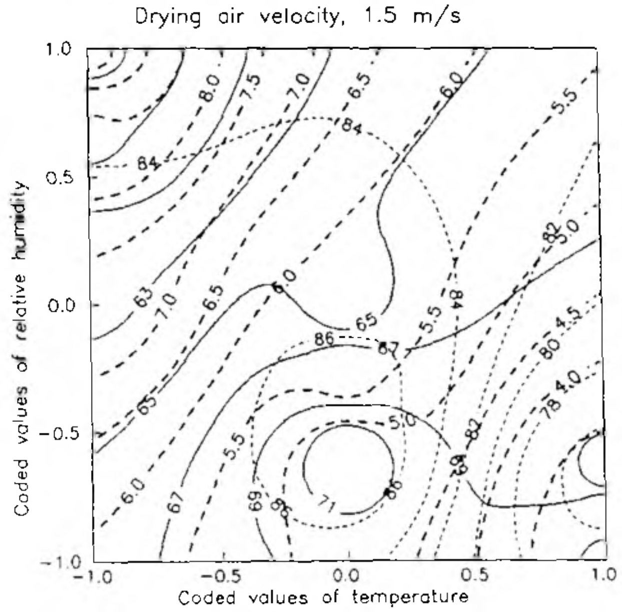


Fig. 4.39 Superimposed response contours for retention of lycopene and ascorbic acid over moisture content of tomato powder dried at varying air temperatures and relative humidities at 1.5 m s^{-1} air velocity

to others (Table 4.22). Hence, 2.0 m/s air velocity with temperature and relative humidity range of 62-65°C and 10-22.5% respectively may be considered as the optimum condition for drying 3 mm thick slab of tomato foam for the production of powder.

Table 4.21 **Levels (coded) of temperature and relative humidity showing maximum possible retention of lycopene and ascorbic acid at different air velocities**

Air velocity, m s^{-1}	Coded levels		Maximum possible retention	
	Temperature, °C	Relative Humidity, %	Lycopene, %	Ascorbic acid, %
1.0	0	- 0.55	87	67
1.5	0	- 0.60	87	72
2.0	0	- 0.81	90	78

Table 4.22 **Retention of lycopene and ascorbic acid at optimum conditions with different drying air velocities for a product of 3.5% (db) moisture content**

Drying air conditions			Retention		Drying time, min
Velocity, m s^{-1}	Temperature, °C	Relative Humidity, %	Lycopene, %	Ascorbic acid, %	
1.0	63.5 - 65.0	10 - 19.5	70	60	101 - 121
1.5	62.0 - 65.0	10 - 21.5	77	68	94 - 119
2.0	62.0 - 65.0	10 - 22.8	81	72	83 - 114

4.8 Process Technology

Preparation of tomato powder (dehydrated tomato juice) involved a series of processing operations, *viz.*, extraction and filtration of juice, concentration, foaming, drying, and cooling/conditioning and conversion into powder of the foam-mat dried material. Based on the findings at different stages of the investigation (Sec. 4.1 to 4.7), optimum conditions for each unit operation were worked out. Process and material flow chart for the preparation of tomato powder is presented in **Fig. 4.40**. Some important properties of the powder prepared using optimum conditions of the process variables are given in **Table 4.23**. From 1 kg of fresh tomato, 55.5-57 g powder was obtained with 85-86% total soluble solids. The powder had an average of 2.9% (db) moisture content, 51 mg lycopene and 183 mg ascorbic acid per 100 g. The powder which was free-flowing in nature retained 77.32% of lycopene and 52.2% of ascorbic acid (fresh tomato basis). It had good reconstitution property and dissolved easily in lukewarm water (40-42°C) in 125-156 seconds.

Table 4.23 Some important properties of tomato powder

Moisture, % (db)	2.85	-	3
Total soluble solids, %	85.5	-	85
Time to dissolve completely, min	2	-	2.5
Lycopene, mg/100 g	49.6	-	52.2
Ascorbic acid, mg/100 g	181.8	-	183.5

4.9 Storage of Tomato Powder

The dehydrated tomato juice (tomato powder) samples packed in three types of packaging materials, *viz.*, BOPP, saran and MPC, were stored under accelerated storage condition of 38°C temperature and 90% relative humidiy. Samples were evaluated for their physico-chemical properties and organoleptic qualities at different intervals of storage period. Experimental data are presented in **Appendix - F (Table F-1 and F-2)**.

4.9.1 Physico-chemical properties

The analysis of variance for some important physico-chemical properties of tomato powder packed in three different packaging materials and stored at 38°C temperature and 90% relative humidity is presented in **Table 4.24**. Results of the statistical analysis of experimental data **(Table 4.24)** revealed that the type of packaging materials as well as period of storage had significant effect at 1% level on colour (reconstituted juice), moisture, ascorbic acid and lycopene contents of the product.

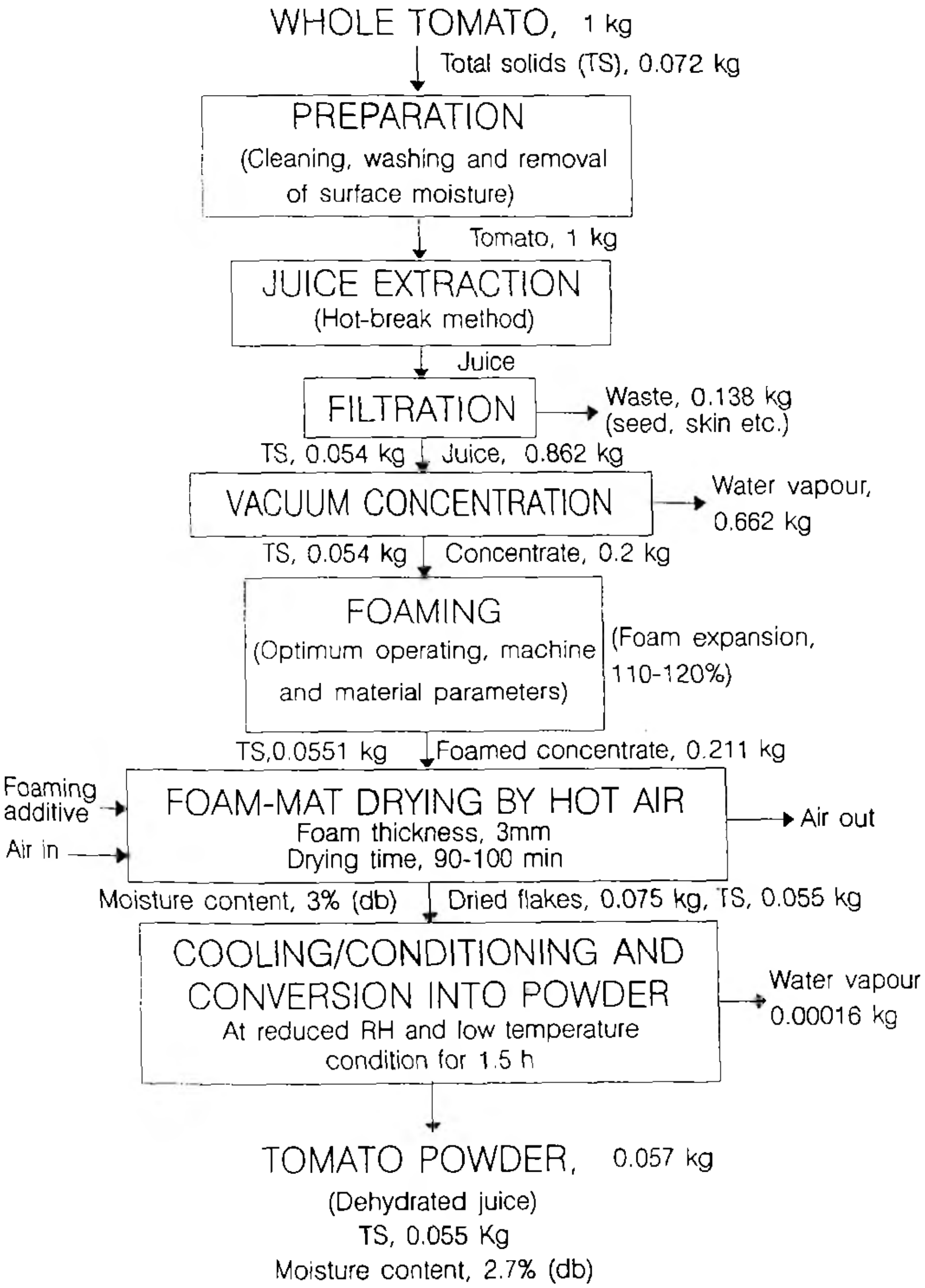


Fig. 4.40 Process and material flow chart for preparation of tomato powder (dehydrated tomato juice) using foam-mat drying technique

Variation in moisture content

The variation in moisture content of tomato powder packed in three different types of flexible materials and stored at 38°C temperature and 90% RH in is shown in Fig. **4.41**. There was a gradual increase in moisture content of the powder in all the three types of packages. The rate of increase of moisture content was dependent upon the water vapour transmission rate of the packaging film. The increase in moisture content of powder was maximum in case of BOPP package followed by saran and MPC, and the values of moisture content after 90 days of storage period were found to be 12.65, 9.60 and 3.33% (db), respectively.

Table 4.24 Analysis of variance for some physico-chemical properties of tomato powder packed in three types of packaging materials and stored at 38°C and 90% relative humidity condition

Source of variation	Degrees of freedom	Moistre content		Colour		Ascorbic acid		Lycopene	
		MSS	F_{cal}	MSS	F_{cal}	MSS	F_{cal}	MSS	F_{cal}
Replication	1	0.01	0.30^{NS}	5.34	0.66^{NS}	5.34	0.36^{NS}	3.51	0.50^{NS}
Packaging material (PM)	2	105.72	2348.52**	489.52	60.64**	3222.59	216.31**	96.39	13.69**
Storage period (SP)	7	19.45	432.10**	407.48	50.48**	2339.24	157.01**	59.23	8.41**
PM×SP	14	3.93	82.24**	47.59	5.90**	195.92	13.15**	6.11	0.87^{NS}
Error	23	0.05		8.07		14.90		7.04	
Total	47								

** Significant at 1% level

^{NS} Non significant

The moisture content of tomato powder in BOPP and saran packages was 8.00 and 6.00% (db), respectively after 30 days, beyond which the rate of increase was slightly decreased. It was observed during the experiment that the powder became a hard cake after 30 and 45 days of storages in BOPP and saran packages, respectively. This might have resulted in greater resistance to diffusion of moisture inside the powder leading to lower rate of moisture absorption. In addition to this, the vapour pressure gradient between the external and internal atmosphere decreased with the storage period. However, this trend was not observed in case of MPC packages (Fig. **4.41**) probably due to its negligible WVTR. The tendency of caking and discoloration of the tomato powder samples was observed at moisture level greater than 7.5-8.0%. Below this moisture content the product retained free flowing characteristics. The observed caking phenomenon in tomato powder was of critical importance and may be considered as an important index in deciding the shelf-life of the product under different environmental conditions of storage. The formation of hard cakes in freeze-dried bananas even at low moisture levels had been observed previously by Lima and Cal-Vidal (1983).

Fig. 4.41 shows the predicted values for moisture content (Eqn. 3.21) of tomato powder in all the three packages. A good agreement exists between theoretical and experimental data. The experimentally determined values for moisture content in samples are slightly higher than the predicted ones upto 30 and 60 days of storage in BOPP and Saran packages respectively. In case of MPC, the predicted value remains lower than the experimental value during the entire storage period of 90 days. Higher values of observed moisture content may be due to the pin holes in packaging materials and weak sealing edges formed during heat sealing. After 30 and 60 days of storage in BOPP and Saran packages the powder samples completely lost flowability and became a solid mass (8.0 to 8.8% moisture content and above). Beyond this moisture, the experimental value of moisture content was less than those predicted from theory.

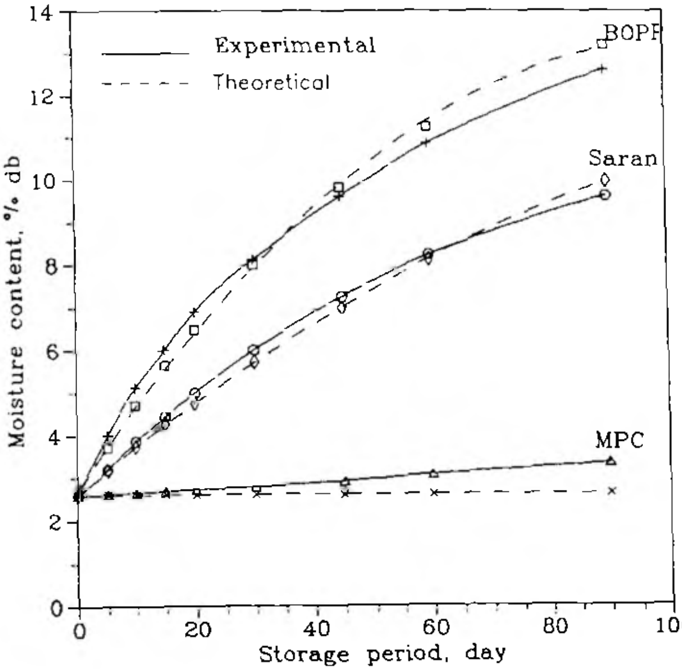


Fig. 4.41 Effect of storage period on moisture absorption by tomato powder in different packaging materials at 38°C temperature and 90% relative humidity

Variation in colour

The effect of packaging material and period of storage on the colour of tomato powder was assessed in terms of tintometer units (red, yellow and blue units) after reconstituting the powder into single strength juice of 5.5 to 6.0°B. The analysis of variance showed that the type of packaging material as well as period of storage had significant effect (1% level) on the colour of powder **(Table 4.24)**. **Fig.4.42** shows the change in colour value of tomato powder during its storage in BOPP, Saran and MPC packages. The values increased with increase in storage period indicating darkening of the colour with time. The maximum darkening of colour was noted in case of BOPP followed by Saran and MPC. The initial colour value for reconstituted juice from the dried powder was 45 in tintometer units (TU) which increased to 80, 68 and 56 TU for the samples stored for 90 days in packages made of BOPP, Saran and MPC, respectively. The variation in colour with time followed a linear relationship for powder under MPC packages, whereas the relationship was found to be curvilinear for those stored in BOPP and saran packages.

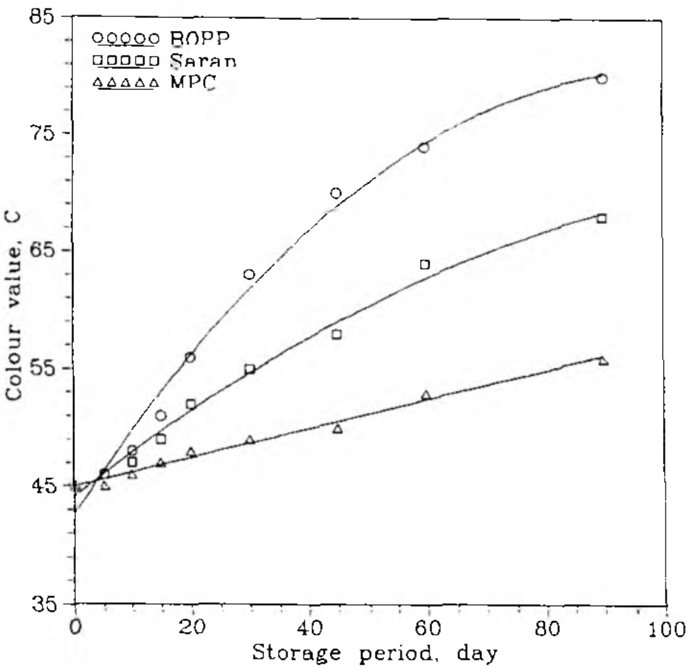


Fig. 4.42 Variation in colour values of tomato powder during storage at 38°C temperature and 90% RH in different packaging materials

The change in colour of tomato powder during storage was related to its moisture absorption. As mentioned earlier, the increase in moisture content of the product was maximum in BOPP packages followed by Saran and MPC packages. A similar trend was observed for variation in colour. It is evident from **Fig. 4.42** that there was substantial protection against discoloration or browning of the product in MPC packages probably due to the fact that the moisture content of the samples in these packages did not increase appreciably throughout the storage period. According to Wong *et al.* (1956) decreasing the moisture content of fruits and vegetables decreases the rate of non-enzymatic browning. The rate of colour loss also varies with availability of oxygen to the product (Cole and Kapur, 1957).

Variation in lycopene content

Effect of packaging material on changes in lycopene content of tomato powder during storage at 38°C temperature and 90% relative humidity is shown in **Fig. 4.43.** The type of packaging material as well as storage period had significant effect on the retention of lycopene in tomato powder as evident from the variance test **(Table 4.24).** The observed data indicated that the lycopene in tomato powder remained stable during the initial period of storage and decrease as storage progressed. The relationship between lycopene content and storage period in case of MPC packages was linear, whereas the relationship was curvilinear in case of other two packages, *viz.*, BOPP and Saran.

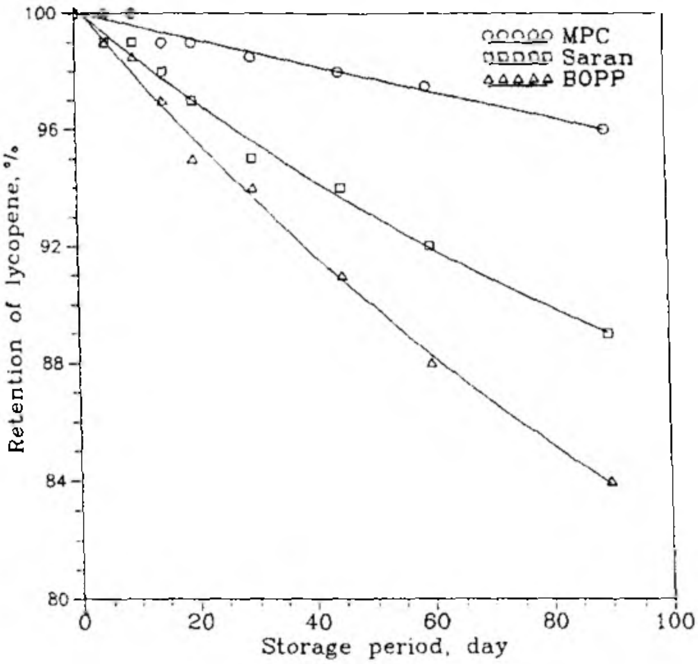


Fig. 4.43 Retention of lycopene in tomato powder during storage at 38°C and 90% RH in different packaging materials

It is evident from **Fig. 4.43** that the retention of lycopene was maximum in the samples stored in MPC packages followed by those in saran and BOPP packages. The corresponding values after 90 days of storage were 96, 89 and 84% respectively of initial lycopene content in the powder. The loss of lycopene was probably due to oxidation, as indicated in a study by Cole and Kapur (1957). The better retention of lycopene in MPC packages might, therefore, be attributed to the negligible oxygen transmission rate of the packaging material. The figure also shows that the destruction rate of lycopene in tomato powder decreased considerably after 30 and 45 days of storage in case of BOPP and saran packages, *i.e.* beyond the moisture content of 6-8%. This indicated that the oxidation of lycopene was more pronounced at moisture content between 4 and 8%. Similar observations have also been reported by Arya *et al.* (1985) while studying the storage behaviour of watermelon juice powder.

Variation in ascorbic acid

The tomato powder had an average ascorbic acid content of 12.5 mg/100 g of powder initially. The retention of ascorbic acid in tomato powder packed in different types of packaging materials and stored at 38°C temperature and 90% relative humidity is represented in **Fig. 4.44**. The figure shows that the ascorbic acid decreased during storage period of 90 days in all the packaging materials used. The decrease in ascorbic acid in the powder followed a linear relationship with storage period in all the cases. At the end of 90 days of storage the retention of ascorbic acid in the powder was found to be 71, 31 and 7% in MPC, saran and BOPP packages, respectively. Thus destruction of ascorbic acid was minimum in MPC and maximum in BOPP packages.

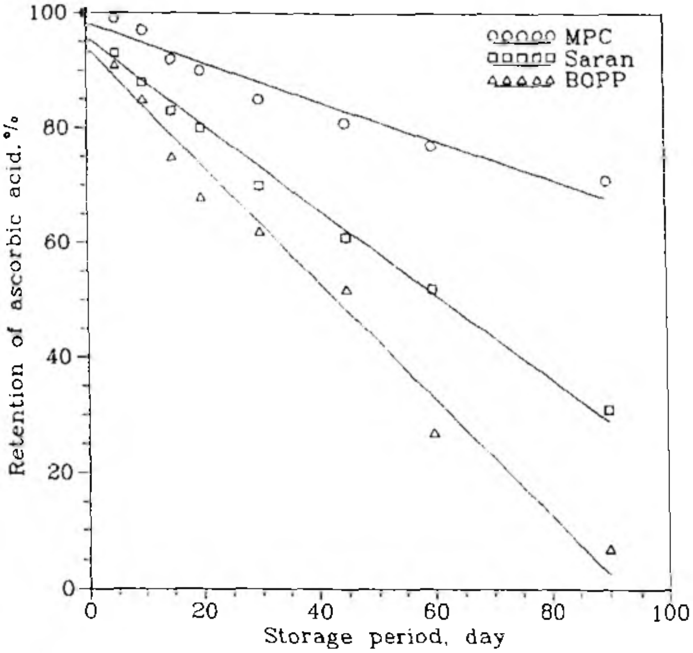


Fig. 4.44 Retention of ascorbic acid in tomato powder during storage at 38°C temperature and 90% RH in different packaging materials

The loss of ascorbic acid in tomato powder during storage was related to moisture content of the powder. Comparing **Fig. 4.41** with **Fig. 4.44** it may be observed that a sharp decrease in ascorbic acid was due to a sharp increase in moisture content of the powder. Previous work (Legault *et al.*, 1954; Mylne and Seamans, 1954 and Wong *et al.*, 1956) on storage of dehydrated fruit and vegetable products had shown that decreasing the moisture content to very low levels remarkably decreased the rate of loss of ascorbic acid. Wong *et al.* (1956) also reported that high moisture content of powder reduced the retention of ascorbic acid during storage.

In addition to the moisture content, high oxygen transmission rate probably accelerated the oxidation of ascorbic acid in BOPP and saran packages compared to those in the MPC packages.

4.9.2 Organoleptic quality

Samples of tomato powder stored in different packaging materials at 38°C temperature and 90% relative humidity were drawn at 5, 10, 15, 20, 30, 45, 60 and 90 days interval and reconstituted into 5.5-6°B juice. The reconstituted juice was evaluated organoleptically for different quality attributes and overall acceptability. Mean sensory scores for quality attributes (colour, flavour, taste and smell/odor) and overall acceptability of the tomato powder at different storage intervals for BOPP, Saran and MPC packages are given in **Appendix-F (Table F-2).**

Samples which recorded a mean score of 9 were considered to be excellent, while those with 1 were rated as poor. The mean score of all the quality attributes as well as acceptability decreased gradually as the storage period increased in all the cases irrespective of the packaging materials used. This indicated gradual deterioration of the powder with storage period. A mean score of less than 5 for any of the quality attributes indicated rejection of the product in regard to that particular attribute. **Table 4.25** presents the results of variance test for mean scores of quality attributes and overall acceptability. The packaging material as well as storage period had significant effect (1% level) on each of the quality attributes and overall acceptability.

Table 4.25 **Analysis of variance for sensory scores for different quality attributes and overall acceptability of tomato powder stored at 38°C temperature and 90% relative humidity in three types of packaging materials**

Source of Variation	Degrees of freedom	Statistics	Colour	Flavour	Taste	Smell/odor	Overall acceptability
Replication	9	MSS	0.32	0.27	0.26	0.40	0.40
		F_{cal}	1.43^{NS}	1.40^{NS}	1.35^{NS}	1.62^{NS}	1.29^{NS}
Packaging material (PM)	2	MSS	84.20	24.80	68.00	36.60	102.28
		F_{cal}	382.50**	127.56**	354.03**	151.03**	327.05**
Storage period (SP)	7	MSS	155.68	104.25	100.90	75.41	138.05
		F_{cal}	707.20**	536.23**	525.25**	311.18**	440.99**
PM × SP	14	MSS	2.25	1.65	0.85	0.67	6.39
		F_{cal}	10.21**	8.48**	4.34**	2.77**	20.41**
Error	207	MSS	0.22	0.19	0.19	0.24	0.31
Total	239						

** Significant at 1% level
* Significant at 5% level
NS Non significant

4.9.3 Shelf-life

The overall acceptability scores were taken as an index to determine the shelf-life of tomato powder stored in different packaging materials. The product was good and acceptable in quality with scores ranging from 5 to 9 and the shelf-life was determined accordingly. Effects of packaging materials and storage period on overall acceptability of tomato powder under accelerated condition of storage are presented in **Fig. 4.45**. It may be seen from the figure that the powder remains acceptable upto 30, 45 and 75 days of storage period in BOPP, Saran and MPC packages, respectively. Beyond these periods, the samples are unacceptable. It was observed that the powder stored in MPC package had moisture content of about 3.3% and remained free flowing even at the end of 90 days of storage period. The powder stored in BOPP and Saran packages attained nearly 6 and 8% moisture after 30 and 45 days of storage respectively. The colour of the powder packed in BOPP changed to dark brown after 20 days of storage and developed off flavour. This suggests that the moisture content of the powder is not the only factor that determines the shelf-life and other quality factors are involved and are equally important.

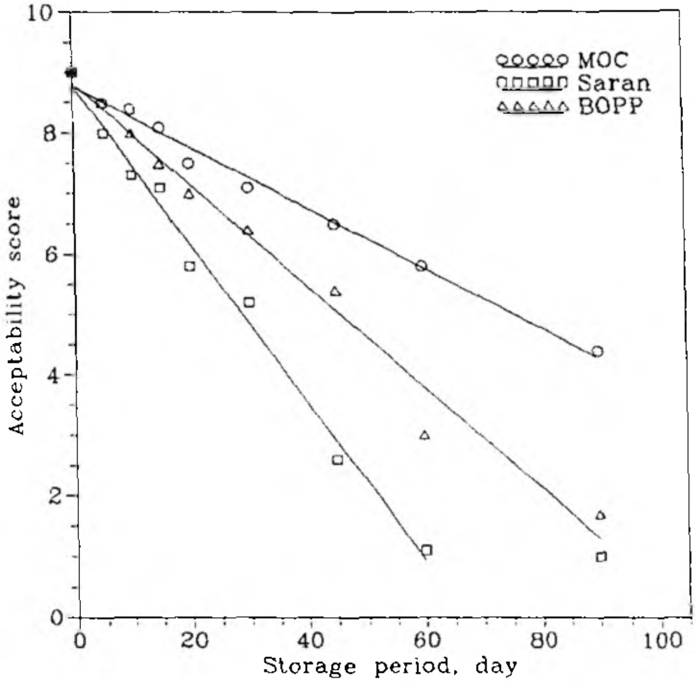


Fig. 4.45 Effect of packaging materials and period of storage on overall acceptability of tomato powder stored under accelerated conditions (38°C temperature and 90%RH)

In general, the powder remained free flowing below about 7.5-8% moisture content and its reconstitution was good in lukewarm water. No mold growth was noticed upto 90 days of storage in all the three types of packages. The study reveales that the samples packed in BOPP, Saran and MPC packages will have shelf-life of 30, 45 and 75 days respectively under accelerated storage condition (38°C temperature and 90% relative humidity).

CHAPTER - V

SUMMARY AND CONCLUSION

Tomato (*Lycopersicon esculentum* Mill) is the second largest vegetable crop of India. With an annual production of about 5 million tonnes, India contributes about 7.1 per cent to the world production. Being highly perishable in nature, tomatoes have a limited shelf-life of about 5-10 days at 21-34°C and 45-85 per cent relative humidity. Although tomato products rank first among the processed vegetables, the fact remains that this industry has not progressed well in India with only about 1-2 per cent of its total produce being processed and marketed in the form of products, like puree, paste, ketchup, sauce, pickles, *chutney etc.* Further, these products continue to be produced by traditional methods involving energy-intensive thermal processes which generally downgrade their quality. Short shelf-life coupled with inadequate processing facilities results in heavy annual losses (20-30%). Thus a need exists to develop suitable technology for processing this valuable produce in a way that will not only check losses but also generate additional revenue for the country.

Tomato has the potential for meeting the increasing demand for quality fruit and vegetable juices in India and abroad. Among the various methods of processing fruit and vegetable juices, dehydration is the most economical. This is not only because dehydrated products require inexpensive packaging and transportation, and almost no energy during storage, but they are also highly stable against deteriorative microbial, chemical and enzymic reactions. Dehydrated juice can be used as the base for soft drinks, baby foods, vegetable curry, pharmaceutical preparations *etc.*

For conversion into powders, vegetable juices are first concentrated to 20-32°B and then dried to 2-3 per cent moisture level. Concentration, the major unit operation in the vegetable processing industry, is of critical importance as it determines the quality of the final product. Some of the commercially adopted methods include vacuum evaporation, freeze concentration and membrane processes, such as reverse osmosis and ultrafiltration. Even though considerable developments have taken place in all these methods, evaporation is still considered to be the most developed one and is widely used by the industry.

Concentrated juices can be dehydrated using the existing standard methods. These are spray drying, vacuum drying, freeze drying, drum drying and foam-mat drying. Conventional spray dryers are not suitable for dehydration of tomato juices/concentrates as they induce thermoplasticity in the product owing to its high sugar content, and the powder does not flow easily out of the drying chamber. Being costlier, freeze drying seems less feasible under Indian conditions. Vacuum drying is a time consuming batch process apart from its high energy consumption. Standard drum dryers are unsuitable for drying of food stuffs with high sugar content including tomato concentrate, due to sticking of the product on to the doctor blade. The foam-mat drying method is the latest development in the area of drying and has been found suitable for dehydration of products which are heat sensitive and difficult to dry by other techniques.

The foam-mat drying process consists of formation of a stable foam of the material to be dried followed by air drying of the foam to form a thin porous sheet or mat, and compression of the dried mat which is disintegrated to yield a free-flowing powder. Concentration of the material prior to conversion into a stable foam may or may not be an essential requirement and will depend on its consistency. A thick mass is difficult to be converted into a stable foam, but this can be achieved by adding certain additives. The advantages of the foam-mat drying process are that the material can be dried in a relatively short period of time and that the dried powder reconstitutes readily. This is a comparatively cheaper method for drying of liquid foods.

Published literature is rather limited on details of vacuum concentration of tomato juice. Also, very little work has been done on foam-mat drying of tomato juice. For process upgradation and quality improvement, intensive engineering and technological support is necessary.

The present investigation was undertaken to develop a process technology for preparation of dehydrated tomato juice (tomato powder) using foam-mat drying technique and optimize the process parameters pertaining to different unit operations involved *viz.*, extraction of juice, concentration, foaming of concentrate and drying of foam. The study also included evaluation of quality characteristics and storability of the powder.

Ripe and firm tomatoes (cv. *Pusa Ruby*) of uniform red colour were procured from the local market. They were washed under running water and trimmed to remove stalks, calyx, blemished portions *etc.* if any, and dried under a fan at room temperature to remove the surface moisture. his was followed by physico-chemical analysis and subsequent processing.

The first-step in the processing was extraction of juice. The two commonly used processes for extraction of juice from tomato *i.e.*, `hot-break' and `cold-break', were studied for their effects on the recovery of juice and its quality.

In the cold-break extraction method, tomatoes were sliced into small pieces (0.5-1.0 mm thick) and crushed in a high-speed domestic mixer-cum-grinder for 4-5 min till they were converted into a pulp having a smooth uniform body. In the hot-break extraction method, tomatoes were given heat treatment by dipping in boiling water for 60-75 s prior to slicing. The pulp obtained from each method was filtered through a fine muslin cloth to separate seeds, skin and the portion of pulp which could not be ground well into fine particles. The fines of seeds and skin, if any, passed through the cloth. The juice thus obtained was analysed for important physico-chemical and quality attributes and stored in sanitised amber-coloured glass bottles at -5 to -1°C till further use.

The hot-break extracted tomato juice (5.5°B) was concentrated at 45, 55, 65 and 75°C temperatures using a bench scale rotary vacuum evaporator and the effects of temperature and time on different physico-chemical properties, *viz.*, total solids, total soluble solids, colour, pH, acidity, ascorbic acid, lycopene and sugars, were studied. In order to keep the juice boiling during the concentration process, the vacuum level was required to be monitored and raised to compensate for the increase in its concentration, and consequently its boiling point. This was found out from a parallel study wherein the rise in boiling-point of tomato juice of different concentrations (9-32°B) was determined at pressures of 760, 525, 355, 235, 150, 93 and 55 mm Hg abs. corresponding to 100, 90, 80, 70, 60, 50 and 40°C boiling temperature of water respectively.

Desorption studies of tomato concentrate (25°B) at different temperatures (20-60°C) and water activity (a_w) levels (0.11 to 0.90) were conducted using static method. Samples of tomato concentrate (3-4 g) in small glass weighing bottles were placed inside desiccators containing different saturated salt solutions to maintain the required a_w level and kept in a temperature-adjusted incubator. Samples were allowed to equilibrate with the environment which took about one month. The equilibrium moisture contents (EMC) were determined by heating in a vacuum oven at 70°C temperature and vacuum below 450 mm Hg for 6-8 hours.

Two isotherm equations, *viz.*, Brunauer-Emmett-Teller (BET) and Guggenheim-Anderson-de Boer (GAB), were tested for fitting of the EMC-a_w data using non-linear regression technique. The analysis of experimental data was also extended to establish the temperature dependence relationship for both the models.

The concentrated tomato juice was converted into stable foams using chemical foaming agents. A whipping/foaming device having provision for air incorporation at varying flow rates was developed for the purpose. It consisted of a cylindrical vessel/holding tank (160 mm high and 100 mm ID) and a compression air chamber mounted below the tank. A whipping blade having three cutting edges was connected to an electric motor through a shaft and was placed centrally in the holding tank. Compressed air was spurged into the material through a fine wire mesh (100 μm) placed between the holding tank and compression chamber via small perforations drilled on the base plate of the holding tank.

The performance evaluation of the foaming device and optimization of the machine and operating parameters were done using 62°B sugar solution containing 1 per cent glycerol monostearate as foam inducer. Five independent variables, *viz.*, whipping speed, whipping time, air flow rate, diameter of the blade and the liquid depth were found to be affecting the foaming process. Five levels each of the variables in the respective ranges, selected on the basis of preliminary trials were used for the experiments; these variable and ranges were respectively 580 to 1220 rev min^{-1}, 1 to 8 min, 6 to 25 *l* min^{-1}, 41 to 79 mm and 20 to 80 mm. Experiments were conducted using a five-factor central composite rotatable design which included 52 runs. Response surface methodology (RSM) was used to study the system and for optimization of the parameters for maximum foam expansion.

The optimum values of machine and operating parameters for the maximum foam expansion were used to investigate the effect of different chemicals on the foaming properties of tomato concentrate (25°B) followed by selection of suitable chemical as the foaming additive. Four different chemicals *viz.*, glycerol monostearate (GMS), pectin, carboxy methylcellulose (CMC) and a mixture of GMS and pectin (1:1) in the concentration ranges of 0.5 to 2.5 per cent on the basis of total solids were used for the foaming of tomato concentrate. A two-factor factorial design was used to evaluated the foaming properties, *viz.*, foam expansion and foam stability of the concentrate.

The foam (303-314% moisture content, db) prepared by using the optimum operating and material parameters was subjected to air drying. A batch-type tray dryer having provisions to vary air temperature and velocity was used for the purpose. A rotating desiccant bed type dehumidifier was connected to the air inlet of the dryer to vary the relative humidity of air before being sucked by the blower of the drying unit.

The foamed tomato concentrate was uniformly spread on drying trays (3 mm thick, 1.8 kg m^{-2} density). Three such trays were loaded into the dryer after it attained a desired air condition. Three levels of temperature (45, 55 and 65°C) and velocity (1.0, 1.5 and 2.0 m s^{-1}) of air and three levels of relative humidity of the drying air at each temperature (40, 35 and 26% at 45°C; 25, 21 and 16% at 55°C and 15, 13 and 10% at 65°C) were used depending on the ambient air condition and capability of the dehumidifier. At regular intervals, the trays were taken out, weighed and then returned into the dryer. The moisture and the corresponding drying time were recorded. Drying was continued until the product attained constant weight. The moisture content of the dried product was determined using a vacuum oven at 70°C and 450 mm Hg for 6-8 h. The dried samples were analysed for sugars, acidity, ascorbic acid and lycopene contents. The dried samples, obtained in the form of flakes, were cooled and conditioned at 15-20°C under reduced relative humidity (below 30%) air condition and ground immediately using a domestic kitchen grinder.

In all, twenty seven experiments were conducted with three levels each of the drying air temperature, air velocity and the relative humidity. Effect of process variables on drying characteristics of the tomato foam was assessed by constructing plots between moisture content and drying time. A diffusion model based on *Fick's law* of diffusion was used to study the mass transport mechanism in the falling rate period of drying of the tomato foam.

Regression equations, after normalizing the values of independent variables between -1 and +1, were developed to estimate the effect of process variables on mass transfer and quality of the foam-mat dried tomato concentrate. Using response surface methodology, process parameters were optimized for the minimum final moisture content and maximum quality value in the product. The quality parameters studied included the contents of ascorbic acid and lycopene in the dried product.

Based on the results obtained at various stages of the investigation, a process technology for the production of tomato powder was worked out.

Storage studies on the prepared tomato powder were carried out under accelerated condition of 38°C temperature and 90 per cent relative humidity. Saturated potassium nitrate solution was used to maintain the relative humidity. Three different packaging materials, *viz.*, biaxially oriented polypropylene (BOPP), Saran and metallised polyester/adhesive coextruded LD/LLD/HD (MPC) were used for packaging of the powder. Packets of size (80x70 mm) were filled with 15 g tomato powder (2.7% moisture content, db) and heat sealed after evacuating. The packets containing tomato powder were placed in black coloured desiccators maintained at the desired relative humidity. The relative humidity inside the desiccators was checked from time to time. The desiccators were placed in an incubator maintained at 38±0.5°C. Periodic examination of the tomato powder for moisture pick-up, colour, ascorbic acid and lycopene contents, and organoleptic quality was made during a storage period of 90 days. The packets once drawn out for the analysis were discarded after use. The effects of packaging material and storage period on different physico-chemical properties and organoleptic quality of powder were studied by analysing the experimental data through the variance test.

Standard analytical and other methods were adopted for evaluating different physico-chemical properties and quality attributes of the tomato, juice, concentrate and powder at various stages of the investigation. Samples of concentrate and powder were reconstituted nearly to the same total soluble solids as of the original juice (5.5-6°B), wherever necessary.

The results obtained at various stages of the investigation are summarised as follows:

1. Some important physico-chemical properties/constituents of the tomato (cv. *Pusa Ruby*) were: total solids, 7.22%; total soluble solids, 5.5°B; ascorbic acid, 21.54 mg/100 g; lycopene, 4.45 mg/100 g; acidity 0.6% (citric acid); pH, 4.23; protein, 1.16% and fat, 0.15%.

2. The yield of juice was higher in the hot-break extraction method (HBEM) (86.2%) than in the cold-break extraction method (CBEM) (81%).

3. The recovery of total solids and lycopene was higher (6.25% and 4.1 mg/100 g of juice, respectively) and that of ascorbic acid was lower (20.95 mg/100 g of juice) in HBEM than those in the CBEM (5.75%, 3.22 mg/100 g and 22.55 mg/100 g of juice, respectively). The other constituents were found to be similar in the two juices.

4. The total solids content of the concentrated tomato juice was greatly influenced by the process temperature and time of concentration. The maximum concentration attained at 45°C was 25°B after 240 min, whereas it was possible to increase the concentration upto 33.5°B at 75°C in 75 min. There was a linear relationship between the sample concentration and process time at all the temperatures under study.

5. The relationship between total soluble solids (TSS) and total solids (TS) content of the juice was found to be independent of process temperature and time of concentration. The following linear equation adequately described the relationship between TSS and TS of tomato juice.

$$TS = 0.7937 + 1.052\,TSS$$
$$(r^2 = 0.99)$$

where TS is the total solids in per cent and TSS is the total soluble solids in °B.

6. The acidity of the juice decreased slightly with the increase in concentration. The average decrease in acidity of the concentrated juice was found to be 3.5 per cent of that of the fresh juice.

7. Contents of ascorbic acid and lycopene decreased and that of reducing sugars increased with the increase in concentration of the juice. The loss of ascorbic acid was found to be 30.8, 32, 29 and 42.4 per cent and that of lycopene 5, 9.7, 14 and 22% upon concentrating the tomato juice samples upto 25, 29, 31 and 33.5°B at 45, 55, 65 and 75°C, respectively. Reducing sugar content increased to 83, 86, 88 and 90% from its initial value of 62% for the same degree of concentration levels at the respective temperatures.

8. During the concentration process, the colour development in tomato juice followed the first-order reaction kinetics and the rate constant increased with the increase in concentration temperature. The value of activation energy for the colour change reaction was found to be 487.5 kJ kg^{-1} $mole^{-1}$.

9. Concentration temperature of 60°C was found to be the optimum for the maximum quality retention in tomato concentrates of 25 and 30°B concentration.

10. The boiling-point rise (BPR) of tomato juice increased from 0.4°C to 4.15°C with the increase in concentration in the range of 9 to 32°B. A second-order polynomial equation of the type given below adequately described the BPR.

$$\Delta T_b = 0.45 \quad 0.00438x \times 0.005x^2$$
$$(r^2 = 0.99)$$

where ΔT_b and x are the boiling-point rise of tomato juice in °C and concentration of tomato juice in °B, respectively.

11. The equilibrium moisture content (EMC) of tomato concentrate increased with the increase in equilibrium relative humidity (ERH) or water activity (a_w) at a particular temperature and it decreased with the increase in temperature at the same a_w.

12. Small values of slopes of the desorption isotherm curve in the range of 0.2 to 0.45 a_w were obtained for all the temperatures indicating that the product absorbs moisture slowly below 0.45 a_w.

13. The experimental data fitted well into the GAB equation over the entire range of a_w (upto 0.90) investigated, while the BET model could be fitted only for $a_w < 0.55$. The mean relative percentage deviation between observed and predicted values of EMC was less for the GAB model as compared to that for the BET model.

14. The monolayer moisture content of tomato concentrate was found to decrease (from 7.93 to 3.51% for the GAB and 8.98 to 3.78% (db) for the BET model) with increase in the temperature from 20-60°C. The values obtained by BET and GAB models showed no significant difference at 5% level.

15. Temperature dependence of the BET and GAB constants was found to be adequately represented by second-order polynomial equations; however, the values could be predicted more closely for GAB than for BET constants.

16. The developed foaming device worked satisfactorily with sugar solution as well as tomato concentrate within the experimental ranges of the operating and machine parameters.

17. The foam expansion in the sugar solution varied between 80 and 152% with the variation in operating conditions of the foaming device.

18. All the factors except whipping speed had significant effect on foaming behaviour of sugar solution, however, its interactions with other factor influenced the process significantly. The relationship between foam expansion, FE_{Spred} and the independent variables was adequately described by the following second-order polynomial regression equation.

$$\begin{aligned} & -164.83 + 0.33\,W_S + 7.8\,W_\theta - 5.1\,A_f + 8\,D_b + 64.84\,L_h - 5\times10^{-4}\,W_S^2 - 1.7\,W_\theta^2 \\ FE_{Spred} = \; & 0.36\,A_f^2 - 8.75\,D_b^2 - 6.67\,L_h^2 + 8.2\times10^{-3}\,W_S W_\theta + 9.85\times10^{-3} W_S A_f + 0.79\,W_S D_b \\ & 0.022\,W_S L_h + 2.05\,W_\theta W_b - 0.544\,W_\theta L_h + 0.44\,A_f D_b + 0.354\,A_f L_h + 2\,D_b L_h \\ & (r^2 = 0.95) \end{aligned}$$

where FE is the foam expansion in per cent, W_S is the whipping speed in rev min^{-1}, W_θ is the whipping time in min, A_f is the air flow rate in l min^{-1}, D_b is the diameter of whipping blade in mm and L_h is the liquid height/depth in mm.

19. The operating and machine parameters yielding maximum foam expansion in sugar solution were determined as whipping speed: 840 rev min^{-1}; whipping time: 4.5 min; air flow rate: 10.3 l min^{-1}; blade diameter: 58 mm; and liquid depth: 47 mm.

20. The tomato concentrate containing 26.5-27% total solids (25°B total soluble solids) gave the best results on foam expansion and the foam was found to be quite stable at room temperature.

21. Both foam expansion and foam stability of the tomato concentrate were dependent on the type of additive and its concentration. Foam expansion varied from 20 to 34%; 23 to 39%; 30 to 66% and 33 to 122% with CMC, pectin, mixture of pectin and GMS (1:1) and GMS, respectively in the concentration range of 0.5 to 2.5% of each additive. Stability of the corresponding foam varied from 65 to 100%; 63 to 99.5%; 55 to 99% and 49.5 to 98.5%, respectively.

22. The air drying of foamed tomato concentrate did not show any constant drying rate period. It exhibited falling rate period for all the drying conditions studied.

23. The major factor affecting the drying rate was the drying air temperature followed by relative humidity and air velocity.

24. The drying rate increased with the increase in drying air temperature and air velocity, and decreased with the increase in relative humidity. This not only helped in reducing the total drying time but also reduced the final moisture content of the product.

25. The dynamic equilibrium moisture content of dehydrated tomato juice under the three experimental conditions of drying air varied from 3 to 11% (db).

26. The effect of air flow rate on drying behaviour of tomato foam was more pronounced in the final stages of drying, where higher air velocity helped in attaining equilibrium quickly in comparison to the lower air velocities. An air velocity upto 2.0 m s^{-1} could be safely used for foam-mat drying of tomato concentrate.

27. Relative humidity of drying air below 15% level did not show any significant effect on the drying rate of tomato foam irrespective of the air velocity.

28. A simplified approach for mass transfer in infinite slab based on *Fick's law* of diffusion was successfully used to analyse the drying data. The calculated values for effective moisture diffusivity varied from 0.92 x 10^{-9} to 3.46 x 10^{-9} m^2 s^{-1} over the experimental range of drying conditions. The effective moisture diffusivity for 3 mm thick slab of tomato foam was linearly related with the drying air condition and could be predicted by the following equation.

$$D = 10^{-9} (-0.91 + 0.05\, T_d - 0.0335\, Rh_d + 0.59\, V_a)$$
$$(r^2 = 0.96)$$

where D is the effective moisture diffusivity in m^2 s^{-1}, T_d, Rh_d and V_a are the drying air temperature in °C, relative humidity in per cent and air velocity in m s^{-1}, respectively.

29. The residual ascorbic acid and lycopene content of the dehydrated tomato product were significantly affected by drying air temperature and time. Maximum retention of ascorbic acid and lycopene in dried samples was found to be 78% and 90% (concentrate basis) respectively of that of concentrate with 55°C drying air temperature. Retention of ascorbic acid and lycopene in the dried product could be calculated by the following equations.

$$Ly_{ret} \quad 201 + 10.59\, T_d + 0.375\, \theta_d \quad 9.5 \times 10^{2}\, T_d^2 \quad 2.38 \times 10^{4}\, \theta_d^2$$
$$- 6.9 \times 10^{-3}\, T_d\, \theta_d$$
$$(r^2 = 0.99)$$

$$Aa_{ret} = -111.7 + 7.9\, T_d + 0.135\, \theta_d - 7 \times 10^{-2}\, T_d^2 - 0.43\, Rh_d - 7 \times 10^{-3}\, T_d\, \theta_d$$
$$+ 2.1 \times 10^{-3}\, Rh_d\, \theta_d$$
$$(r^2 = 0.98)$$

where Ly_{ret} and Aa_{ret} are the retention of lycopene and ascorbic acid in per cent respectively, and T_d, Rh_d, and θ_d are the air temperature in °C, relative humidity in per cent and drying time in min, respectively.

30. Drying air velocity and relative humidity did not affect significantly the retention of ascorbic acid and lycopene contents in the final product.

31. Drying air temperature and relative humidity in the range of 62-65°C and 10-23% respectively and 2.0 m s^{-1} air velocity were found to be the optimum for maximum retention of quality and minimum moisture content in the end product.

32. Hygroscopicity and caking were the major problems in the production of tomato powder. However, it was possible to grind the dried porous flakes into free flowing powders after cooling it to about 15°C under an atmosphere having relative humidity below 30%.

33. Dried tomato flake samples with moisture content more than 4.0% (db) could not be converted into fine powders even after conditioning.

34. From 1 kg of fresh tomato (93% moisture content, wb), 57 g powder with 2.85-3.0% (db) moisture content and 187.19 and 50.68 mg/100 g (moisture free basis) ascorbic acid and lycopene contents, respectively was obtained which could be easily reconstituted in lukewarm water.

35. Moisture content in the tomato powder increased gradually during storage under accelerated condition in all the three types of packages studied. It increased from an initial 2.7% to 12.7%, 9.6% and 3.3% (db) in BOPP, Saran and MPC packages, respectively over the storage period of 90 days.

36. The colour of the tomato powder became darker with the increase in storage period, maximum being in BOPP followed by Saran and MPC packages.

37. The dehydrated tomato powder showed maximum retention of lycopene and ascorbic acid when stored in MPC packages followed by Saran and BOPP packages. The per cent retention of lycopene and ascorbic acid content after 90 days of storage was 96, 89 and 84%, and 71, 31 and 7% in MPC, Saran and BOPP packages, respectively.

38. Powder samples stored in MPC packages were rated best by the judges for colour, flavour, smell/odor, taste and overall acceptability upon organoleptic evaluation at different storage intervals.

39. The dehydrated tomato juice could be stored successfully without any appreciable loss in quality for 75 days in MPC packages followed by 45 days in Saran and 30 days in BOPP.

In conclusion it may be stated that good quality tomato powder was successfully prepared using foam-mat drying technique. The hot-break extracted tomato juice (5.5°B TSS) concentrated to 25°B TSS could be converted into stable foam (114% volume expansion) using 2% glycerol monostrarate (TS basis) as foaming agent. Foam slabs of 3 mm thickness spread on aluminium trays were dried to 3% final moisture content using air at 62-65°C temperature, relative humidity 10-15% and air velocity 2 m s^{-1} for 90 min. Hygroscopicity and thermoplasticity were the major probelms encountered during grinding of the dried product. Conditioning of the product under reduced relative humidity (below 30%) and temperature below 20°C helped in grinding. The powder retained 77.32% of lycopene and 52.2% of ascorbic acid (fresh tomato basis), and had good reconstitution properties in lukewarm water. The powder remained free flowing in metallised polyester laminated packages upto 75 days under accelerated condition of storage (38°C temperature and 90% RH) without any appreciable loss in colour, flavour, nutritional quality and acceptability.

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APPENDIX - A

Table A-1 Some physico-chemical changes during concentration of hot-break extracted tomato juice at varying time and temperature under vacuum

Process variable		TSS, °B	TS, %	pH	Acidity* % (CA)	Ascorbic acid*		Lycopene*		Sugars*			Colour**,
Temperature, °C	Time, min					mg/100 g	Loss, %	mg/100 g	Loss, %	Reducing, %	Total, %	Degree of inversion, %	(C'), TU
45	0	5.5	6.15	4.25	9.00	341.46		65.53		42.46	62.11	69.00	52.22
	30	7.5	8.83	4.30	8.80	320.97	6.03	65.20	0.05	44.73	62.12	72.00	53.80
	60	10.5	11.66	4.35	8.72	297.07	12.67	64.22	2.00	46.76	62.26	75.10	54.40
	90	13.0	14.87	4.28	8.70	276.58	19.00	63.90	2.50	48.37	62.13	77.85	56.00
	120	16.0	17.93	4.26	8.69	262.92	23.00	62.91	4.00	49.45	62.12	79.60	57.30
	150	19.0	20.95	4.22	8.68	250.97	26.50	62.58	4.50	49.87	61.95	80.50	58.45
	180	21.0	22.76	4.20	8.68	249.27	27.00	62.65	4.40	50.38	62.11	81.12	60.00
	210	23.0	24.98	4.20	8.68	239.02	30.00	62.45	4.70	50.94	62.12	82.00	61.67
	240	25.0	27.40	4.20	8.68	235.61	30.82	62.25	5.00	51.56	62.12	83.00	62.47
55	0	5.5	6.21	4.25	9.00	338.17		66.21		42.45	61.52	69.00	52.00
	30	9.3	10.13	4.28	8.80	311.11	7.95	64.89	2.00	45.11	61.42	73.44	54.00
	60	13.5	14.86	4.37	8.70	287.44	14.67	62.90	5.00	47.19	61.55	76.67	55.58
	90	17.5	19.57	4.28	8.70	263.77	22.00	62.24	6.00	49.69	61.34	81.00	58.32
	120	22.0	24.34	4.25	8.68	253.63	24.82	61.11	7.70	51.28	61.05	84.00	61.25
	150	26.0	28.24	4.20	8.68	240.10	29.00	60.72	9.30	53.13	61.78	86.00	63.50
	180	29.0	31.55	4.20	8.68	229.95	32.00	60.45	9.97	53.27	61.76	86.25	65.25
65	0	5.5	6.31	4.25	9.00	335.00		65.67		42.37	61.54	68.85	52.35
	15	9.0	10.57	4.30	8.82	318.25	5.00	64.36	2.00	43.84	60.89	72.00	53.05
	30	13.0	14.40	4.35	8.77	301.50	9.92	62.65	4.60	46.86	61.45	76.25	55.55
	45	16.5	18.31	4.27	8.72	288.10	14.00	61.34	6.60	49.41	61.76	80.00	56.50
	60	21.0	23.10	4.28	8.70	274.70	18.00	59.10	10.00	50.81	61.22	83.00	58.00
	75	25.0	26.75	4.25	8.71	261.30	22.13	58.75	10.50	51.94	61.11	85.00	59.70
	90	28.5	30.25	4.20	8.69	251.25	25.00	57.13	13.00	53.37	61.35	87.00	61.25
	105	31.0	33.51	4.20	8.69	237.85	29.00	56.45	14.00	54.15	61.53	88.00	62.55
75	0	5.5	6.21	4.25	9.00	340.74		65.85		42.88	62.10	69.05	50.00
	15	11.0	11.55	4.27	8.82	313.48	8.00	63.22	4.00	45.06	61.56	73.20	53.40
	30	16.0	17.11	4.28	8.75	282.82	16.66	57.95	12.00	47.70	61.16	78.00	56.75
	45	20.5	21.87	4.30	8.70	255.56	25.00	57.10	13.30	50.72	61.48	82.50	57.90
	60	25.0	27.00	4.26	8.69	228.30	32.80	54.80	16.80	52.84	61.23	86.30	60.00
	75	29.5	31.12	4.20	8.69	211.26	38.00	52.68	20.00	54.68	61.44	89.00	62.00
	90	33.5	35.21	4.20	8.69	197.63	42.42	51.63	22.00	55.02	61.13	90.00	64.00

* Moisture free basis, ** C' = (R' + Y' + B') (1 + Brightness), TU = Tintometer unit, CA = Citric acid

APPENDIX - B

Table B-1 Boiling-point rise in tomato juice at different concentrations and pressures

Pressure (P), mm Hg abs.	Concentration (x), °B	Observed boiling point* (T_S), °C	Boiling-point rise ($\Delta T_b = T_S - T_A$), °C
55	9.0	40.40	0.40
	12.5	40.75	0.75
	17.0	41.20	1.20
	22.0	41.80	1.80
	26.0	42.65	2.65
	29.0	43.60	3.60
	32.0	44.05	4.05
93	9.0	50.40	0.40
	12.5	50.75	0.75
	17.0	51.20	1.20
	22.0	51.80	1.80
	26.0	52.65	2.65
	29.0	53.60	3.60
	32.0	54.15	4.15
150	9.0	60.45	0.45
	12.5	60.75	0.75
	17.0	61.20	1.20
	22.0	61.80	1.80
	26.0	62.70	2.70
	29.0	63.60	3.60
	32.0	64.10	4.10
235	9.0	70.45	0.45
	12.5	70.80	0.80
	17.0	71.20	1.20
	22.0	71.70	1.70
	26.0	72.65	2.65
	29.0	73.60	3.60
	32.0	74.15	4.15
355	9.0	80.40	0.40
	12.5	80.75	0.75
	17.0	81.20	1.20
	22.0	81.80	1.80
	26.0	82.70	2.70
	29.0	83.60	3.60
	32.0	84.10	4.10
525	9.0	90.45	0.45
	12.5	90.70	0.70
	17.0	91.25	1.25
	22.0	91.80	1.80
	26.0	92.75	2.75
	29.0	93.60	3.60
	32.0	94.10	4.10
760	9.0	100.40	0.40
	12.5	100.75	0.75
	17.0	101.20	1.20
	22.0	101.80	1.80
	26.0	102.65	2.65
	29.0	103.60	3.60
	32.0	104.15	4.15

*** Average of two replications** **T_A = Boiling point of water**

Table B-2 Analysis of variance for boiling-point rise of tomato juice

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F_{cal}
Replication	1	0.002	0.002	0.250
Concentration (x)	6	252.758	28.390	940.854**
Pressure/Vacuum (P)	6	0.008	0.001	0.046^{NS}
x × P	36	0.050	0.001	0.046^{NS}
Error	48	1.448		
Total	97			

APPENDIX - C

Table C-1 EMC (%, db) of tomato concentrate (25°C) at varying levels of a_w and temperature

20°C		30°C		40°C		50°C		60°C	
a_w	ECM, % (db)	a_w	ECM, % (db)	a_w	ECM, % (db)	a_w	ECM, % (db)	a_w	ECM, % (db)
0.113	4.48	0.113	4.04	0.112	3.25	0.111	2.15	0.110	1.57
0.213	6.42	0.216	5.84	0.208	3.86	0.204	3.13	0.181	2.20
0.331	9.40	0.324	7.71	0.316	5.73	0.305	4.28	0.284	3.40
0.432	12.63	0.432	10.41	0.400	7.56	0.385	5.39	0.365	4.37
0.544	17.27	0.414	14.24	0.484	9.98	0.454	6.78	0.420	5.49
0.699	30.93	0.679	25.15	0.661	17.26	0.645	12.92	0.611	11.47
0.755	41.26	0.751	32.23	0.747	25.76	0.744	24.67	0.715	19.97
0.851	77.36	0.836	53.94	0.823	49.00	0.812	38.67	0.785	31.27

Average of three replications

APPENDIX - D

Table D-1 Experimental results of the foaming test of 25°B (27% TS) tomato concentrate with different foaming additives

Foaming agent	Concentration of additive (% of TS)	Foam expansion (%)	Foam stability (%)
1. Carboxy methylcellulose (CMC)	0.5	20.0	65.0
	1	27.0	84.0
	1.5	33.0	92.0
	2	35.5	100.0
	2.5	34.0	100.0
2. Pectin	0.5	23.0	63.0
	1	35.0	85.3
	1.5	40.5	95.0
	2	41.2	98.0
	2.5	39.0	99.5
3. Glycerol monostearate (GMS)	0.5	34.0	49.5
	1	58.0	63.5
	1.5	84.5	79.0
	2	113.5	92.0
	2.5	122.0	98.8
4. Combination of GMS and Pectin (1:1)	0.5	30.0	55.0
	1	42.0	78.0
	1.5	54.0	87.0
	2	62.0	93.6
	2.5	66.0	99.0

Average of two replications

APPENDIX - E

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(a) Air temperature - 45° C, Relative humidity - 40% Equilibrium moisture content (M_e) - 6.80% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	306.0	1.0000	-	-	0	305.0	1.0000	-	-	0	305.0	1.0000	-	-
5	293.1	0.9569	2.5	1.55	5	290.1	0.9500	2.5	1.80	5	288.6	0.9450	2.5	1.97
10	273.0	0.8897	7.5	2.41	10	268.9	0.8789	7.5	2.54	10	267.8	0.8753	7.5	2.50
15	252.0	0.8197	12.5	2.52	15	248.0	0.8089	12.5	2.51	15	239.4	0.7800	12.5	3.41
20	230.0	0.7465	17.5	2.64	20	228.0	0.7418	17.5	2.40	20	221.5	0.7200	17.5	2.15
30	196.0	0.6324	25.0	2.04	30	192.0	0.6211	25.0	2.16	30	185.8	0.6001	25.0	2.15
40	168.0	0.5388	35.0	2.04	40	156.5	0.5020	35.0	2.16	40	149.6	0.4780	35.0	2.20
50	145.0	0.4619	45.0	1.68	50	138.0	0.4400	45.0	1.11	50	127.0	0.4031	45.0	1.34
60	123.0	0.3884	55.0	1.38	60	113.0	0.3561	55.0	1.50	60	104.0	0.3260	55.0	1.38
70	108.0	0.3382	65.0	0.90	70	93.9	0.2921	65.0	1.15	70	77.8	0.2381	65.0	1.57
80	88.0	0.2714	75.0	1.20	80	79.0	0.2421	75.0	0.90	80	65.0	0.1952	75.0	0.77
100	67.0	0.2012	90.0	0.63	100	56.9	0.1680	90.0	0.66	100	43.2	0.1221	90.0	0.65
120	50.0	0.1444	110.0	0.51	120	39.9	0.1110	110.0	0.51	120	28.0	0.0711	110.0	0.46
140	35.6	0.0963	130.0	0.43	140	28.0	0..7110	130.0	0.36	140	22.0	0.0510	130.0	0.18
170	24.5	0.0592	155.0	0.22	170	19.0	0.0409	155.0	0.18	170	14.3	0.0250	155.0	0.16
200	18.2	0.0381	185.0	0.13	200	14.3	0.0250	185.0	0.10	200	10.5	0.0122	185.0	0.08
230	14.0	0.0241	215.0	0.08	230	11.9	0.0170	215.0	0.05	230	9.5	0.0091	215.0	0.02
260	12.3	0.0184	245.0	0.03	260	10.7	0.0131	245.0	0.03					
290	11.3	0.0149	275.0	0.02	290	9.8	0.0101	275.0	0.02					
320	11.0	0.0107	305.0	0.02										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(b) Air temperature - 45° C, Relative humidity - 35% Equilibrium moisture content (M_e) - 6.35% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	305.00	1.0000	-	-	0	305.0	1.0000	-	-	0	307.0	1.0000	-	-
5	290.00	0.9498	2.5	1.80	5	289.5	0.9481	2.5	1.86	5	289.0	0.9401	2.5	2.16
10	269.00	0.8795	7.5	2.52	10	264.4	0.8641	7.5	3.01	10	265.5	0.8620	7.5	2.82
15	248.00	0.8091	12.5	2.52	15	244.1	0.7961	12.5	2.44	15	243.0	0.7871	12.5	2.70
20	228.00	0.7422	17.5	2.40	20	223.5	0.7271	17.5	2.47	20	218.0	0.7040	17.5	3.00
30	192.00	0.6216	25.0	2.16	30	182.6	0.5902	25.0	2.45	30	172.6	0.5530	25.0	2.72
40	158.00	0.5078	35.0	2.04	40	152.7	0.4900	35.0	1.79	40	142.3	0.4522	35.0	1.82
50	138.00	0.4408	45.0	1.20	50	124.6	0.3959	45.0	1.69	50	115.0	0.3614	45.0	1.64
60	113.00	0.3571	55.0	1.50	60	101.0	0.3169	55.0	1.42	60	90.5	0.2799	55.0	1.47
70	94.00	0.2935	65.0	1.14	70	81.0	0.2500	65.0	1.20	70	69.5	0.2100	65.0	1.26
80	78.90	0.2430	75.0	0.91	80	68.0	0.2064	75.0	0.78	80	55.1	0.1621	75.0	0.87
100	57.20	0.1701	90.0	0.65	100	41.6	0.1180	90.0	0.79	100	31.9	0.0850	90.0	0.70
120	40.10	0.1130	110.0	0.51	120	25.8	0.0651	110.0	0.45	120	20.5	0.0471	110.0	0.34
140	27.90	0.0720	130.0	0.37	140	17.7	0.0380	130.0	0.24	140	14.4	0.0270	130.0	0.18
170	18.90	0.042	155.0	0.18	170	12.6	0.0209	155.0	0.10	170	10.2	0.0126	155.0	0.09
200	14.10	0.0260	185.0	0.10	200	10.6	0.0141	185.0	0.04	200	8.8	0.0080	185.0	0.03
230	10.70	0.0146	215.0	0.07	230	9.2	0.0095	215.0	0.07					
260	9.50	0.0105	245.0	0.03	260	8.5	0.0070	245.0	0.02					
290	9.20	0.0094	275.0	0.01										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(c) Air temperature - 45° C, Relative humidity - 26% Equilibrium moisture content (M_e) - 4.65% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	305.0	1.0000	-	-	0	305.0	1.0000	-	-	0	305.0	1.0000	-	-
5	288.5	0.9451	2.5	1.90	5	285.5	0.9351	2.5	2.34	5	285.0	0.9334	2.5	2.40
10	268.4	0.8781	7.5	2.41	10	260.0	0.8502	7.5	3.06	10	261.5	0.8552	7.5	2.82
15	241.0	0.7869	12.5	2.29	15	239.0	0.7803	12.5	2.52	15	236.8	0.7729	12.5	2.96
20	221.8	0.7230	17.5	2.30	20	220.9	0.7200	17.5	2.17	20	213.4	0.6950	17.5	2.81
30	187.0	0.6071	25.0	2.09	30	180.0	0.5838	25.0	2.45	30	178.6	0.5772	25.0	2.12
40	149.5	0.4821	35.0	2.25	40	144.9	0.4670	35.0	2.11	40	138.0	0.4440	35.0	2.40
50	126.9	0.4069	45.0	1.36	50	119.1	0.3811	45.0	1.55	50	110.1	0.3511	45.0	1.67
60	103.8	0.3301	55.0	1.38	60	93.0	0.2942	55.0	1.57	60	85.9	0.2670	55.0	1.52
70	79.8	0.2500	65.0	1.44	70	71.1	0.2211	65.0	1.32	70	65.0	0.2009	65.0	1.19
80	64.8	0.2001	75.0	0.90	80	55.1	0.1680	75.0	0.96	80	49.1	0.1480	75.0	0.95
100	43.7	0.1300	90.0	0.63	100	30.8	0.0871	90.0	0.73	100	24.5	0.0661	90.0	0.74
120	27.8	0.0771	110.0	0.48	120	19.0	0.0478	110.0	0.35	120	14.3	0.0321	110.0	0.31
140	21.5	0.0561	130.0	0.20	140	11.9	0.0240	130.0	0.22	140	10.0	0.0178	130.0	0.13
170	13.1	0.0281	155.0	0.17	170	8.3	0.0120	155.0	0.07	170	7.4	0.0090	155.0	0.05
200	9.8	0.0170	185.0	0.07	200	7.5	0.0095	185.0	0.02	200	6.6	0.0065	185.0	0.02
230	8.3	0.0120	215.0	0.03										
260	7.4	0.0090	245.0	0.02										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(d) Air temperature - 55° C, Relative humidity - 25% Equilibrium moisture content (M_e) - 3.5% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	306.0	1.0000	-	-	0	305.0	1.0000	-	-	0	306.0	1.0000	-	-
5	286.0	0.9339	2.5	2.40	5	284.0	0.9304	2.5	2.52	5	284.9	0.9302	2.5	2.53
10	263.0	0.8579	7.5	2.76	10	260.7	0.8531	7.5	2.80	10	257.6	0.8400	7.5	3.28
15	236.0	0.7686	12.5	3.24	15	231.0	0.7546	12.5	3.57	15	225.9	0.7350	12.5	3.81
20	216.0	0.7025	17.5	2.40	20	210.0	0.6849	17.5	2.52	20	195.6	0.6350	17.5	3.05
30	175.0	0.5669	25.0	2.46	30	164.6	0.5343	25.0	2.72	30	144.8	0.4671	25.0	2.23
40	134.0	0.4314	35.0	2.46	40	123.5	0.3980	35.0	2.45	40	107.6	0.3441	35.0	1.89
50	100.0	0.3190	45.0	2.04	50	85.8	0.2730	45.0	2.26	50	76.1	0.2400	45.0	1.27
60	76.1	0.2400	55.0	1.44	60	60.8	0.1900	55.0	1.50	60	55.0	0.1702	55.0	0.97
70	58.0	0.1802	65.0	1.01	70	45.0	0.1376	65.0	0.95	70	38.9	0.1169	65.0	0.78
80	43.0	0.1306	75.0	0.90	80	34.9	0.1041	75.0	0.61	80	25.9	0.0740	75.0	0.34
100	26.3	0.0754	90.0	0.50	100	19.5	0.0531	90.0	0.46	100	14.7	0.0369	90.0	0.15
120	16.5	0.0430	110.0	0.30	120	11.9	0.0279	110.0	0.23	120	9.9	0.0210	110.0	0.09
140	11.8	0.0274	130.0	0.14	140	8.6	0.0169	130.0	0.10	140	6.8	0.0109	130.0	0.03
170	8.2	0.0155	155.0	0.07	170	7.1	0.0119	155.0	0.03	170	5.3	0.0358	155.0	
200	6.5	0.0099	185.0	0.03	200	5.9	0.0078	185.0	0.03					
230	6.1	0.0086	215.0	0.01										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(e) Air temperature - 55° C, Relative humidity - 21% Equilibrium moisture content (M_e) - 3.0% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	307.00	1.0000	2.5	2.55	0	303.00	1.0000	2.5	2.88	0	305.00	1.0000	2.5	3.25
5	285.75	0.9301	7.5	3.25	5	279.00	0.9200	7.5	3.05	5	277.90	0.9103	7.5	3.27
10	258.65	0.8410	12.5	3.48	10	253.60	0.8353	12.5	3.43	10	250.65	0.8200	12.5	3.80
15	229.70	0.7457	17.5	2.60	15	225.00	0.7400	17.5	3.05	15	219.00	0.7152	17.5	3.70
20	208.00	0.6743	25.0	2.64	20	199.60	0.6553	25.0	3.61	20	188.20	0.6132	25.0	3.41
30	164.00	0.5296	35.0	2.70	30	139.50	0.4550	35.0	1.98	30	131.40	0.4252	35.0	2.45
40	119.00	0.3816	45.0	2.10	40	106.50	0.3450	45.0	1.71	40	90.60	0.2901	45.0	1.99
50	84.00	0.2664	55.0	1.50	50	78.00	0.2500	55.0	1.89	50	57.40	0.1801	55.0	1.05
60	59.00	0.1842	65.0	0.96	60	46.50	0.1450	65.0	0.62	60	40.00	0.1225	65.0	0.78
70	43.00	0.1316	75.0	0.72	70	36.15	0.1105	75.0	0.64	70	27.00	0.0795	75.0	0.54
80	31.00	0.0921	90.0	0.39	80	25.50	0.0750	90.0	0.45	80	18.00	0.0497	90.0	0.23
100	18.10	0.0495	110.0	0.22	100	10.60	0.0253	110.0	0.06	100	10.50	0.0248	110.0	0.11
120	10.70	0.0253	130.0	0.08	120	8.70	0.0190	130.0	0.06	120	6.70	0.0126	130.0	0.05
140	8.00	0.0164	155.0	0.04	140	6.60	0.0120	155.0	0.03	140	5.00	0.0066		
170	6.00	0.0099	185.0	0.01	170	5.15	0.0072							
200	5.65	0.0087												

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(f) Air temperature - 55° C, Relative humidity - 16% Equilibrium moisture content (M_e) - 2.55% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	305.00	1.0000	-	-	0	305.00	1.0000	-	-	0	306.00	1.0000	-	-
5	280.70	0.9197	2.5	2.92	5	279.25	0.9149	2.5	3.09	5	275.65	0.9000	2.5	3.64
10	253.60	0.8301	7.5	3.25	10	251.15	0.8220	7.5	3.37	10	242.30	0.7901	7.5	4.00
15	224.80	0.7349	12.5	3.46	15	220.30	0.7200	12.5	3.70	15	205.90	0.6701	12.5	4.37
20	196.70	0.6420	17.5	3.37	20	192.00	0.6265	17.5	3.40	20	180.00	0.5848	17.5	3.11
30	152.90	0.4973	25.0	2.63	30	145.00	0.4712	25.0	2.82	30	124.00	0.4002	25.0	3.36
40	104.80	0.3383	35.0	2.89	40	99.00	0.3191	35.0	2.76	40	81.45	0.2600	35.0	2.55
50	71.00	0.2286	45.0	2.03	50	64.50	0.2051	45.0	2.07	50	49.30	0.1541	45.0	1.93
60	45.60	0.1426	55.0	1.52	60	38.45	0.1190	55.0	1.56	60	31.70	0.0961	55.0	1.06
70	33.00	0.1010	65.0	0.76	70	26.00	0.0778	65.0	0.75	70	19.30	0.0552	65.0	0.77
80	24.00	0.0712	75.0	0.54	80	16.25	0.0456	75.0	0.59	80	13.20	0.0351	75.0	0.37
100	12.50	0.0332	90.0	0.35	100	9.10	0.0220	90.0	0.22	100	6.55	0.0132	90.0	0.20
120	8.25	0.0192	110.0	0.13	120	6.08	0.0120	110.0	0.09	120	4.10	0.0051	110.0	0.07
140	6.00	0.0117	130.0	0.07	140	4.58	0.0070	130.0	0.05					
170	5.00	0.0084	155.0	0.02										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(g) Air temperature - 65° C, Relative humidity - 15% Equilibrium moisture content (M_e) - 1.4% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	307.00	1.0000	-	-	0	306.00	1.0000	-	-	0	306.00	1.0000	-	-
5	282.85	0.9210	2.5	2.90	5	275.50	0.8999	2.5	3.66	5	272.50	0.8900	2.5	4.02
10	240.70	0.7830	7.5	5.06	10	234.40	0.7651	7.5	4.93	10	233.80	0.7630	7.5	4.64
15	202.00	0.6564	12.5	4.64	15	200.00	0.6520	12.5	4.13	15	199.00	0.6487	12.5	4.18
20	177.10	0.5749	17.5	3.00	20	172.00	0.5601	17.5	3.36	20	169.00	0.5502	17.5	3.60
30	122.00	0.3946	25.0	3.30	30	118.70	0.3851	25.0	3.20	30	114.10	0.3700	25.0	3.29
40	81.75	0.2629	35.0	2.42	40	78.50	0.2531	35.0	2.41	40	77.30	0.2490	35.0	2.21
50	47.85	0.1520	45.0	2.03	50	45.20	0.1438	45.0	2.00	50	44.00	0.1399	45.0	2.00
60	29.00	0.0903	55.0	1.13	60	25.50	0.0791	55.0	1.18	60	22.20	0.0683	55.0	1.31
70	14.60	0.0432	65.0	0.86	70	14.30	0.0422	65.0	0.67	70	13.30	0.0389	65.0	0.53
80	10.25	0.0290	75.0	0.26	80	8.50	0.0233	75.0	0.35	80	7.20	0.0190	75.0	0.37
90	6.86	0.0179	85.0	0.20	90	5.90	0.0148	85.0	0.16	90	4.50	0.0100	85.0	0.16
100	4.45	0.0100	95.0	0.14	100	3.90	0.0080	95.0	0.12	100	3.40	0.0065	95.0	0.07
120	3.77	0.0078	110.0	0.04	120	3.30	0.0062	110.0	0.02					
130	3.70	0.0075	125.0	0.004										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(h) Air temperature - 65° C, Relative humidity - 13% Equilibrium moisture content (M_e) - 1.2% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	306.00	1.0000			0	307.00	1.0000			0	307.00	1.0000		
5	278.00	0.9081	2.5	3.36	5	273.40	0.8901	2.5	4.03	5	272.75	0.8880	2.5	4.11
10	235.00	0.7671	7.5	5.16	10	227.50	0.7400	7.5	5.51	10	229.00	0.7449	7.5	5.25
15	194.00	0.6325	12.5	4.92	15	193.80	0.6300	12.5	4.04	15	193.00	0.6272	12.5	4.32
20	168.00	0.5472	17.5	3.12	20	169.00	0.5487	17.5	2.98	20	164.50	0.5340	17.5	3.44
30	118.00	0.3832	25.0	3.00	30	114.20	0.3695	25.0	3.29	30	110.00	0.3558	25.0	3.27
40	75.00	0.2421	35.0	2.58	40	76.20	0.2451	35.0	2.28	40	68.00	0.2184	35.0	2.52
50	44.00	0.1404	45.0	1.86	50	39.60	0.1257	45.0	2.20	50	35.00	0.1105	45.0	1.98
60	21.00	0.0650	55.0	1.38	60	18.00	0.0549	55.0	1.30	60	17.80	0.0543	55.0	1.03
70	13.50	0.0404	65.0	0.45	70	11.10	0.0324	65.0	0.42	70	8.50	0.0239	65.0	0.56
80	9.45	0.0271	75.0	0.24	80	7.00	0.0190	75.0	0.25	80	5.40	0.0137	75.0	0.19
90	7.00	0.0190	85.0	0.15	90	4.90	0.0121	85.0	0.13	90	3.60	0.0078	85.0	0.11
100	4.15	0.0097	95.0	0.17	100	3.40	0.0072	95.0	0.09	100	3.05	0.0060	95.0	0.033
120	3.50	0.0075	110.0	0.02										

DM = Dry matter

Table E-1 Data on foam-mat drying of tomato concentrate under different drying air conditions

(i) Air temperature - 65° C, Relative humidity - 10% Equilibrium moisture content (M_e) - 0.9% (db)

Air Velocity 1.0 m s^{-1}					Air velocity 1.5 m s^{-1}					Air velocity 2.0 m s^{-1}				
Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water / kg DM h)	Elapsed time (min)	Moisture content (%, db)	MR $(M-M_e)/(M_o-M_e)$	Mean time (min)	Drying rate (kg water/ kg DM h)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	305.00	1.0000	-	-	0	305.00	1.0000	-	-	0	305.00	1.0000	-	-
5	276.40	0.9060	2.5	3.43	5	271.00	0.8882	2.5	4.08	5	265.50	0.8701	2.5	4.47
10	233.25	0.7641	7.5	5.18	10	224.40	0.7350	7.5	5.59	10	224.70	0.7359	7.5	4.90
15	189.70	0.6208	12.5	5.23	15	192.20	0.6291	12.5	3.87	15	186.00	0.6087	12.5	4.64
20	165.10	0.5400	17.5	2.95	20	164.00	0.5363	17.5	3.39	20	159.00	0.5199	17.5	3.24
30	116.00	0.3785	25.0	2.95	30	110.00	0.3588	25.0	3.24	30	105.80	0.3450	25.0	3.19
40	72.10	0.2341	35.0	2.63	40	69.00	0.2239	35.0	2.46	40	66.20	0.2147	35.0	2.38
50	42.00	0.1352	45.0	1.81	50	37.50	0.1204	45.0	1.89	50	32.00	0.1023	45.0	2.05
60	19.80	0.0622	55.0	1.33	60	17.40	0.0543	55.0	1.21	60	14.75	0.0455	55.0	1.04
70	12.60	0.0385	65.0	0.43	70	10.00	0.0299	65.0	0.44	70	7.70	0.0224	65.0	0.43
80	8.00	0.0233	75.0	0.28	80	5.90	0.0164	75.0	0.25	80	4.85	0.0130	75.0	0.17
90	5.20	0.0141	85.0	0.17	90	4.40	0.0115	85.0	0.09	90	3.05	0.0071	85.0	0.11
100	3.70	0.0092	95.0	0.09	100	3.00	0.0069	95.0	0.08					
120	3.20	0.0076	110.0	0.015										

DM = Dry matter

Table E-2 Analysis of variance for effective moisture diffusivity (D)

Source of variation	Degrees of freedom	Sum of squares	F_{cal}
Air temperature (X_1)	1	0.99×10^{-18}	31.58**
Air re;ative humidity (X_2)	1	0.56×10^{-18}	17.80**
Air velocity (X_3)	1	1.55×10^{-18}	49.27**
Error	23	0.72×10^{-18}	

** Significant at 1% level

Table E-3 Analysis of variance for retention of lcopene and ascorbic acid during drying

Source of variation		Degrees of freedom	Lycopene		Ascorbic acid	
			MSS	F_{cal}	MSS	F_{cal}
Air temperature	(X_1)	1	88.24	459.96**	161.28	214.80**
Drying time	(X_4)	1	48.8	254.38**	369.85	429.60**
	X_1^2	1	60.69	316.38**	65.52	87.27**
	X_1^4	1	2.09	10.89**	-	-
	$X_1\times X_4$	1	6.06	31.60**	14.4	19.18**
	$X_2\times X_4$	1	-	-	5.29	7.04**
Error		20	0.19	-	0.75	-

** Significant at 1% level

APPENDIX - F

Table F-1 Mean values* of physico-chemical properties of tomato powder at diferent storage periods invarious packaging materials under 38°C temperature and 90% relative humidity condition

Storage period (day)	Moisture content (%, db)			Colour (TU)			Retention (%)**					
	MPC	Saran	BOPP	MPC	Saran	BOPP	Ascorbic acid			Lycopene		
							MPC	Saran	BOPP	MPC	Saran	BOPP
5	2.62	3.22	4.00	45.2	45.5	46.0	99.0	93.0	91.0	100.0	99.5	99.0
10	2.65	3.85	5.30	46.3	47.0	48.0	97.0	88.0	85.0	100.0	99.0	98.0
15	2.68	4.44	6.00	47.0	48.9	51.0	92.0	83.0	75.0	99.0	98.0	97.0
20	2.73	5.00	7.10	48.1	52.1	51.3	90.0	80.0	68.0	99.0	97.0	95.0
30	2.78	6.00	8.12	49.5	55.0	63.0	85.0	65.0	62.0	98.5	95.0	94.0
45	2.91	7.25	9.60	50.0	58.0	70.2	81.0	61.0	52.0	98.0	94.0	91.0
60	3.06	8.22	10.85	53.1	64.1	74.1	77.0	52.0	27.0	97.5	92.0	90.0
90	3.33	9.60	12.60	55.9	68.3	78.9	71.0	31.0	7.0	96.0	89.0	84.0

* Average of 2 determinations

** On the basis of initial value (moisture free basis)

Table F-2 Mean Values* of sensory scores for different quality attributes and overall acceptability of tomato powder packed in different packaging materials and stored under 38°C and 90% relative humidity condition

Storage period (day)	Colour			Flavour			Taste			Smell			Overall acceptability		
	MPC	Saran	BOPP	MPC	Saran	BOPP	MPC	Saran	BOPP	MPC	Saran	BOPP	MPC	Saran	BOPP
5	8.8	8.4	7.9	8.4	7.9	7.8	9	7.6	7.8	8.7	8.3	7.9	8.7	8.6	8
10	8.5	7.7	7.4	7.6	7	6.8	8.3	7.3	6.9	8.3	7.6	7.4	8.5	7.8	7.4
15	8.4	7.3	5.9	6.7	6.2	5.8	7.8	6.4	6.3	8.1	7.4	6.6	7.8	7.5	7.1
20	7.2	6.1	5.3	6.4	5.5	5.3	6.9	5.8	5.6	7.5	6.6	6.2	7.5	7	5.7
30	5.8	5.2	4.7	5.3	5	4.7	6.4	5.2	4.9	6.4	5.9	5.2	7.2	6.4	4.8
45	5.3	3.8	2.3	4.5	4.5	3.7	5.7	4.3	3.7	5.7	5.4	4.5	6.5	5.3	2.6
60	4.6	2.8	1.3	4.1	3.7	2.3	4.9	2.8	2.9	5.5	4.7	3.4	5.8	3.3	1.5
90	3.8	2.3	1.2	3.3	3.3	1.1	4.7	2.4	2.1	4.7	4.2	2.9	4.5	1.6	1.3

* **Average of 10 panelists**

APPENDIX-F

F-3 Evaluation card for hedonic rating test

Name :
Product :

Date :
Time :

Instruction : *You are requested to assess the given tomato juice samples with reference to the control sample in terms of the characteristics mentioned on the basis of nine-point hedonic scale given below.*

	Scores
Liked extremely	9
Liked very much	8
Liked moderately	7
Liked slightly	6
Neither liked nor disliked	5
Disliked slightly	4
Disliked moderately	3
Disliked very much	2
Disliked extremely	1

Sample Code	Quality characteristics				Overall acceptability
	Taste	Smell/ odour	Colour	Flavour	

Comments (if any)

Signature

APPENDIX - G

Specifications of the instruments and equipments used in the investigation

1. **Abbe Refractometer** :
Manufacturer : Adiar Dutt & Co., Calcutta, India

2. **Air compressor** :
Model : HS-WP-1
Manufacturer : Highspeed Appliances Bombay
Electrical specification : Volts: 230, AC, 50Hz, HP: 0.75
Working air pressure : 7 kg cm^{-2}

3. **Anemometer** : Model - 24-6111 (Anemomaster)
Manufacturer : Nihan Koguku Kogy Co. Ltd., Osaka, Japan
Specification : DC, Volts: 12
Velocity range : 0-5 m s^{-1}
: 0-50 m s^{-1}
Temperature range : 0-50°C and 50-100°C
Accuracy : ± 2%

4. **Balance**
(a) Manufacturer : Adair Dutt
Model AD-500B
Capacity : 500g
Readibility : 0.01g
(b) Manufacturer : Anand Instruments Pvt. Ltd.
Model Z-2000DR
Capacity : 200/2000g
Sensitivity : 0.001/0.01

5. **Centrifugal Blower** : Type NWB E
Manufacturer : Rally Wolf Ltd., BOmbay, India.
Electrical Specification : AC/DC 220-250 Volts, Watts: 0.4

6. **Dehumidifier** : Model RA-1.5A
Manufacturer : Bry Air (India) Pvt. Ltd., Guagaon, India
Electrical Specification : 230 Volts, AC, single phase, 0.05 kW

7. **Dial Thermometer**
Manufacturer : Premium Instruments Chicago, Ill., USA
Range : 0-50°C and 0-100°C

8. **Digital pH Meter** : Model - LI-120
Manufacturer : Elico Pvt. Ltd., Hyderabad, India
Temperature compensate : 0-100°C
Electrical Specification : AC, Volts: 230, 0.1 A,

9. **Digitial Thermometer/ Temperature Indicator**
(a) Model- 441E, J-type
Manufacturer : Vikram Scientific Instruments, Calcutta, India
Specification : AC, Volts: 230, Single phase, 50 Hz
Range : 0-600°C
Thermocouple : Fe-Constantan
Least count : 1°C

(b) Model: Fluke - 52, Type - K/J
Manufacturer : John Fluke Manufacturing Co. Inc., Everett WA 98206-9090, USA
Specification : DC, Volts: 12
Range : - 200 to 760°C
Least count : 0.1°C

10. **Domestic mixer-cum-grinder** : Make Sumeet, Model 842-1
Manufacturer : Mathur Micro Motor and Appliances Pvt. Ltd., Gujarat, India.
Electrical Specification : AC, Volts: 230, 0.04 kW
Rating : 30 min

11. **Glass Bulb Thermometer**: Type - Mercury-in-glass tube
Range : 0-100°C and 0-150°C

12. **Hair hygrometer**
Manufacturer : Barigo
: Made in Geremny
Range : 0-100%

13. **Hand Refractometer**
Manufacturer : Erma Inc., Tokyo, Japan.
Range : 0-32%
: 28-62%

14. **Heat Sealing Machine** : Model 86AS
Manufacturer : Dairy udyog, Bombay, India
Electrical Specification : AC, Single phase, Volts: 230,

15. **Hot Water Bath** : Model - 11-x-2, No. 66586
Manufacturer : Precision Scientific Company, Chicago, Illinois, USA.
Temperature range : Room temperature to 100°C (± 0.5°C)
Electrical Specification : AC, Volts: 240, Single phase, 4.5A, 1000 Watts50Hz.

16. **BOD Shaker Incubator**
Manufacturer : Sambros, Calcutta
Range : 0 to 70°C
Electrical Specification : AC, Volts: 240, 50Hz, Single phase

17. **Lovibond Tintometer** : Model - E
Manufacturer : Associate Instruments Pvt. Ltd., India,
Electrical specification : AC, Volts: 230-250, Single

18. **Magnetic Stirrer-cum-Heater** : Type - 2MLH
Manufacturer : Remi Equipments, Bombay, India
Heating Capacity : 0-100°C
Speed : 1-5 positions
Electrical Specifications : AC, Volts: 220-230; Single phase, 0.5 A

19. **Rotameter**
Capacity : 100 l min^{-1}

20. **Rotary vacuum evaporator**
Manufacturer : Annapurna Chemical Industries
: Calcutta, India
Capacity : 750 ml per batch
Electrical Specifications : AC, Volts: 230, 50Hz, single phase, 0.05 kW
rpm : 4000 max

21. **Sling Psychrometer** : Type - Mercury-in-glass tube
Manufacturer : Taylor Instrument Companies Rochester, New York, USA.
Range : 120°F (Dry bulb and Wet bulb (Temperature)

22. **Stop watch** : Racer, Made in Swiss
Least count : 1/10 s

23. **Spectrophotometer** : Model- 54D,
Manufacturer : Ultra-Spec, Elico Pvt. Ltd., Hyderabad, India
Electrical specification : AC, Volts: 230, Single phase, 50 Hz.

24. **Stroboscope** : Model - Strobotac, Type - 1531AB
Manufacturer : G R Co., Concord Massaachusetts, USA
Electrical Specification : AC, Volts: 195-235, Single phase, 50-60 Hz,
Range : 110-25000 rpm

25. **Temperature controller**
Manufacturer : Yellow Spring Instrument Co.
: Yellow Springs, Ohio 45387
Range : upto 400°C
Relay : 10 A
Electrical Specification : 230 Volts, 50-60 Hz, 6 Watts
Sensor : Thermistor temperature probe

26. **Vacuum Oven** : Make -Suan
Manufacturer : Instrument Manufacturing Co. Calcutta, India.
Vacuum : 0-1 bar
Temperature range : 0-150°C
Chamber : 0.3 x 0.3 m

27. **Variable transformer** : Model - VT/15
Manufacturer : Geolite Electricals, India.
Electrical Specifications : AC, Volts 230, 50Hz
Capacity : 15 A

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