To

My Dear Wife Necmiye and

Daughters Aslıhan and Berfin

INVESTIGATION OF SPRAY DRYING OF TOMATO PASTE

A Doctor of Philosophy Thesis
in
Food Engineering
Middle East Technical University

By
Şükrü Karataş
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ABSTRACT

INVESTIGATION OF SPRAY DRYING OF TOMATO PASTE

KARATAŞ ŞÜKRÜ

Ph.D. in Food Eng.

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Double concentrated tomato paste 28-30 % wt was diluted (NTSS) to 5,10,15,20 and 28 % wt and ascorbic acid loss during heat treatment was investigated at 105-160°C for different heating time.

Studying the effect of different temperatures 105-160°C on different solid contents of tomato droplet 5-28 % wt at different saturated initial humidity air inlet for 20°C and 30°C at constant air flow rate 11.90 ml/s, drying rates versus time were estimated.

The yield of tomato powder was studied by spray drying of different concentrate concentration of tomato paste with different air inlet temperatures, air flow rate through nozzle, feed rate and air flow rate through drying chamber with Buchi type spray dryer model-190. In addition to that, additives and their combinations, the effect of counter-current cooling of outer surface of the drying chamber and direct cooling by bleeding air into the drying chamber were investigated.

The above parameters were applied to design the scraper type of drying chamber with direct air bleeding system and placement of fluidized bed. By this chamber, the effect of speed of scraper, the mixture of additives, the temperatures and feed rate on the yield of product were estimated.

It was concluded that the yield of product increased with the development of the scraper type of drying chamber. It was observed that the quality and the yield of product increased with combination of additives, direct air bleeding into the drying chamber and using a fluidized bed.

Key words : Tomato paste, spray drying, scraper, type of drying chamber, tomato powder.

ÖZET

DOMATES SALÇASININ PÜSKÜRTMELİ KURUTULMASININ İNCELENMESİ

KARATAŞ ŞÜKRÜ

Doktora Tezi : Gıda Müh.Bl.

Tez Yöneticisi : Doç.Dr. Ali Esin

İki defa konsantre edilmiş % 28-30 katı ihtiva eden domates salçası 5,10,15,20 ve % 28 çözünen katı madde ihtiva edecek şekilde sulandırıldı. Bunlardaki askorbik asit kayıpları 105-160^oC sıcaklıklarda ve değişik zaman aralıklarında araştırıldı.

105-160^oC arasındaki değişik sıcaklıkların, sabit 11.90 ml/s akış hızında, başlangıç doymuş nem sıcaklıkları 20, 30^oC olan hava ortamında, % 5-28 katı ihtiva eden domates salçası damlacıkları üzerinde etkisi incelenerek damlacıkların zamana karşı kuruma hızları tespit edildi.

Değişik konsantrasyonlardaki domates salçası Buchi model-190 tipi kurutucuda kurutularak domates tozunun verimliliği incelendi. Bu esnada değişik hava giriş sıcaklığı, püskürtücüden geçen değişik hava akımı ve beslenme miktarı ile birlikte kurutma çemberinden geçen hava akış miktarı uygulandı. Bunlara ilave olarak, değişik katkı maddeleri ve bunların karışımları, ve ayrıca kurutma çemberinin dış cidarında ters akımla ve içerisine direk hava üflenmesi ile yapılan soğutmanın etkinliği araştırıldı.

Yukardaki parametreler uygulanarak, direk hava üflenmesi ile kurutma çemberinin soğutulması ve içerisinde bir akışkan yatak yerleştirilmesi suretiyle sıyırıcı tipi bir kurutma çemberi dizayn edildi. Bu kurutma çemberi kullanılarak sıyırıcı hızının, katkı maddelerinin karışımlarının, kurutma sıcaklığının ve beslenme miktarının domates tozu verimi üzerine etkisi incelendi.

Deneysel bulgular sıyırıcı tipi kurutma çemberinin geliştirilmesi ile ürün verimliliğinin arttığını göstermiştir. Söz konusu püskürtmeli kurutucuda katkı maddelerinin karışımlarının kullanılması, içerisine direk hava üflenmesi ve akışkan yatak yerleştirilmesi ile ürün verimliliğini ve kalitesini arttırdığı gözlenmiştir.

Anahtar kelimeler : Domates salçası, püskürtmeli kurutucu,
sıyırıcı tipi kurutucu, domates tozu.

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TABLE OF CONTENTS

Page

LIST OF TABLES

Appendix

Appendix Page

Appendix Page

Appendix Page

Appendix Page

Appendix Page

Appendix Page

LIST OF FIGURES

Fig. Page

Fig. Page

Fig. Page

Fig. Page

Appendix

NOMENCLATURE

Ad	Additives	
Afr	Air flow rate through drying chamber	(m^3/h)
An	Air flow rate through nozzle	(lt/h)
B	Transformation blue in CIE standard illuminant	
C_i, C_{io}	Fraction of nutritive value retained	
C_c	Amount of ascorbic acid	(mg/100 g)
CIE	Commission Internationale de L'Eclairage	
CMC	Carboxymethyl cellulose	
CS	Corn starch	
D	Product deposit on the chamber wall	(g)
D_{eff}	Diffusion	(cm^2/sec)
DCIP	2,6-Dichlorophenol indophenol	
da	Diameter of the pipes	(mm)
E	Activation energy	(kJ/mol)
F	Volumetric flow rate	(ml/min)
H_s	Saturated air inlet temperature	(°C)
k'_o	Frequency factor	
k	Reaction rate constant	
M	Moisture in the powder	
m	Mass of tomato paste	
$\bar{m}$	Average moisture content dry basis.	(g)
m_o	Initial moisture content dry basis	(g)
m_e	Equilibrium Moisture content	(g)
m	$\frac{\bar{m} - m_e}{m_o - m_e}$ dimensionless	
N	Speed of scraper	(rpm)

NTSS	Natural total soluble solids	
P	Product recovered	(g)
Po	Position of the pipe placement in the drying chamber	(mm)
ppm	Parts per million	
R	Gas constant	(kJ/mol K)
Re	Transformation red in CIE standard illuminant	
r_2	Radii of the droplet	(cm)
r_1	Radii of the glass	(cm)
r_i	Reaction rate of component	(kg/m^3s)
r	Arithmetic mean radius of the droplet	(cm)
δ^2	Correlation coefficient	
S	Amount of solid in concentration	(g)
T	Temperature	(^oK)
T^m	Temperature dependency	
TS	Total solid dry basis	
t	Air inlet and air temperatures	(^oC)
U_s	Volumetric air rate	(ml/s)
Y	Yield of powder ($\frac{\text{g solid in powder}}{\text{g solid in feed}}$ x100)	
Ye	Transformation yellow in CIE standard illuminant	
y	Moisture (g H_2O / g dry solid)	
x',y',z'	The coordinates of the colors on the CIE graph	
z_1	Amount of ascorbic acid per ml of dye as determined for standard solution	
x	Moisture content in the droplet	(mg)
Δx	Moisture difference in the droplet during drying	(mg)

W	Weight of sample	(mg)
wt	Weight	
w_1	Amount of sample taken	
Q	Droplet drying time	(min)
ΔQ	Time difference between drying periods	(min)
θ_1	Air inlet temperature	(^{o}C)
θ_2	Air outlet temperature	(^{o}C)
ϕ_1	Product	
ϕ_2	Composition	
ρ_s	Density of tomato paste	(g/cm^3)

CHAPTER I

INTRODUCTION

Intensive research has resulted in spray drying a wide variety of products in industries ranging from chemical industry to biochemical industry and food industry. Briefly, spray drying involves the atomization of a feed into a spray and contact between the sprayed liquid and the drying medium results with moisture evaporation. The drying of the spray continues until the desired moisture content is obtained in the dried particles and then the product is recovered from the air.

The spray drying of tomato paste has advanced a great deal during the last two decades and nowadays the production of dehydrated tomato paste is considered as a rival to tomato paste in U.S.A. and Europe. However, in Turkey, the advantages of spray dried tomato powder over tomato paste have not yet been recognized.

Obviously, tomato solid in powder form has many advantages including ease of packaging, transportion, mixing, no drum clingage losses and also spray dried tomato powder produces microbiological stability which restricts enzymic activity and chemical reaction increasing storage life.

Special precautions are required in the production of spray drying tomato paste. The product particles are very hygroscopic and readily become sticky under conditions of high relative humidity or high temperature. If the wall temperature is too high, the tomato powder which is thermoplastic softens, becomes tacky and does not discharge properly. For preventing that property of tomato powder many types of dehydration techniques have been developed such as drum drying, vacuum drying, foam-mat drying and spray drying none of which have been sufficient in producing a free-flowing tomato powder due to thermoplastic and sticky character,[28] [26] [27] [3] .

Basing on these facts, it is possible to claim that, during spray drying of tomato paste the following parameters appear to be important

1. Drying temperature
2. Concentrate concentration
3. Drying rate characteristics
4. Air rate through drying chamber
5. Air rate through nozzle
6. Presence of additives
7. Cooling possibilities

It is believed that the optimum combination of these parameters will be entirely reflected by the,

1. Yield of tomato paste
2. Nutritional quality
3. Sensory values

Aim of this study is to obtain a free flowing tomato powder of maximum possible sensory and nutritive properties in a spray drier. Thus, as preliminary studies how the nutritional value of the tomato concentrates are effected during drying or upon exposure to high temperatures and the behavior of concentrate during drying will be sought. By this means, essentially an insight about the physical and other properties will be obtained, so that during spray drying the most effective variables can be adjusted.

The following study will be the investigation of the additional parameters during spray drying in the light of the thus far obtained data. The main objective in this phase of the work will be the establishment of the drawbacks on the yield due to the design and operational conditions.

The final task in conjuction with the results of the above studies will be the design and manufacture of a spray dryer which will maximize the yield, nutritional and sensory qualities.

CHAPTER 2

SURVEY OF PREVIOUS WORK

2.1 Introduction

The operation of spray drying which involves the transformation of a feed from fluid state to the dried form in one continuous operation is commonly used in food industry. Drying or dehydration of biological materials especially foods, is used as a preservation technique.

In this chapter, the survey of previous work on the development in the production of primary tomato products, the basics of spray drying, types of dehydrators, advantages and disadvantages of spray drying, special types of spray driers for tomato paste dehydration and use of additives is presented.

2.2 Tomato Plant

Tomato, botanically (Lycopersicon Esculentum) is classified as a fruit. The tomatoe comes originally from Central Mexico and South America. It was cultivated before Columbus (i.e.A.D. 1500) and amongst the countries where it was found during that time are Peru, Equador and Bolivia, Goose and Bensted [1] . The tomato came to Europe from Mexico. A description found in printed report in Italy in 1554, gives the tomato as "Mala Urea Pomid'oro". The tomato appeared in quick succession in other Europen Countries such as England, Spain, France even in Central Europe. Probably by this time it also appeared in the Middle East Countries and Turkey.

2.3 Development in the Production of Primary Tomato Products

The production of tomato juice from the entry of the raw fruit into the plant is shown on the flow diagram in Fig.2.1. Goose and Bensted [1], Cruess [2], Goose [3].

2.3.1 Washing and Sorting

The first unit operation, following the receipt of the tomatoes and their acceptability for quality consists of a thorough washing and sorting to remove extraneous matter and defective or diseased fruit, and if necessary to carry out trimming operations. Equipment for this purpose has been standardised to include pre-washing flumes and/or soaking tanks from which the tomatoes are transferred to the main washing tank in which they are subjected to a relatively violent cleaning operation provided by water in agitation, either by the action of air or stream jets. As the fruit is lifted out of the main washing tank by a roller conveyor, the tomatoes are rotated under high pressure water jets. When fruit is received in very dirty conditions to be infested with a warm water (50^{o}C)soak, either during fluming, or while held in a tank, may be much more effective than violent treatment with cold water alone. Detergents and/or wetting agent may also be used when considered necessary, and chlorination of the water in the soak tanks to a residual chlorine content of 6-8 ppm may prevent possible built up of thermophilic spores. After the clean water, pressure-jet rinse, the tomatoes on the roller conveyor are inspected and sorted by operatives and, in most present day layout, after a final rinse from water sprays, fall directly into the hopper of the chopper, or other macerating equipment.

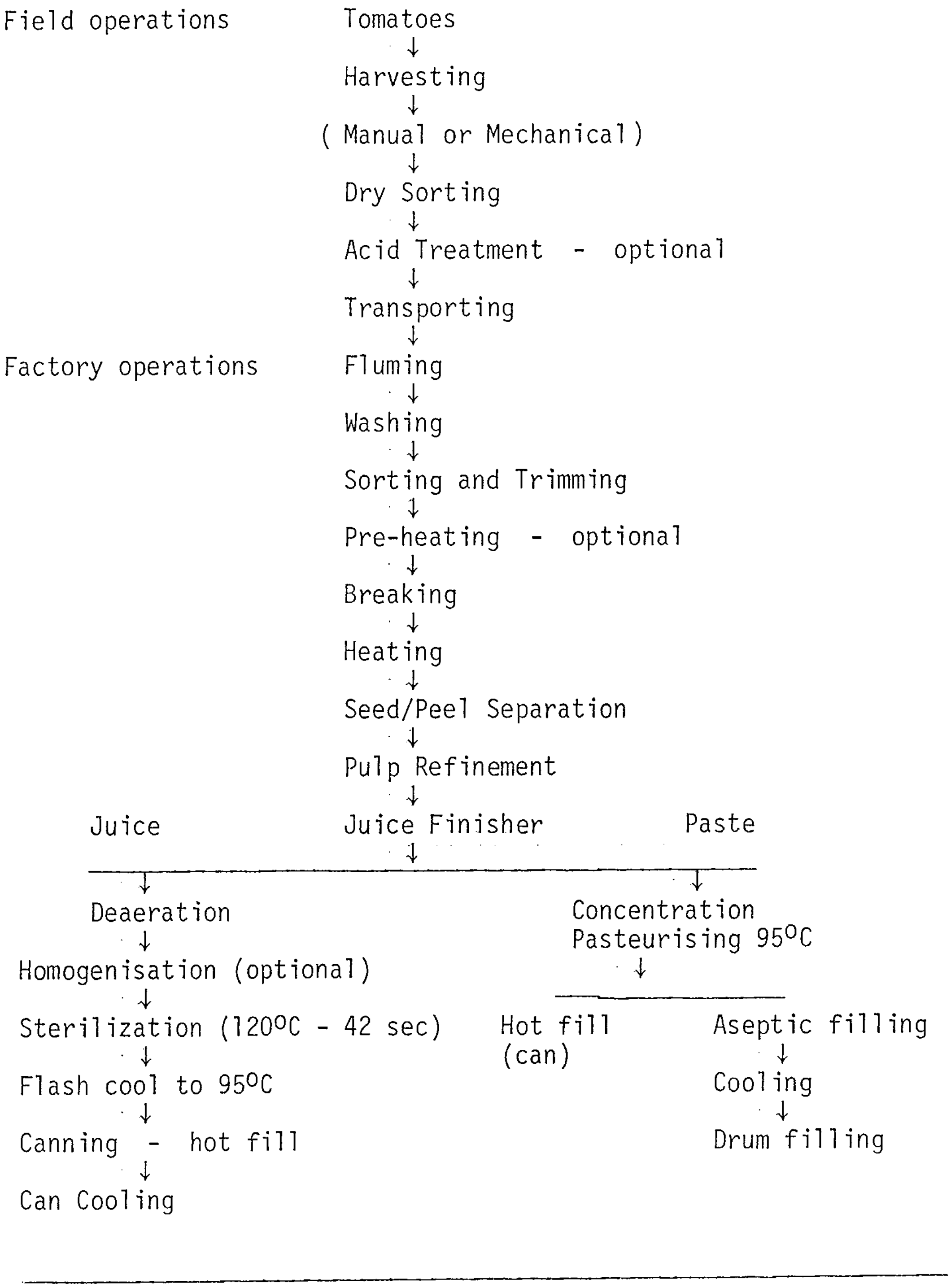


Figure 2.1 The Production of Tomato Products.

2.3.2 Pulping

One of the peculiarities of the tomato is the seed with which enzymes liberated by the fracture of the fruit can bring about the destruction of the natural tomato pectin, Ory and Angelo [4]. Loss of such pectin causes a lowering of the consistency of the product and, in order to prevent or reduce this effect, systems of heating the macerated tomato pulp during or very shortly following the actual crushing of the fruit must be applied. This so-called "hot-break" process is of great significance in parting "body" to the juice or tomato paste. It also aids extraction of seed gum which helps to stabilise the pulp and reduce syneresis in products made therefrom.

After crushing and heating, the pulp is passed through a two or three stage refining process to remove skins and seeds and break down the remaining pulp to a fine particle size. The coarse pulping screen is about 1.5 mm with the second sieve being 0.5 to 1 mm and the refining screen can be as small as 0.4 mm.

The screening systems used for natural juice usually employ "juice extractions" in which the juice is forced through cylindrical screens by rotation of helical worms (screw presses). In pulp intended for making tomato paste, it is a common practice to use "cyclone" paddles. This system has a higher output than juice extractors but, does tend to beat air into the juice which is not desirable because oxidative changes and loss of Vitamin C can be so induced Krochta [5].

After the pulp has been refined by screening and possibly homogenising, it constitutes natural tomato juice, which may be canned diretly in consumer size packs for distribution to the retail market, or in large cans, or bulk containers , for use as an ingredient by soft drink manufactured in plate or tubular heat exchangers with holding loops giving full sterilising conditions for destruction of flat-sour spores (120°C for at least 42 secs.) followed by hot-filling into can immediately after flashing down to not less than 95°C. After inversion and a short holding time, the cans must be cooled as quickly as possible.

If tomato juice is destined for concentration, it does not usually receive this high temperature treatment, but is passed directly to the evaporation equipment, which is the most important stage in the production of tomato paste.

The vacuum pans were used, and these "boules " as they were called, became standard items of concentration equipment, and many such installations are still in operation.

By incorporating a large capacity tubular-type pre-concentrator to such a system, double effect operating conditions can be applied, with almost continuous flow of finished paste by the sequential discharge of individual batches from the boules. When correctly controlled, the quality of tomato made under the low temperature conditions of the vacuum pan combined with the action of the scraped surface mechanical agitators, can be very intent.

Continuous evaporation system, such as the Manzini 'titano' system and the Rossi and Catelli "D.F.F series" (downward forced flow), have largely superseded the use of vacuum pans, however, particularly in major paste plants.

A completely new principle has been developed in newly patented machines which are the ultra-modern tomato paste plants,the mechanical vapor recompression and the reverse osmosis which are widely used for concentration of tomato products, Dale[6] , Mans[7] .

Although large volumes of tomato paste are still supplied to commercial users in 5 kg tin-plate cans in order to ship the high quantities produced by many modern plants, much larger packaging containers are being used. These consist mainly of steel drums about 45 gallons capacity, filled aseptically by special equipment which presterilises the empty drum and then carries out the filling cycle and closing operations automatically. During concentration the solid content of the tomato juice is increased from approx. 5 % to around 32 % in the evaporator and finishing pan. For the continuous method the concentrate is finally pumped to the spray dryer with atomizer.

2.4 General Aspects of Dehydration

Tomato has quite a wide range of uses varying from being used as a fresh raw vegetable to tomato paste or in form of powder. Several methods are used to produce tomato powder such as drum drying and spray drying, Cruess[2] and Masters[8] .

Dehydration is an ancient method still in practice on large scale. Drying or dehydration of biological materials, especially foods, is used as a preservation technique. Microorganisms that cause food spoilage and decay cannot grow and multiply in the absence of water. Also enzymes that cause chemical changes in food and other biological materials cannot function without water, when the water content is reduced below about 10 % wt., the microorganisms are not active. However, it is usually necessary to lower the moisture content below 5 % wt in foods to preserve flavor and nutritive value, Geankoplis [9] and Brennan [10]. However, it has been only recently recognized that it is not the absolute quantity of water, but rather a combination of the state and the amount of available water which controls the nature and extent of spoilage. There is ever increasing evidence to indicate the influence of properties of water on mechanisms of its movement during drying, as well as on the physical, chemical and microbial stability of stored products. Several excellent and extensive reviews on these subjects are available in the literature, Rizvi and Benado [11], Brock [12], Nickerson and Sinskey [13], Labuza, Acott and Lee [14], and Frazer and West [15].

2.5 Basic Principles of Spray Drying

The operation of spray drying is commonly used in food industry and the fundamentals of the drying process are given below, Masters [16], Masters [17] and Masters [18]. Feeds in solution, suspansion and paste form can be dried. The feed is sprayed into a hot drying medium and depending upon the physical and chemical properties of the feed and dryer design and operation, a dried product is produced in the form of the powder granules or agglomerates.

Spray drying consists of four process stages :

A - Atomisation of feed into a spray

B - Contact of atomised spray with drying air

C - Evaporation of moisture from the spray

D - Separation of dried product from the exhausted air

2.5.1 Mechanisms of Atomization

The selection and operation of the atomizer are of supreme importance, Masters[16][17][18] and Spraco [19]. The prime function of atomization is the production of ;

a - A high surface to mass ratio resulting in high evaporation rates,

b - Kinetic energy of air as in two fluid nozzles

c - Centrifugal energy as in rotary atomisers. Although the mechanism of atomization has been studied by many researchers the subject is still highly controversial in spite of much published data, Krischer [20] and Crawe [21].

2.5.2 Spray - Air Contact and Flow Profile

The way in which spray is contacted with air is determined by the position of the atomizer in relation to the drying air inlet, Masters[17][18].

The actual flow profile is dependent upon the design of the air disperser incorporated into the dryer. Air flow patterns within spray drying chambers is a major consideration in obtaining optimum product quality at maximum evaporation capacities. The movement of air predetermines the rate and degree of evaporation by influencing the passage of spray drops through the drying zone, the concentration of the product in the region of the chamber wall and the extent to which semi-dried particles re-enter hot spots around the disperser.

Air flow is classified as co-current, counter current or mixed flow (a combination of the two) accelerated to the passage from the atomizer to the drying chamber outlet.

2.5.3 Evaporation From Droplet

When droplets, formed during atomization of the feed, contact the hot air, evaporation from the droplet leads to the formation of a crust on the surface of the particle. Evaporation is completed when this dried layer extends down to the centre of the particle.

Permeability and strength of this crust are determining factors for the appearance of the end product. The rapid evaporation keeps the particles cool. This is essential when handling products that are heat sensitive. Due to the evaporation,cooling effect of the product thus seldom reaches the temperature of the air at the chamber outlet. The evaporation of single droplet has been estimated by sevaral authors Masters[18] , Topar [22] and Christensen [23].

Migration of solutes to the surface of drying pieces may be responsible for an operational difficulty, sometimes very troublesome, known by the picturesque term "case hardening". The same term is often used to denote the condition responsible for the warping and internal checking of green lumber or macaroni during drying, due to improper temperature or humidity control, Van Arsdel, Copley and Morgan [24] .

Operators of fruit dehydrators, as well as experimenters who had worked on the drying of soap, meat, fish, leather, and other colloidal materials, sometimes found that a drying run would begin normally but then after a time come almost to a standstill, piece surfaces being apparently dry, but piece centers still very wet. Sometimes the formation of a gummy, glassy, or leathery surface layer, substantially impermeable to water, was observed.

In the text above it has been indicated that, under some conditions, the outward migration of solutes may lead to the formation of such resistant surface layers. Although the conditions which lead to serious trouble on this account have not been conclusively defined, as a general rule satisfactory results are obtained by controlling the drying conditions so that material temperature will be relatively high (for example, 48 - 53°C) in the early stages of drying, and thus accelerate internal diffusion and redistribution of moisture, but the wetbulb depression will be relatively small at first (perhaps no more than -1.1 or -6.6°C) so that too steep a moisture gradient will not be created just below the surface of the material.

On the other hand, in the dehydration of cut vegetables or apple slices, the phenomenon of, "case harding" apparently does not occur (except, possibly, in moist-type sweet patato pieces). Consequently, instead of controlling drying conditions so as to reduce the initial rate of drying, dehydrator operators purposely use drastic drying conditions (high air temperature, low humidity, high air velocity) from the very begining. This ordinarily leads to the formation of internal shrinkage cracks, and this "honey combing" in turn greatly facilitates the late stages of drying. The rule seems to be that, the early stages of drying must be carried out as quickly as possible in order to assure a reasonably good drying rate in the final stages.

It is well known that the diffusitivity of water in typical food substances is not constant, Keey [25] but is strongly dependent on the water concentrations ; the diffusivity in the range of 5-10 % moisture may not be more than one-hundredth as great as it is at 25-30 % moisture. The inference has sometimes been drawn that therefore, a nearly dry outside layer on a piece of material must act like a nearly impermeable skin, preventing further drying, and hence that the formation of such a dry layer must be prevented at all costs. Much theoretical dicsussion of this point has been published, Masters[16] [17].

2.6 Advantages of Spray Drying

Spray drying is characterised by the following advantages, Masters[17] and Christensen [23].

- a - The product will dry while floating without getting in touch with heated metal surfaces.
- b - Product temperatures are low even when the inlet drying air is relatively high temperature.
- c - As the evaporation takes place from a large surface, the time of the drying operation is a matter of a few seconds.
- d - The temperature of the particles will not approach that of the outgoing air until the major part of water is removed, thus avoiding the possibility of over-heating : It must also be pointed out that many products, which in a humid state are heat-sensitive, can stand higher temperature when they are dried.
- e - The finished product is often a free-flowing powder, which must be considered as a great advantage.
- f - The finished product is a stable powder, easy to handle and transport.

Spray drying has been accepted as the solution in many drying problems because, the operation has proved out to be not only efficient but also economical. Overall cost analysis shows how spray drying is competitive in comparison to other forms of drying especially at high capacities.

2.7 Disadvantages of Spray Drying

a - Low bulk densities are frequently obtained by spray drying

b - For a given capacity, larger evaporation loads are generally required for spray drying a given material than would be required with other types of dryers. The material to be dried must be in a pumpable form for delivery to the atomizer.

c - Frequently the problem of product recovery and dust collection increase the cost of drying by an appreciable factor.

d - In general spray dryers are relatively inflexible. Thus a spray dryer designed for fine atomisation is generally incapable of producing a coarse product if such is required, Crawe [21] and Masters [18].

2.8 Methods Used in the Dehydration of Tomatoes

A number of methods have been applied to dehydration of tomato paste. A brief account is given here about some of them.

2.8.1 Vacuum Drying

In this field, two procedures have been developed, Perry and Chilton [26], Goose and Brensted [1] and Brennan [10].

A - A direct vacuum-drying procedure by which high density tomato paste can be converted in one step to powder.

B - A split drying procedure in which the tomato pulp is separated from the serum of the single strength juice, the serum is concentrated, the serum and pulp are dried separately, and the serum solids and pulp are re-combined in the right proportions.

2.8.1.1 Direct Vacuum Drying

In preparing tomato powder by direct drying the loaded trays are placed in a vacuum shelf dryer, the pressure is reduced to about 1 mm of Hg, and the temperature of the shelves is raised to 104.5°C as rapidly as possible. As the product temperature increased the shelf temperature is decreased and does not rise above 65.5°C. Above the latter temperature heat damage occurs. With the addition of 0.05 % of sodium bisulphate (as SO_2) to the paste prior to drying the maximum product temperature without heat damage occuring is about 88.8°C and drying time could be reduced from 2.5 hours to about 1 hour.

2.8.1.2 Split Drying Procedure

Single-strength canned tomato juice is run through a high speed bowl type centrifuge so as to separate 90 to 95 % of pulp from the serum. The serum is concentrated to 62 to 65 Brix in vacuum operating at about 15 mm Hg with jacket temperature of 57.2°C.

The loaded trays are placed in a vacuum shelf drier, the pressure is reduced to 30 mm Hg. The serum dried and puffed in much the same manner as orange concentrate. The concentrated tomato serum could be puff dried to 3 % moisture in about 1 hour.

2.8.2 Foam Mat Drying

The continuous pilot scale production of tomato powder by foam mat-drying was studied by Ginnette , et.al. [27] . Tomato paste and juice concentrates from some ten different sources were dried. Concentrates of both the hot break and cold break types were used, ranging in solid contents from 26 to 36 %, a solids content close to 30 % was the best.

Several types of foam stabilizers were used, but glyceryl monostearate (G.M.S.) gave the best performance at the lowest concentration, minimum G.M.S. levels varied from 0.6 to 1.5 % based on tomato solids, depending on the source and the solid content of concentrate.

Typical operating conditions for drying 30 % solids tomato were feed rate ; 0.0176 kg/s, residence time ; 15 min, and air inlet temperature ; 99°C, 76.6°C and 54.4°C in three dryer stages. The superficial velocity of the air in each of the stages was 1.525, 0.508, and 0.254 m/s.

It was found advisable to select the highest foam specific gravity that was compatible with good drying.

2.8.3 Low Temperature Dehydration

The problem associated with chamber wall temperatures gave rise directly to the low temperature spray drying system in which a maximum air inlet temperature of 52°C (125°F) was supplied, Goose [1] and Masters[18] .

In order to allow sufficient drying time at this temperature of tomato paste the designed drying chamber took the form of a Birs tower about 76.2 m high and 15.2 m diameter. The tomato paste of 30-48 % total solids is pumped to the top of the tower and atomised by a disc or nozzle atomiser. The air is introduced at the base of the tower through baffled inlets which has previously been dried by a passage through beds of silicagel and heated to the required temperature.

The low temperatures employed retained very good quality features in the powder produced by Birs tower. However, extremely large size of drying chamber required and the possibility of spoilage problems temperature employed, which may arise because of the undestroyed microorganisms, the low temperature constitues a draw back in this process Goose [3] and Masters[17]. This could prove troublesome and such plants may be quite expensive to operate. When the tomato powder produced is reconstituted.

2.8.4 Drum Drying

Laboratory double-drum drier with a capacity of 1.26×10^{-4} - 2×10^{-4} kg/s dried product per m^2 drum surface (Mitchell England) was modified for tomato paste.The counter rotating drums were 0.1651 m diameter and 0.1524 m long by Heing [28].

Tomato concentrates (28 Brix) were prepared for drum drying. The concentrate was fed at a constant rate of 5 to 7 kg per hour, using a mono pump. Vapours evolved during were removed by means of a hood and overhead exhaust fan. The drier was modified so that it became possible to cool the drier film by a stream of dehumidified and chilled air in the doctor blade zone.

To ensure steady state conditions the dryer was run at least 15 min. before drying was started. The dried sheets were immediately stored in desiccators. Due to its hygroscopicity the dry material near the doctor blades was up to as much as 0.5 - 1% moisture in a few seconds and optimal condition was found.

2.8.5 Types of Spray Dryers Used for Tomato Paste

Tomato powder is a difficult product to handle both during the final stages of spray drying and in subsequent operations unless special precautions are taken. This is due to two main factors;

A - The dry powder is thermoplastic and becomes extremely tacky at high temperatures.

B - It is also very hygroscopic and readily takes up water from atmosphere to become sticky or even "toffee-like".

Due to this property of tomato paste a number of methods have been applied to avoid these during spray drying as listed below:

a - Experimental production of tomato powder by spray dryer
b - "cool wall" spray dryer
c - spray drying of tomato powder at low temperature

In order to produce tomato powder economically which is readily suitable and of high organoleptic quality, there have been big advances in the design of spray-drying plants specially designed or adapted to overcome the difficulties mentioned , Lazar [31] , Christensen [23] , Karl, Arnold , and Heid [32] , Utag [33] ,and Masters [18] .

The use of conventional spray driers had not proved succesful in producing a free-flowing tomato powder due to thermoplastic effects, At the necessary outlet drying air temperature, the wall temperature of the spray drier chamber became high enough to cause powder stickiness through overheating even to the point of burn-on and thus powder becomes very sticky due to its holding too high a moisture content, Goose [3] . For this powder, further drying will be required with addition of excess dryer at the outside of the chamber wall.

2.8.5.1 Experimental Production of Tomato Powder by Spray Dryer

An experimental spray dryer was modified for drying tomato concentrate. Modification included provisions for the introduction of controlled amounts of ambient air into the lower part of the drying chamber. The surfaces of the particles were conditioned before they entered the primary cyclone collector and an aspirator was provided to collect the warm dehumidified air used in the secondary collection system. This arrangement prevented the sticking of powder in the collection zone, Lazar [31] .

A feed stock, a commercial pack, contained 30 % total solids. Careful collection was made of "hot-break" high pectin paste which had been finished on an "0.035" screen. Removal of coarse pulp, skin and fibre reduced the hazard of plugging the spray nozzles during operation.

A solution of sodium chloride and sodium bisulphate in the proper proportion was added to adjust the feed paste to 20 % tomato solids, and 2 % sodium chloride. The mixture was homogenized to promote good atomisation and reduce plugging of spray nozzles.

The conditions selected, which were satisfactory for this purpose were approximately as follows :

1 - A hot air inlet temperature 125°C

2 - Feed rate, 0.31 kg per second 22 % total solids

3 - Air flow rate 1.20 kg/s

4 - Atmospheric secondary air dry 1.05 kg/s

5 - Dehumidified air 0.151 to 0.166 kg/s

6 - Primary cyclone temperature, 74°C

7 - Secondary cyclone temperature, 43.5°C

The yield obtained under these conditions was 60 to 65 % and the products moisture content was about 2 %.

2.8.5.2 "Cool wall" Spray Dryer

The problem is tried to be overcome by installing a spray dryer with a hollow shell wall that drew ambient air through the annulus for cooling by Karl, Arnold and Heid [32] ,and Christensen [23] . As the air was heated in passing through the annulus, additional heated ambient air was admitted through inlet parts to keep the wall temperature below 50°C but above 37.7°C.

The recommended concentration of tomato paste was 36-38 % wt for "cold-break" and 26-32 % wt for "hot-break". After filtering and additional heating to 140°C the air entered the drying chamber through annular ring jets surrounding the centrifugal atomiser at the top of the spray dryer. The outlet temperature of the air was reported as 76.6°C

The warm tomato powder of 3 to 4 % moisture was dropped into an air conditioned conveyor and discharged into an air conditioned packing room. The other particles which stuck to the chamber wall builds up on the chamber wall until a loose layer of about 2.5 cm thickness is reached before breaking away and falling to the base of the chamber. This built up was important for the completion of evaporation . Further drying takes place in a fludized bed at the bottom of the drying chamber and a third drying stage can be added if necessary, Utag [33] . The yield obtained by this method was reported as 85 to 90 %. The drawback of this method is due to the long exposure time of the powder on the chamber wall which causes overheating. According to the views expressed by the above authors [17] [18] [3] increasing the drying temperature above 150°C results with thermal degradation of the tomato powder.

2.8.5.3 Spray Drying of Tomato Powder at Low Temperature

In this technique, evaporation of moisture is controlled by the dryer operation so that the tomato particles remain at a low temperature. Following completion of evaporation, the particles are separated out exhausted drying air and conveyed to the packing area. The spray drying operation thus consists of three stages :

1 - Paste atomization

2 - Spray / air contact and moisture evaporation

3 - Product separation

The atomization stage converts the paste into a spray of droplets of desired size distribution. The surface area of the paste droplets offers an extensive surface area for evaporation of the moisture.

Moisture removal from the droplet is rapid. Droplet temperature remains low and no heat damage occurs during evaporation. Flavour, colour and nutritive constituents of the tomato solid are not heat degraded. The separation of products from drying air (the majority of which is accomplished in the drying chamber) completes the unit operation, Masters [16] [17] [18] , Heid and Maynard [34] .

Design of spray dryers for tomato paste are far from standard. Special chamber designs are required to enable droplet moisture evaporation to proceed without overheating. Special handling and packing techniques are required to deal with hygroscopicity of the powder, Goose [3] .

There are two main types of spray dryer designs used for tomatoes:

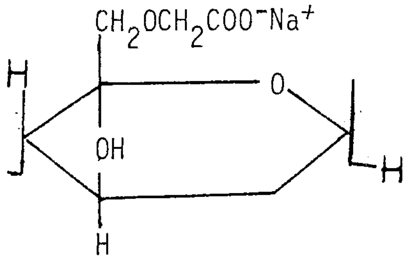
i) Operation at a moderate drying air temperature. This is a high powder production rate process using athmospheric air for drying. Rotating-vane disc atomisers are used. Drying temperature range is 77-78°C. The dryer installation requires limited building height.

ii) Low temperature drying operation. Dehumidified air is used for drying. To achieve industrial powder production rates, very high drying chambers or towers are required. The drying temperature is in the range of 27-60°C. Nozzle atomisers are used.

2.9 Use of Additives

Fruit juices and vegetable extracts present considerable difficulties in the production of free flowing powders when spray dried, because of the naturally occuring sugars, acids, etc. which produce products that are relatively hygroscopic. This hygroscopicity when combined with the thermoplastic nature causes difficulties in subsequent handling of these products. The two most fruitful lines of approaches towards solving these problems appear to be the use of additives as drying aids and the use of specially designed equipment to facilitate removal of product from drying chamber as reported by Brennan, Herrera and Jowitt [35] . The most common additives employed in such products are CMC, MgS and salt (NaCl).

i) CMC : it has been suggested that carboxymethylcellulose was first manufactured in Germany towards the end of World War I, but it was not until the 1930's, particularly during and since World War II, that its large-scale uses began to emerge and commercial production appeared justified, Review of Emue and Stab [36] . Carboxymethyl cellulose is an ether of cellulose and hydroacetic (glycolie acid). The cellulose is treated with alkali, then reacted with sodium chloroacetate to yield sodium carboxymethyl cellulose for an anhydroglucose unit degree of substitution of one would be ;



Theoretically a complete reaction would mean the introduction of three carboxymethyl groups per hydroglucose unit.

Carboxymethyl cellulose is frequently added to the system to prevent premature precipitation of either the monomer polymer emulsion and particlarly polymerized products often obtained in the intermediate stage of polymerization.

C.M.C. and salt are widely used as drying aids because of the ease of reconstitution in water, the improved texture and palatable properties that they impart to the product.

ii) Magnesium stearate : Among the substances submitted for use as release agents and classified in group A by the pharmocology sub-comittee report, magnesium stearate (para) has been permitted [36] .

Hygroscopic substances are those which are capable of setting wholly or partially the effect of the change in humidity in the atmosphere to which a food is exposed and of maintaining in a food an optimum amount of moisture, Peleg and Hollenbach [37] .

A group report shows that a maximum of 2 % by weight magnesium stearate on a dry basis could be used.

iii) Salt : A method to produce spray dried powder of fruit and vegetable juices was reported by Brennan et.al. [35] , Labuza [38] , Liu and Luh [39] . They found that, when salt is employed on pectic acid, it acted as a drying aid, and successfully produced non-hygroscopic spray dried powder of lemon, orange and whey. The total solids of these products were of the order of 90-95 % in the mixture. Also it was reported [36] that the method basically consisted of the addition of salt or carboxylmethyl cellulose to juice which produced a satisfactory dry stable, easily packed and easily reconstituted powder.

2.10 Reconstitution of Tomato Powder

For reconstitution a concentration of 5^{0} Brix was assigned to tomato powder by Reeve and Wong [40] , After the entire quantity of water is added under constant stirring, the sample is set aside for 90 sec. and then stirred again for 20 sec. or 30 sec. A few drops of this juice are put on a white tile, covered with a glass plate, and undissolved and/or burned particles are observed visually.

For rapid routine test 1.3 g of powder and 18 ml of water in a 50 ml beaker were found convenient. Up to 10 times these amounts in a large beaker did not alter the reproducibility of these results. When water is added the sample is stirred gently 3 to 4 times with a glass rod to ensure uniform wetting of the powder. The sample is then left undisturbed for 90 seconds. After 90 sec. the sample is again stirred gently for 30 sec. using an uniform motion of about 2 revolutions per sec. of the glass rod around the inside of the beaker.

Two samples of 0.5 ml each are immediately removed with callibrated medicine droppers and spread carefully over the surface of separate 25x75 mm, clean micro-slides. The tip openings of the medicine droppers are enlarged to about 2 mm diameter for the passage of larger powder particles, and after each sampling the droppers are flushed with water. In an alternate method of sampling, 1 ml samples are placed in counting chamber slides. This procedure of reconstitution and sampling is repeated several times in succession allowing 90 sec, delay between each interval of 30 sec. in which the sample in the beaker is stirred. Thus samples representing intervals ranging 2 to 20 minutes for powder reconstitution are obtained.

2.11 Colour of Tomato Paste and Powder

Several different notations have evolved in reporting colour analysis, Goose [1] and Hunter [41], according to the instrument on which the measurements are made, despite the fact that an agreed international system has been in existence since 1931.

The Commission Internationale de L'Eclairage (CIE) system is based on the effect that any colour may have an agreement on "standard observer".

The Lovibond-Schafield Tintometer adapted for measuring opaque materials, enables any coloured sample to be seen through a viewing tube which by a system of prisms and mirrors, is made to occupy half the field of view. The other half receives reflected light from a standard white surface which passes through coloured glasses mounted in racks. The glasses are made in numbered graduations of the substractive primary colours (red, yellow and blue) and this enables every due to be observed. The x, y and z co-ordinates of the CIE system can be obtained from these observations. Hunter [41] noticed that the weaknesses of the Lovibond system are associated with subjective difficulties in matching colours in the extremely small areas which appear in the "half-field" under viewing.

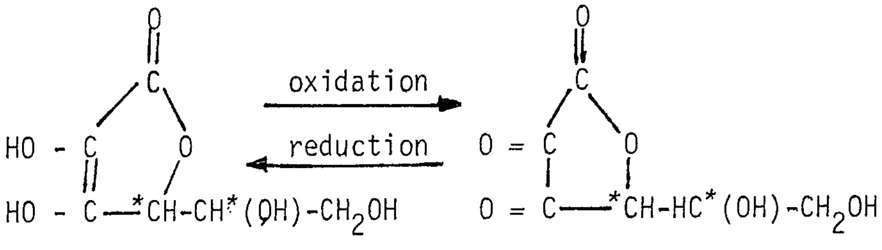
Eye-piece and the eye fatique occurs relatively quickly when various combinations of coloured glasses of almost the same saturation are viewed in attempting to obtain the closest possible match. The colour matching on the instrument may be reported as many units of yellow, red and blue with additional units of brightness.

Other instruments which are widely used in assessing the colour of tomato paste and other tomato products are the tristimulus colorimeter or colour difference meter. In practice this type of a meter evaluates colour by means of three photo-cell connected to a very sensitive galvanometer which records in numerical terms the hue, saturation luminosity of the sample viewed in the reflected light from a standard source. The Garder colorimeter and the Hunter Lab. colourmeter both operate on the same basis, Hunter [42], Linder, Shomer and Vasiliver [43].

2.12 The Stability of Vitamin C

Vitamin C (L-ascorbic acid), which is present in a variety of fruit and vegetables, may easily be destroyed during processing and storage, Brich and Parker [44] . There are many factors for ascorbic acid destruction such as pH, exposure to air, reaction order, water content, presence of enzymes, the presence of copper and iron, heating temperature, and heating period, Benterud [45] and Krochta [5] .

Vitamin C is odorless and has a white crystalline form. It is found in nature as reduced form $C_6H_8O_6$ and oxidised form, $C_6H_6O_6$. They have the same biological activities, but dehydroascorbic acid can be easily oxidised to inactive diketogulanic acid.



Ascorbic acid Dehydroascorbic acid

Vitamin C, among all Vitamins, has the least strength against temperature, oxidation, drying and storage. If it's oxidation is prevented, it is not destroyed by heat.

Naturally occuring Vitamin C is soluble in water and is quite widely distributed in nature being found in many fruits especially in the citrus, in green leafy vegetables and potatoes. The concentration of Vitamin C found in the various fruits can vary considerably, being a function of such diverse factors as country of origin, variety, age of fruit after harvesting .

Data found in the literature on the losses of water-soluble vitamins cover a wide range. The conditions of processing are not always well defined, even minor modifications may profoundly influence the vitamin content. Some general rules may be given for minimising processing losses : slow heating, long cooking and slow cooking should be avoided, and so should the use of copper, copper alloy or black iron equipment. Vacuum dearation or inert-gas treatment is recommended during processing wherever feasible. A major part of the loss is due to a leaching of soluble matter into the cooking water. Small pieces with a relatively large surface area therefore lose more vitamins than pieces, Benterud [45]

Blanching of fruits and vegetables inactivates the ascorbic acid oxidase and stabilises Vitamin C. Losses of ascorbic acid due to blanching may vary from less than 10 % under the most favourable conditions up to 50 % or more in the domestic preparation of foods.

Amongst the various drying techniques to make fruit juice powders, freeze dehydration is perhaps the best because of minimum damage done to the product during processing but it is expensive, Brennan, et.al. [10] .

Ammu, et.al [46] , during storage, amount of ascorbic acid loss is considerable such as at room temperature under vacuum and inert gases the tretention of ascorbic acid is estimated about 57.1 and 61.1 % after 4 months in the Mango. The destruction of ascorbic acid has been studied rather intensively. The reaction is usually modelled as a first-order reaction .

$$r_i = -k\ C_i \qquad \text{kg/m}^3\text{.s} \qquad 2.1$$

Recently, it is reported that the rate constant is a function of water activity and temperature for dehydrated tomato juice, under various conditions of availablility of oxygen for the degradation reactions.

Activation energies ΔE_A is estimated about 75 kj/mol prevails at water activities $a_w > 0{,}4$, more or less independently of the composition of the system. At low water-activity levels, perhaps different levels of diffusion-limitation effects develop in different systems, leading to a scatter in ΔE_A value.

2.13 Powder Packing and Properties

The powder is best packed in an inert atmosphere (nitrogen or CO_2) to obtain a powder that will be used within a few months of production, atmospheric packing in very dry air will normally suffice, if the powder temperature is low during packing. The cooler the powder, the less tendency there is for lumping to occur. The maximum powder temperature for relatively lump-free storage depends upon the type of tomato.

Powder container can be lined drum, waxed cartons, tins or polyethylene bags. Whatever container is used, it must be air and moisture proof. Due to the hygroscopic nature of the powder, any slightest leakage will cause the powder to lump rapidly. To counteract leakage, silica up to 2 % by weight, has been permitted in some countries, Peleg [37] and Goose [3] . Silicagel envelopes are sometimes placed in each container during packing. The packed powder must be stored in a cool place Ammu [46] .

CHAPTER 3

KINETICS OF ASCORBIC ACID (VITAMIN C) LOSS IN TOMATO CONCENTRATES DURING HEAT TREATMENT

3.1 Introduction

As a well established fact, chemical reactions are mostly hastened with temperature increment. Thus, with food materials, essential during high temperature treatment, extreme care is required to minimize the loss of nutritive value and quality factors due to chemical reactions Ogunsua [47] , Benterud [45] , Selman and Rolfe [48] , Silvia and Janice [49] . In conjunction with this fact, it has been shown that most of the degradative chemical reactions are of first-order kinetics with respect to the concentration of the nutrients Toledo [50] .

$$-r_i = \frac{dc_i}{d\Theta} = k.c_i \qquad 3.1$$

and in integrated form,

$$\ln \frac{c_i}{c_{io}} = k.\Theta \qquad 3.2a$$

or

$$c_i = c_{io}e^{-k.\Theta} \qquad 3.2b$$

Objective of this chapter is to investigate the kinetics of degradation of Vitamin C present in tomato concentrates, through the parameters of solids concentration (or water) in the original sample, treatment temperature and duration of treatment. Thus obtained results will be utilized in fixing the variables for the spray drying experiments.

For many reactions and in particular elementary reactions the rate expression (Equ.3.1) can be written as a product of a temperature-dependent term and a composition-dependent term.

$$-r_i = \phi_1(T) \cdot \phi_2(c_i) \qquad 3.3a$$

or

$$= k\ \phi_2(c_i) \qquad 3.3b$$

The temperature-dependent term is proportional to the reaction rate constant according to Arrhenius law ;

$$k \ \alpha \ e^{-E/RT} \qquad 3.4$$

Basing on the predictions of the simpler versions of the various theories, Levenspiel [51] and Yatsimirkii [52], the proportionality in Equ.3.4 can be converted to equality by,

$$k = k_0 . T^m . e^{-E/RT} \qquad 3.5$$

to account for the temperature dependency of the rate constant. In very many cases, because the exponential term is much more temperature sensitive than the T^m term, the variation of k caused by the latter is effectively masked to yield,

$$k = k_0' \ e^{-E/RT} \qquad 3.6$$

3.2 Material and Methods

3.2.1 Preparation of samples

Commercial tomato paste samples of 28% by wt solid were obtained from Demko Gıda Sanayi A.Ş. For each experiment, tomato concentrates of different solids content having pH of 4.30 were determined by an Abbé refractometer (model B, F.G.Bode Co.).

3.2.2 Chemical Reagents

The total Vitamin C content of tomato concentrates were determined by indophenol titration technique using the following chemicals, Welcher [53] .

A - Metaphosphoric acid (Merck) - solution of 6% wt were prepared

B - Standard ascorbic acid solution

C - 2.6 diclorophenol indophenol (DCIP)(Merck) - solutions of 0.025 % were prepared to be used in titration.

3.2.3 Analysis of the Samples For Vitamin C

The visual titration method [53] was used and for each assay 100 g of treated sample was taken into a centrifuge tube and the volume was completed to 100 ml by 3% HPO_3 and centrifuged at 50 Hz for ten minutes. A 10 ml aliquot of the supernatant was then titrated with 0.025% DCIP to faint pink end point. All the titrations were duplicated.

The result of the titrations were then evaluated as follows :

$$C_c \quad \frac{\text{mg ascorbic acid}}{\text{100 g sample}} = \frac{v_1 . z_1}{w_1} \times 100 \qquad 3.7$$

3.2.4 Time Analysis

In order to find out the order of the Vitamin C degradation reaction five tomato concentrate sample of different solid concentration were prepared and analysed as described above. Each four 100 g samples were transferred into flasks and then all were placed in an incubator kept isothermal at 115°C using 15 min. intervals after the placement, one set of five concentrates were analysed for Vitamin C content. Thus, altogether 5x5 Vitamin C concentrations were obtained as a function of concentrate concentrations and time. The results, are presented in Table:3.1 for which $w_1 = 0.50$ g, and $z_1 = 0.1230$ ml dye.

3.2.5 Temperature Analysis

The dependence of reaction rate on temperature was investigated through a run carried for a fixed treatment time of 30 minutes and on fixed solids concentration of 15% wt at different temperature of 115, 125, 135, and 160°C. At the end of 30 minutes the samples were analysed for Vitamin C content. The results are shown in Table: 3.2 for $w_1 = 0.50$ g and $z_1 = 0.1212$ ml dye.

3.3 Results

When the data of Table: 3.1 is presented as a plot of ascorbic acid concentration C_c mg per 100 g of sample versus time Θ min as in Fig.3.1, the trend directly implies an exponential decay of Vitamin C by time. Equation 3.2 was fitted to the experimental data and parameters were calculated by using a linear regression program supplied a HP-11C Hewlett Packard programmable desk calculator.

The curves fitted to the data are shown by indicated lines on Fig.3.1, and the calculated values of ascorbic acid concentration and reaction rate constant are given in Table 3.3 together with the respective regression coefficients.

3.3.1 Reaction Rate Constant

A rough investigation of the values in Table 3.2 implies that reaction rate constant depends on both temperature and solids concentration, or amount of dilution of tomato concentrates.

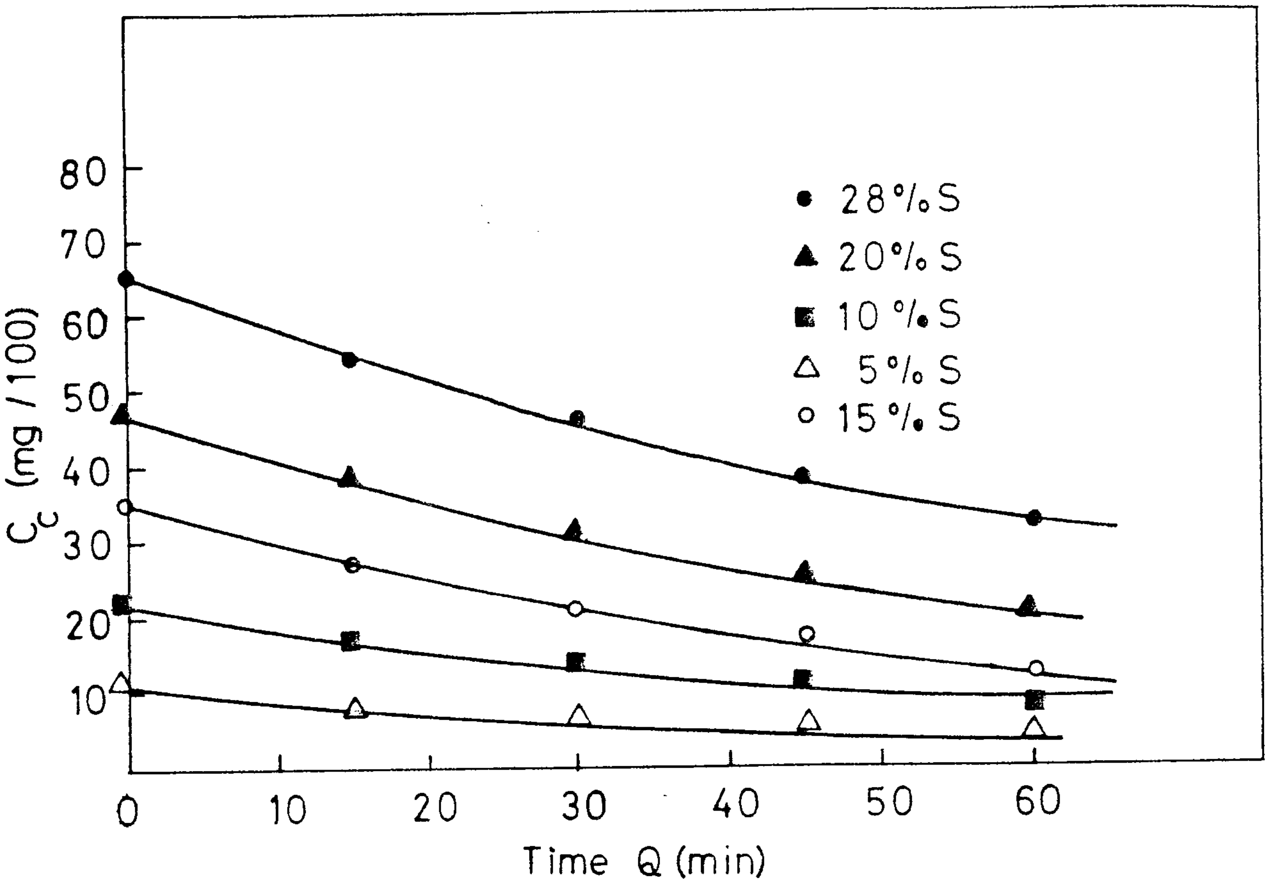
3.3.1.1 Dependence on Solids Concentration

In Equ.3.5, terms k_0' and R are constants leaving temperature T and activatívation energy E to be the variables. Since in the foregoing discussion temperature is fixed, i.e. 115°C, there remains only the concentrate concentration, %S to influence activation energy. Using logarithmic form of Equ.3.5,

$$\ln k = \ln(k_0' \cdot T^m) + \left(-\frac{E}{RT} \right) \qquad 3.8$$

implies ln k to vary linearly with E if all the other terms are held constant.

In the light of this evidence ln k values obtained from k_{calc} column in Table 3.3, were plotted against %S, and through regression analysis Equ. 3.9 is obtained with a correlation coefficient of 0.7655, which is shown in Fig.3.2.



Degradation of vitamin C as a function of time and solids concentrate at 115 °C
Figure : 3.1

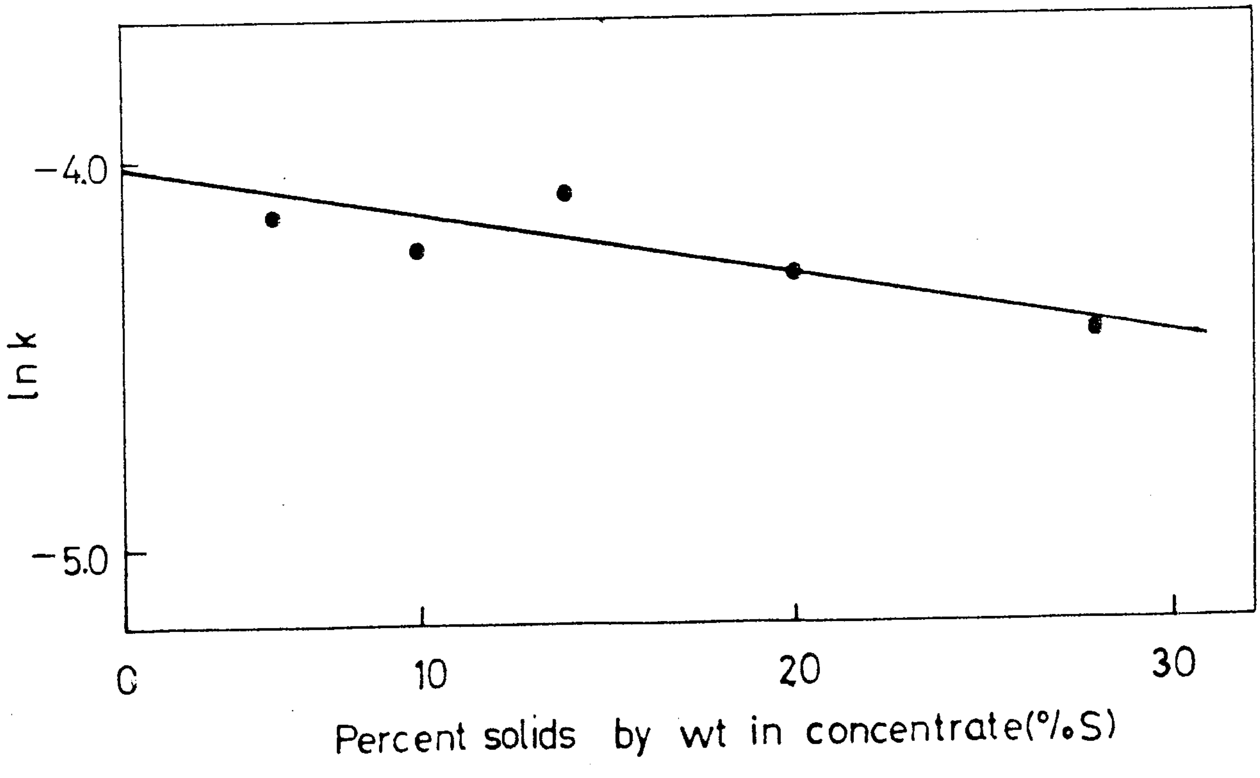


Figure 3.2 Variation frequency factor with concentration

Table 3.1 Degradation of Vitamin C as a Function of Time and Solids Concentration at 115°C.

Time	Per cent total solids in concentrate, % S				
	28	20	15	10	5
Θ min	Ascorbic acid concentration C_c (mg/100 g)				
0	65.69	46.92	35.19	23.16	11.73
15	54.54	39.39	27.27	18.18	8.40
30	46.05	30.90	21.21	12.12	6.00
45	36.90	24.60	17.22	11.20	4.92
60	33.21	20.29	11.99	10.44	5.00

Table 3.2 Degradation of Vitamin C as Function of Temperature

Solids concentration, % S = 15 % (wt)

Treatment time, Θ = 30 min

Initial ascorbic acid content, C_{io} = 35.19 mg/100 g

t, °C	115	125	135	160
C_c mg/100 g	22.42	21.21	19.99	17.27
k_0(Equ.3.12)	0.01798	0.02022	0.02244	0.02792

Table 3.3 Regression Analysis Results for Exponential Fit, $C_c = C_{co}\, e^{-k\Theta}$

Solids	Time parameter as employed in the experiment (min)						
conc.	0	15	30	45	60	k_{calc}	ς^2
% S	Calculated vitamin C concentration C_{calc} (mg/100 g)					(min^{-1})	
28	65.42	54.80	45.91	38.45	32.21	.0118	.9945
20	47.22	38.19	30.89	24.98	20.21	.0141	.9981
15	35.38	27.30	21.07	17.26	12.55	.0173	.9948
10	22.47	18.03	14.46	11.61	9.32	.0147	.9401
5	11.22	8.81	6.92	5.43	4.27	.0161	.9353

$$\ln k = -4.026 - 0.0125\ (\%\ S) \qquad 3.9$$

From the correspondance between Equ. 3.8 and 3.9.

$$-\frac{E}{RT} = -0.0125\ (\%\ S) \qquad 3.10$$

and from which at 388.15^{o}K (115^{o}C).

$$E = 40.34\ (\%\ S)\ \text{Joules/mole} \qquad 3.11$$

or $= 9.642\ (\%\ S)$ Calories/mole

3.3.1.2 Dependence on Temperature

Having correlated reaction rate constant to tomato concentare concentration, there is left only temperature dependence to be solved from the data in Table 3.2, through the following reasoning.

When Equ. 3.2 is reconsidered with the existing variables in logarithmic form,

$$\ln \frac{C_c}{C_{co}} = -(k_o' \, T^m .\ e^{-E/RT}) \ .\ \Theta \qquad 3.12$$

Assigning k_o as $k_o'.T^m$ and k_1 as E/R, and knowing that Θ ,E, and R were constants in the data, solution of Equ.3.12 for k_o yields,

$$k_o = \frac{\ln \frac{C_c}{C_{co}}}{\Theta\ .\ e^{-k_1/T}} \qquad 3.13$$

Where, Θ is 30 minutes, and k_1 is 72.74 K.

Equ. 3.13 permits the evaluation of k_o as a function of temperature as tabulated in the last line of Table 3.2. Further application of the regression analysis in power form, to these values gives,

$$k_o = 9.822 \times 10^{-13}\, T^{3.967}\ (\mathrm{min}^{-1}) \qquad 3.14a$$

$$= 3.37 \times 10^{-5}\, \Delta T^{1.325}\ (\mathrm{min}^{-1}) \qquad 3.14b$$

Where $\Delta T = (T-273.15)K$, or directly equal to ^oC, with regression coefficients of 0.9979 and 0.9998 respectively Fig.3.3.

As a consequence of data treatment the over all relation giving the fraction of the original Vitamin C that can be retained in tomato concentrates during heat treatment is,

$$\frac{C_c}{C_o} = \exp\left(-\ 9.822 \times 10^{-13} .\ T^{3.967}\ e^{-40.34(\%\ S)/RT} .\ \Theta\right) \qquad 3.15$$

dependent on the parameters and conditions employed in this study.

3.4 Discussion

It has been known that nutritive elements of foods are highly sensitive properties. Among these, vitamins have remarkable behavior as being subject to degradation, or gradual loss due to chemical reactions. In accordance with this fact, the presented study indicates that the rate of loss of Vitamin C in tomato concentrates shows a first-order dependence on the concentration of Vitamin C present at any time, with the combined effects of temperature and water content. As to the validity of the proposed correlation the following arguments can be made.

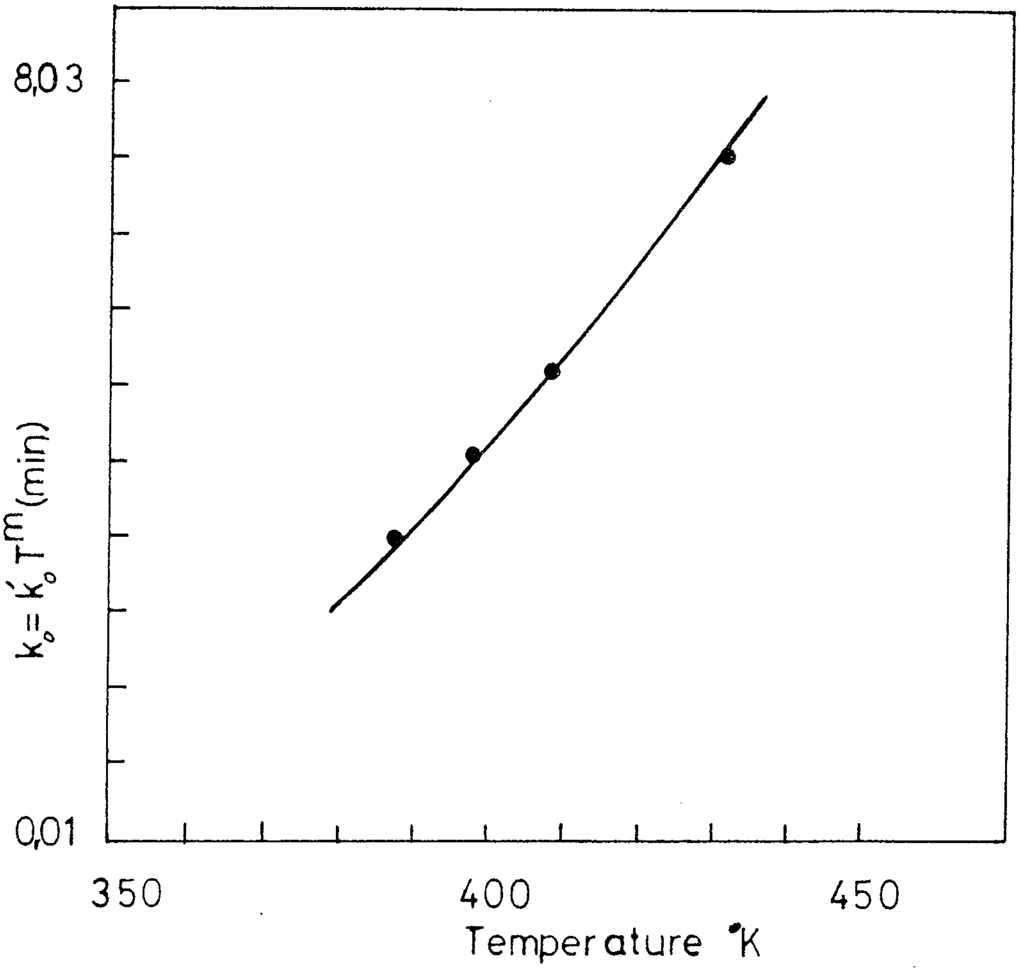


Figure 3.3 Variation of frequency factor with temperature

The reaction rate for degradation of Vitamin C being governed by a first-order mechanism is quite a well known feature Charm [54] , Toledo [50] , Benterud [45] , Mishkin, Saguy and Karel [55] . However, the most important consequence of this work is the establishment of an equation to account for the reaction rate constant.

With regard to the enhancement of the reaction by increased dilution, a possible explanation may be given basing on the physical properties. At the first glance the effect of dilution may not seem to be quite explicit in Equ.3.15., where, activation energy of the reaction E is given as 40.34 (% S), rather than the more correct form 40.34 (100- % H_2O), just for the ease of application. Thus, the net effect of increasing dilution would be exponential on the reaction rate constant. Such a behavior may be attributed to several factors as,

A - increased solubility of Vitamin C favoring oxidation and hydrolysis reactions to be more effective,

B - increased diffusivity due to lowering the apparent viscosity of the medium, enabling a higher rate of transfer of Vitamin C to reaction sites.

In similar studies Benterud [45] , it was pointed out that if the water to green vegetable ratio is increased during cooking , greater loss of Vitamin C had resulted. Furthermore, when compared with tomato concentrates, greater activation energy values for loss of Vitamin C were reported during cooking of green beans and blanching of green peas ,Abrahams [56] ,Selman and Rolfe [48] , Lathrop and Leung [57] whereas lower values for potatoes during cooking .

In these studies either there does not exist a clear correlation attributing the loss of Vitamin C to activation energy, or activation energy hence the rate constant is given as a function of water activity, which is an indirect means of expressing the water content of the material of interest Mishkin, Saguy and Karel [58] . On the other hand, the range specified for the activation energy for ascorbic acid destruction in some food materials as 30-100 kJ/mol seem to be about 50 times greater than the values determined in this work, Auerre et.al.[59].It can be claimed that the differences observed in the degree of loss through the activation energy, is a consequence of the structural differences between various food materials which in turn is responsible for the resistance to diffusional transfer. Therefore, the coefficient 40.34 valid for tomato concentrates will be expected to depend on the type of the material.

Considering the effect of temperature, as can be seen from the final relation a two-fold dependence exists. The exponential one being the implication of the Arrhenius' law, is a common feature for nearly all chemical reactions. However, dependence of the rate to the 3.967 th power of temperature is not so much experienced. It is theoretically possible to account for the presence of temperature raised to a power, through collision or transition-state theories Levenspiel [51] , but these can predict the power in the range 0-1.0, whereas it was also emphasised that, for more complicated versions m could be as great as 3 or 4. As a final remark on the alternate form of the temperature dependence proposed in Equ.3.14, one can easily see that else than practical use for calculations above 0°C, it has no theoretical basis and in fact by implying a discontinuity at 0°C (273.15 K) it is a false relation.

Although we have estimated the amount of ascorbic acid by titration method, the high pressure liquid chromatographic (HPLC) or fluorometric methods can be used for specific work, Welcher [53]. However,it is believed that the titration method was more practical and sufficient for our purpose.

In the light of the results obtained in this work and the foregoing discussion, it can be recommended that in order to maximize the Vitamin C retention in food materials, primarily low temperatures, minimum water and short heat treatment times should be practised.

CHAPTER 4

DEHYDRATION OF TOMATO DROPLET

4.1 Introduction

The drying of tomato concentrates is a great problem because of its thermoplastic and hygroscopic properties, Goose [1] , Masters [16] [17] , Heig [28] , Ginnete [27] and Lazar [31] . A number of workers have developed empirical correlation for the prediction of drying rates of grain, sorgum, onion, papaya fruit, rice and potatoes, Auerre et.al. [59] , Suarez et.al. [60] , Mazza and Lemaguer [61] , Islam and Flink [62] , and have reviewed most of the research done in the area of spherical drying of cereals and some fruits. However, relatively no research has been performed on the drying of tomato concentrate droplet as compared to other food materials.

There are many published mathematical models available for estimating the simultaneous heat and moisture transfer in a drying spherical droplet, Topar [22] , Van Arsdel et.al. [24] and Keey [25] . The main difficulty in describing the transport of heat and mass inside a porous food material based on microscopic analysis is due to the geometry of the structure. This is not easily described quantitatively whereas the individual transport process is related to local values of temperature, pressure and composition.

The aim of this chapter is to investigate the fundamental aspects during drying of tomato droplets at different concentrations when fully exposed to an air stream of constant temperature and humidity. The results obtained from the drying rates were planned to to be used as data for further work.

4.2 Experimental Laboratory Drier

The drier consisted of a centrifugal fan, a rotameter a water bath, a preheater a Bunsen burner for direct heating, a balance, a spherical ended glass rod and connecting pipes.

The fan (F.G. Bode Co. type 15) was utilized to blow the air for drying and the rate of air supplied was adjusted by a rotameter, calibration of which is given in Appendix A Fig. 4.1, Esin [63] .

The thermostate controlled water bath in which distilled water was placed in a separate jar was connected to the air flow pipe from the rotameter. The wet-bulb and dry-bulb thermometers were connected on top of the glass jar.

The air flow pipe one meter of which was in the shape of a spiral about 3.0 m long was placed in paraffin solution. It was made of copper and had an outside diameter of 3.50 mm and inside 3.15 mm.The paraffin solution by means of which the air temperature was adjusted and kept at 98°C on a heater. The copper tubing was further heated by the Bunsen burner until the required air temperature (105-160°C) was reached.The copper pipe was connected to the glass drying chamber.

The glass drying chamber which was 175 mm long,and 110 mm high with three holes each having an inner diameter of 40 mm and an outer diameter of 55 mm was "T" shaped. The two holes were used for air inlet and outlet and the top hole was used for suspending the sample into the glass chamber the surface of which was insulated with glass wool. The spherical ended glass rod which was insulated with glass wool. The spherical ended glass rod which was connected to the balance (Sartorius type ∓ 0.0001 g) was suspended through the top hole of the drying chamber.

The copper pipe which was insulated with glass wool and connected tightly to the air inlet chamber had suitable valves and thermometers for measuring the air temperature. The function of the valves was to regulate manually the air flow which has been raised to the required tempearture, into the drying chamber.

The drying chamber air exit was plugged tightly with a cork which had two holes. To one of the holes a glass tube having a diameter of 15 mm was placed and the other one was used for measuring the outlet air temperature, with a precise thermometer placed in it which was close to the droplet. Details of the equipment and shape of the droplet aer given in Figs. 4.2 a,b, 4,3 and in Table 4.1.

Table 4.1 Specification of Elements in Experimental Set-up

No Equipment	Capitaly size	Cat.No.	Firm
1. Centrifugal fan	6 kg/m^2	No.2200050	F.G.Bode
2. Rotameter	12 scale	No.11-164-50	Fisher Sci.Co.
3. Water bath	10-100^{o}C	5B-100 A.6.8	Nüve.
4. Heater	10-160^{o}C	HOR K1776	F.G.Bode.
5. Balance	0.0001 g	2432S	Sartorius.

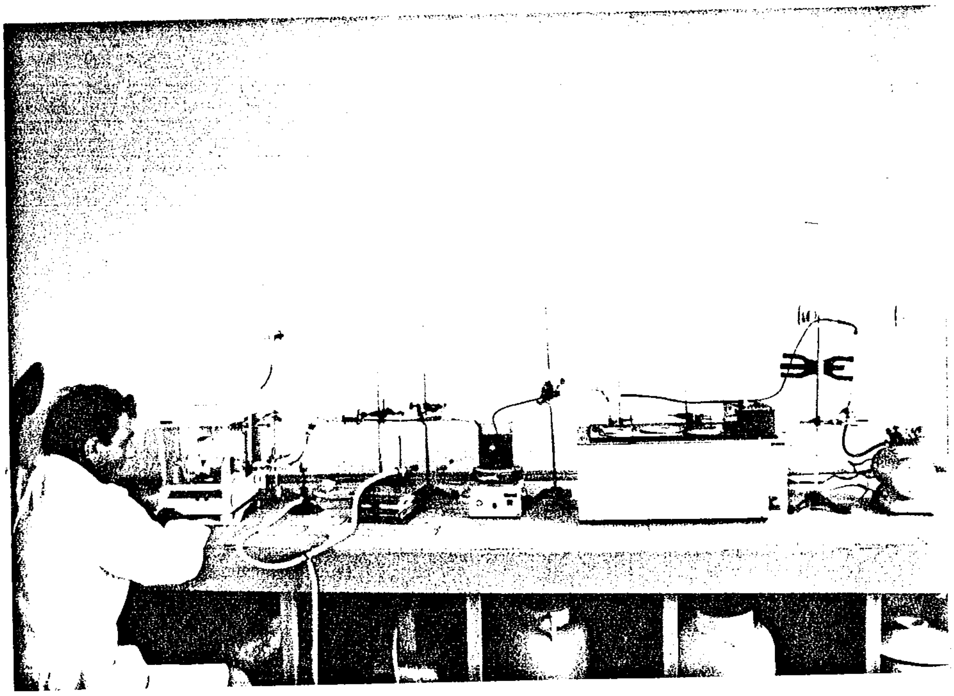


Figure 4.2a Experimental Set-up

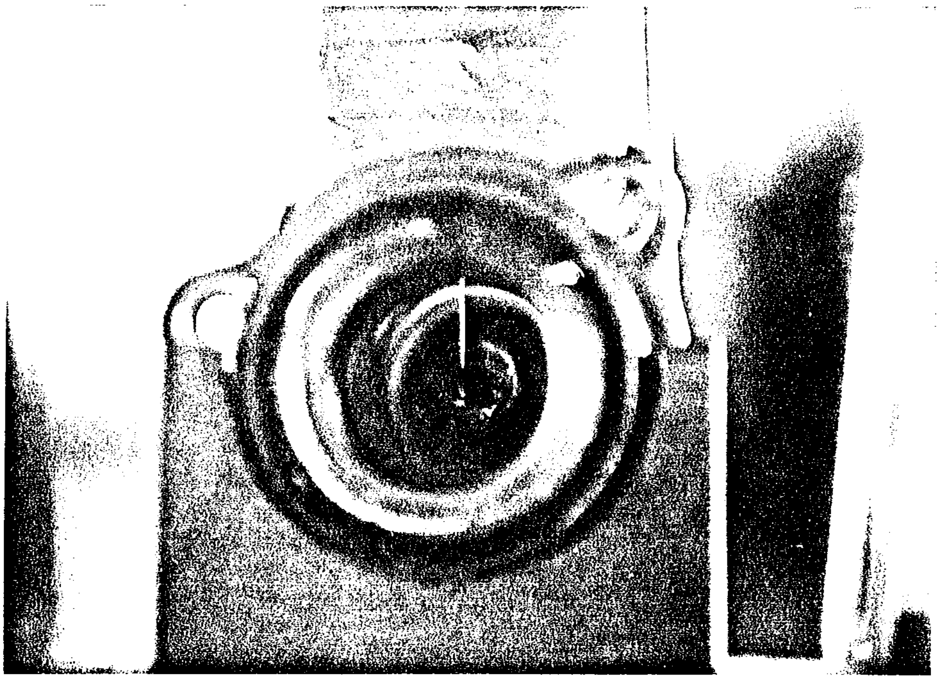


Figure 4.2b Magnified droplet as viewed in drying tunnel

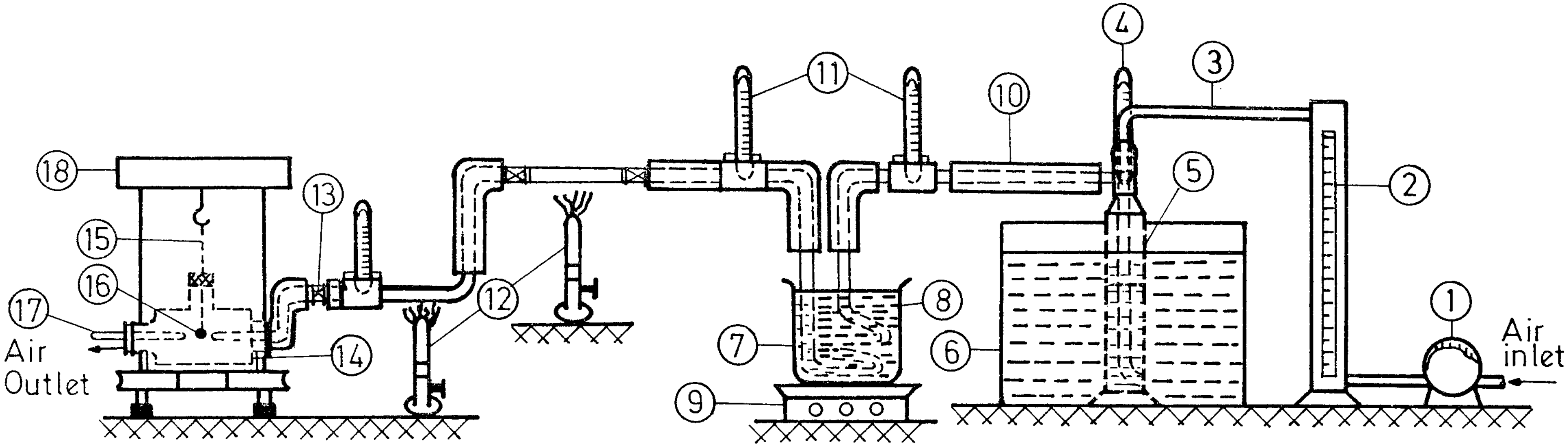


Figure 4.3 Experimental set-up

1. Pump 2. Rotameter 3. Section line 4. Wet-bulb thermometer 5. Water bottle 6. Water bath with thermostat 7. Glass beaker 8. Paraffin solution 9. Electrical heater 10. Glass wool insulator 11. Thermometers 12. Bunsen burners 13. Valve 14. Glass drying tunnel 15. Spherical ended glass 16. Tomato droplet 17. Precise thermometer 18. Balance.

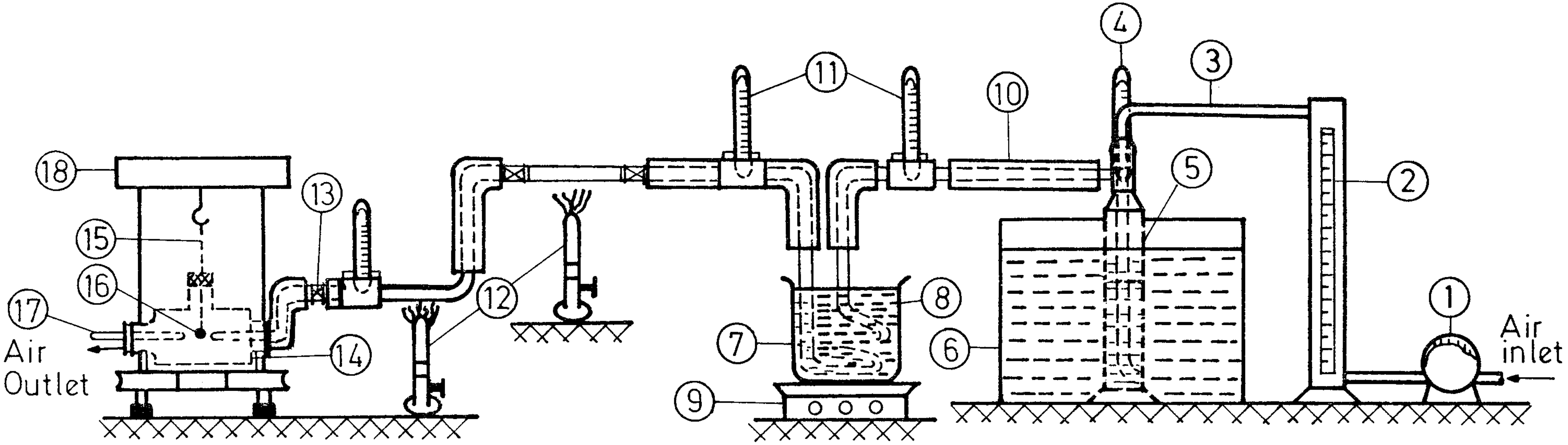


Figure 4.3 Experimental set-up

1. Pump 2.Rotameter 3. Section line 4.Wet-bulb thermometer 5.Water bottle 6.Water bath with thermostat 7.Glass beaker 8.Paraffin solution 9.Electrical heater 10.Glass wool insulator 11.Thermometers 12.Bunsen burners 13.Valve 14.Glass drying tunnel 15.Spherical ended glass 16.Tomato droplet 17.Precise thermometer 18.Balance.

4.3 Materials and Methods

Commercial tomato samples of 28-30 % wt solids were obtained from Demko Gıda Sanayi A.Ş. For each experiment, tomato concentrates of different solids were prepared by dilution with distilled water and were determined by an Abbé refractometer (Model B F.G. Bode Co.) .

Tomato concentrates of 5 %, 10 %. 15 %, 20 % and 28 % wt solids were prepared for each set of experiment and were hung on the end of a glass sphere of 1.5 mm diameter and density of 2.4 g/cm^3. Each sample was weighed and volumetric measurements were conducted. The radii of the droplets were calculated by a mass balance using the density of different concentrate concentration of tomato paste, Goose [1] .

$$m = \frac{4}{3} \pi \rho_s (r_2^3 - r_1^3) \qquad 4.1$$

The values of equilibrium moisture content and the corresponding radius of the dry solids for various drying temperatures were evaluated from drying rate curves which were obtained at adjusted constant relative humidity of the inlet air.

The parameters employed for this study were, temperature of the inlet air 60 ^oC, 70 ^oC, 75 ^oC, 80 ^oC and 100^oC and concentration of tomato paste, 5 %, 10 %, 15 %, 20 % and 28 % wt solids. The humidity of the inlet air was saturated air at 20^oC and at 30^oC for constant air flow rate of 11.90 ml/sec.

4.4 Results and Discussion

In order to analyse the effect of previous parameters, the data were converted to moisture content (dry basis) versus time and plotted on semilog paper as shown on Figs. 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13. In the light of the obtained variations, the following discussion can be made ;

As can be easily followed from the figures, the drying does not take place continuously, in which case the represented relations should have been a single linear variation. The discontinuities implied by the data are believed to be the consequences of case hardening.

As the concentration of the droplets were increased to 15 % wt, 20 % wt and 28 % wt, the migration of vapor became more difficult accordingly. Case hardening phenomenon starts even at higher moisture contents of the droplets, Karel [64] and Van Arsdel [65] , forming almost a dry outer shell nearly like an impermeable skin preventing further drying of the droplet.

Thus, by the commencement of case hardening phenomena , the mass transfer ceases and moisture content of the material remains constant over a period. During this period the material temperature increases which also increases the vapor pressure of the associated moisture within it. This increase in the vapor pressure of the moisture enables the transferring component to form cracks and escape through the impermeable shell. Therefore, each plataeu in such a plot is an indication of case hardened material, whereas the linear portions represent the drying steps.

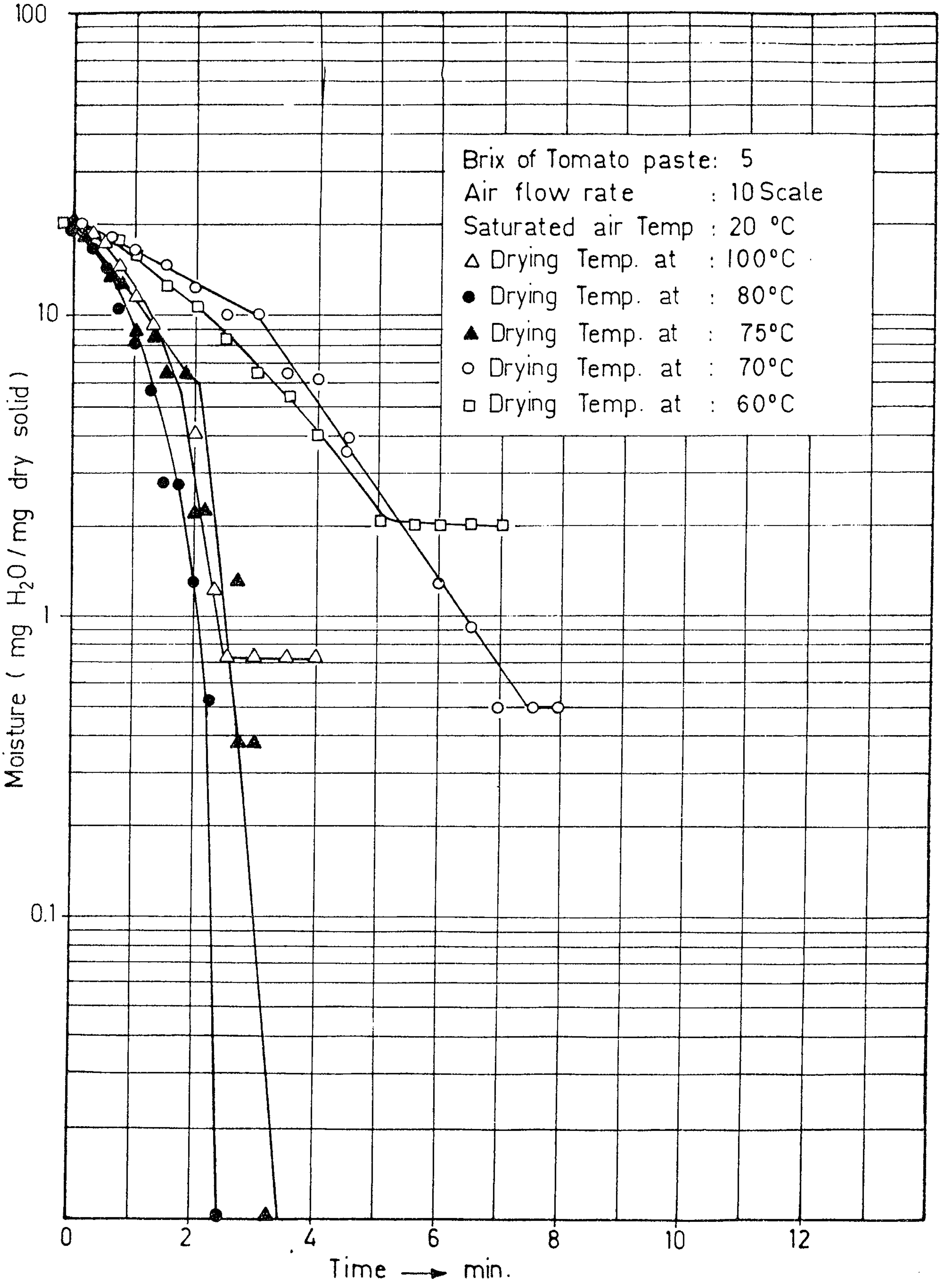


Figure 4.4 Droplet drying tomato paste:5 Brix, $u_S = 11.9$ ml/s $H_S = 20$°C

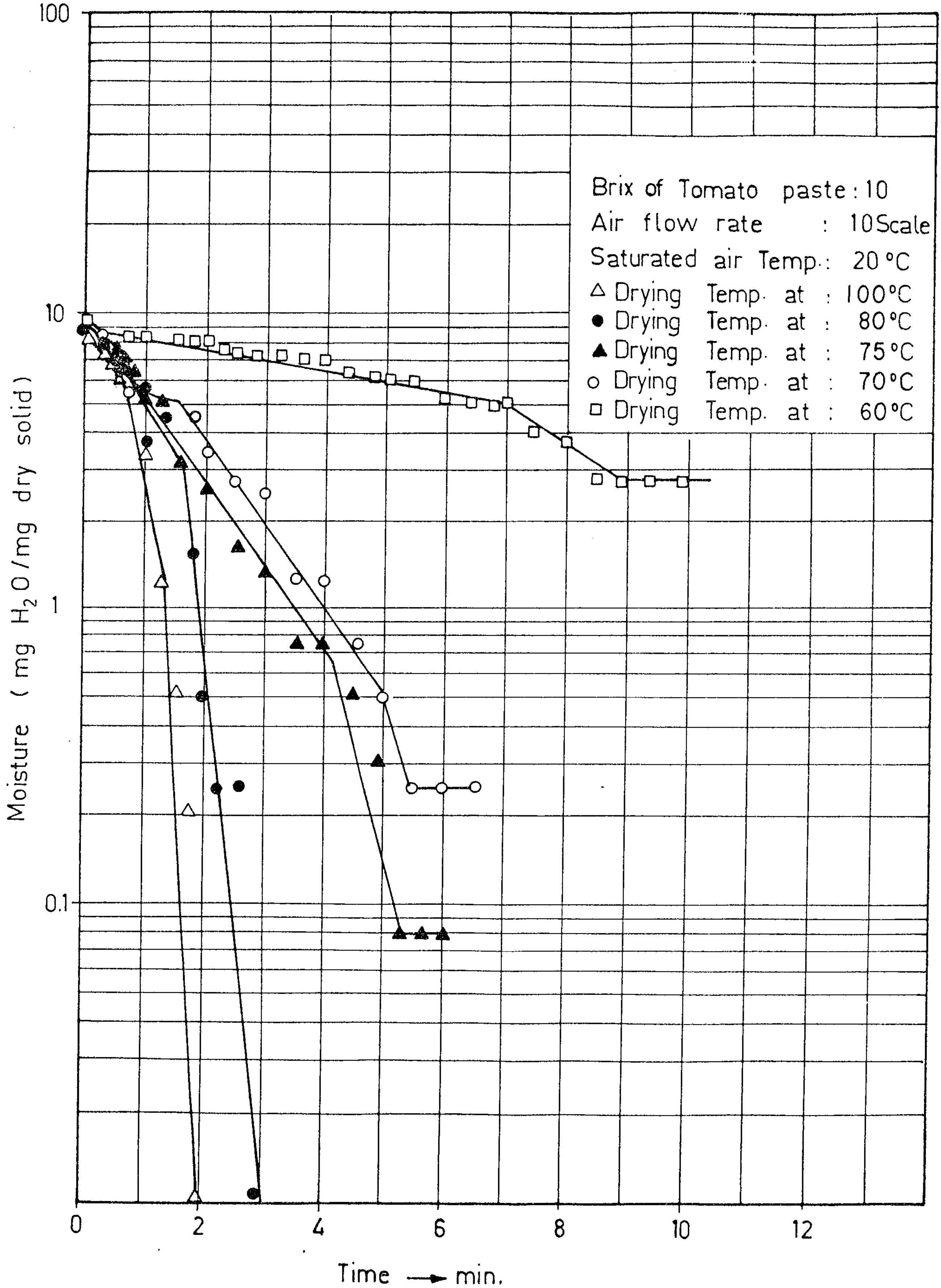


Figure 4.5 Droplet drying tomato paste : 10 Brix, u_S= 11.9 ml/s
H_S = 20 °C

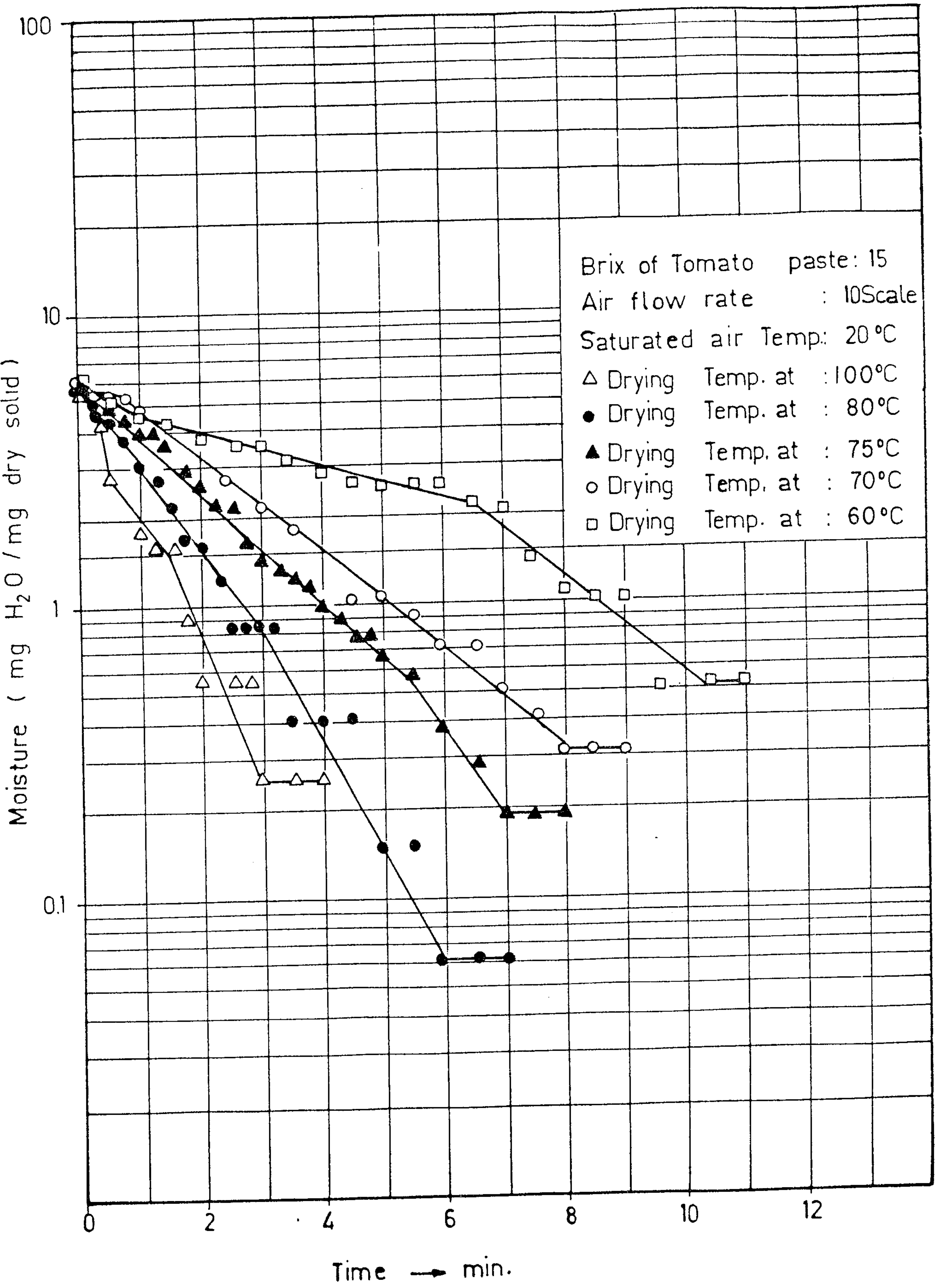


Figure 4.6 Droplet drying tomato paste: 15 Brix, $u_s = 11.9$ ml/s $H_s = 20$°C

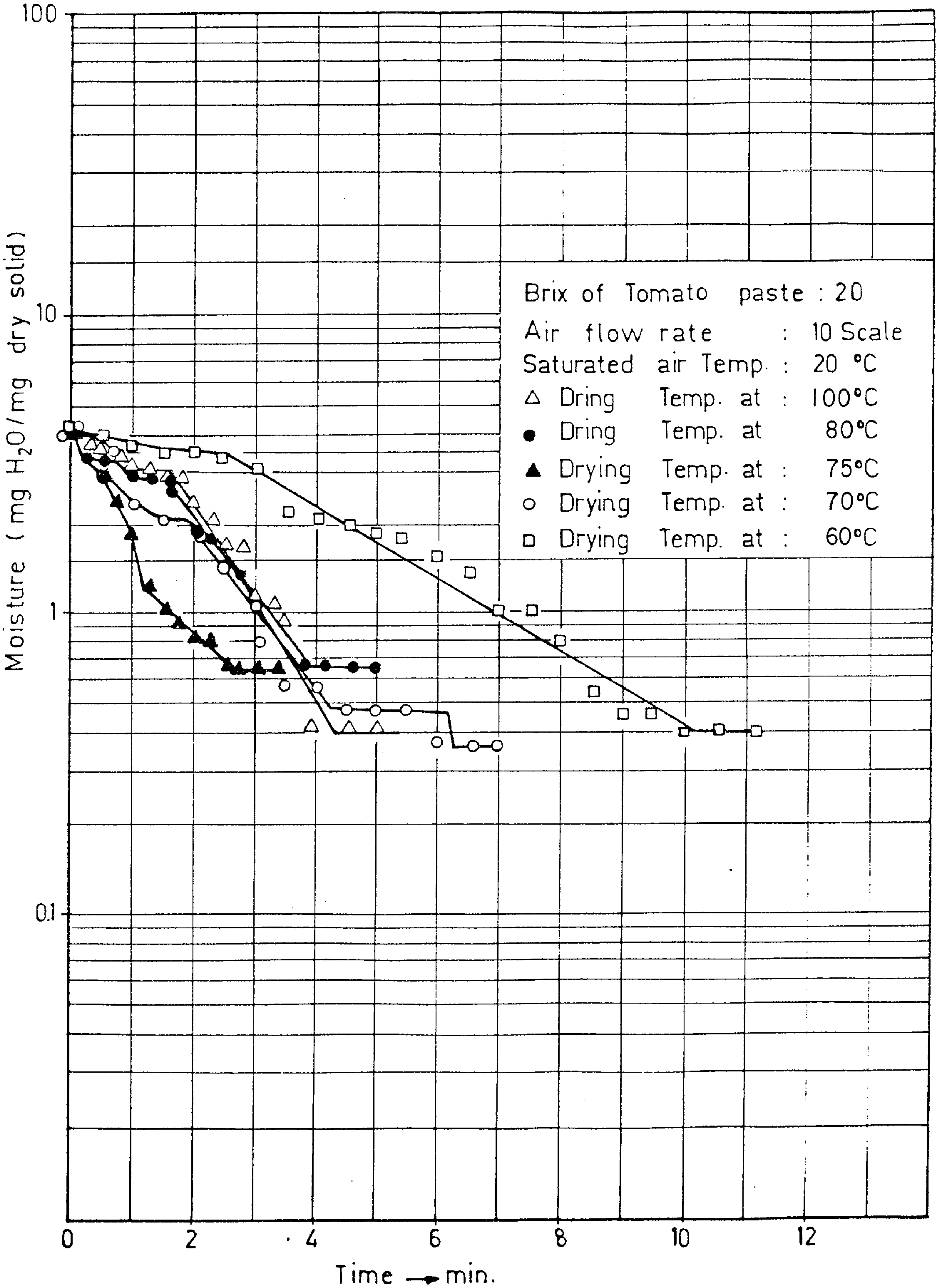


Figure 4.7 Droplet drying tomato paste : 20 Brix, $u_S = 11.9$ ml/s $H_S = 20°C$

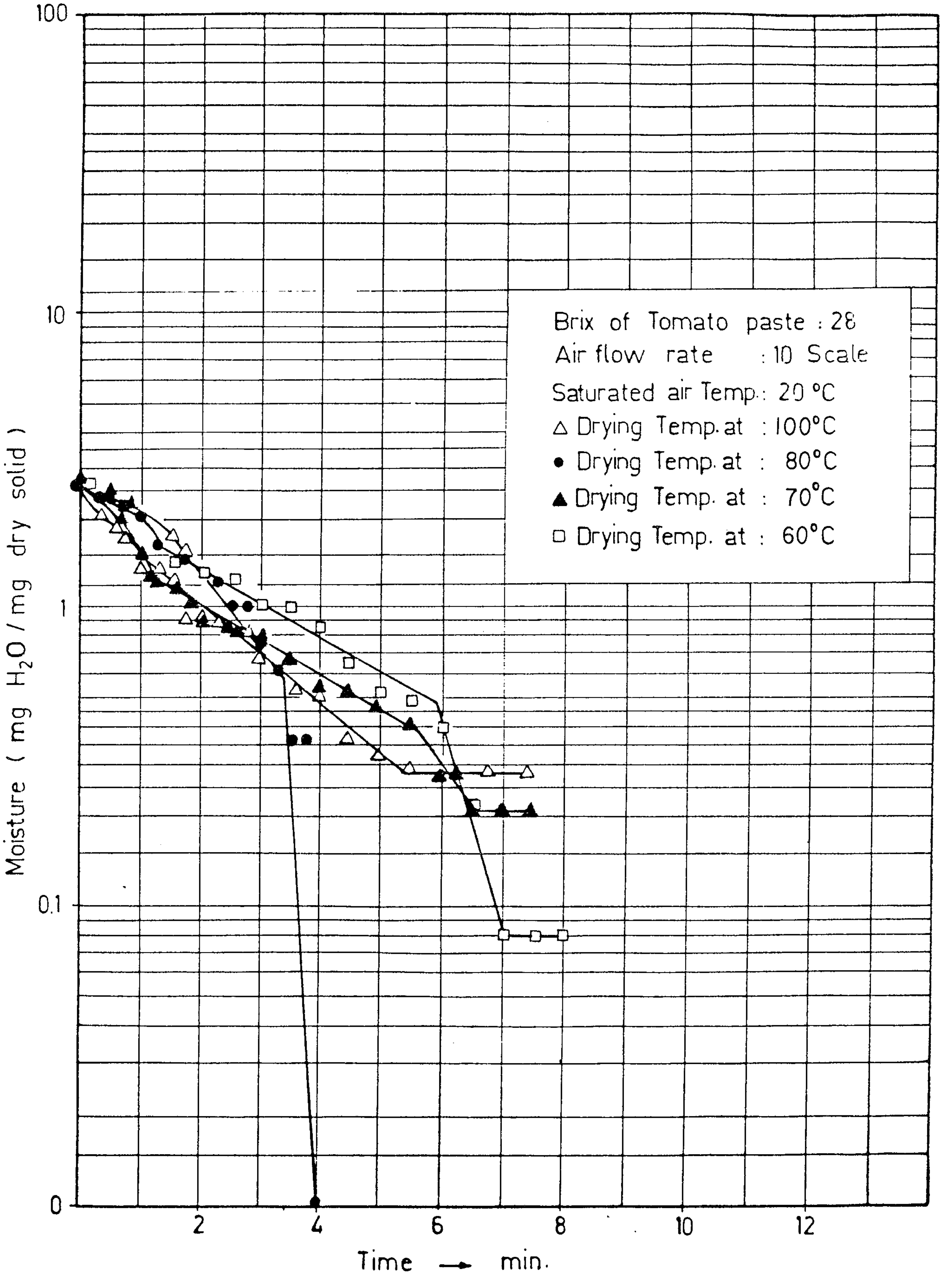


Figure 4.8 Droplet drying tomato paste : 28 Brix, u_s = 11.9 ml/s H_s = 20 °C

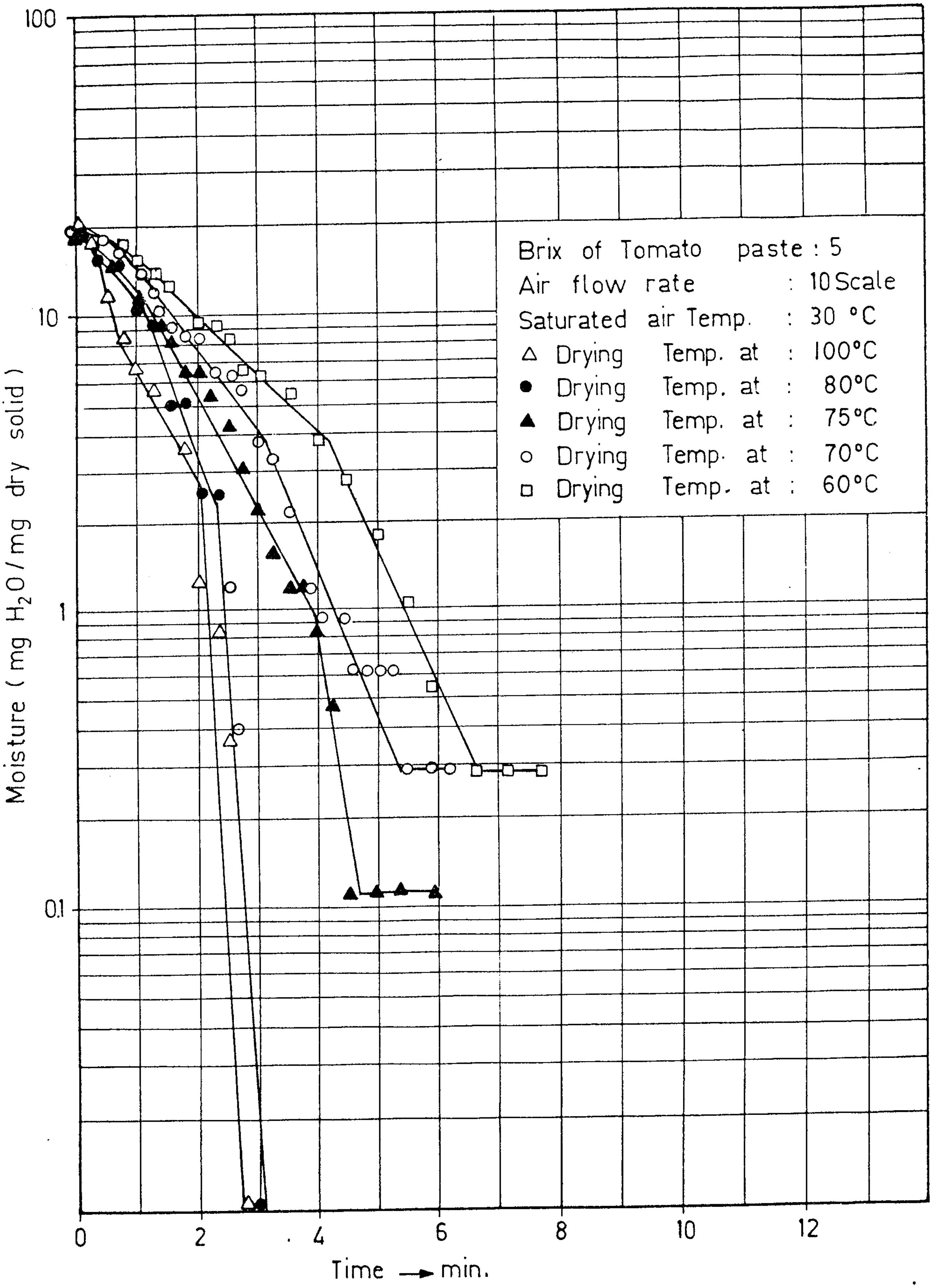


Figure 4.9 Droplet drying tomato paste : 5 Brix, $u_s = 11.9$ ml/s $H_s = 30$ °C

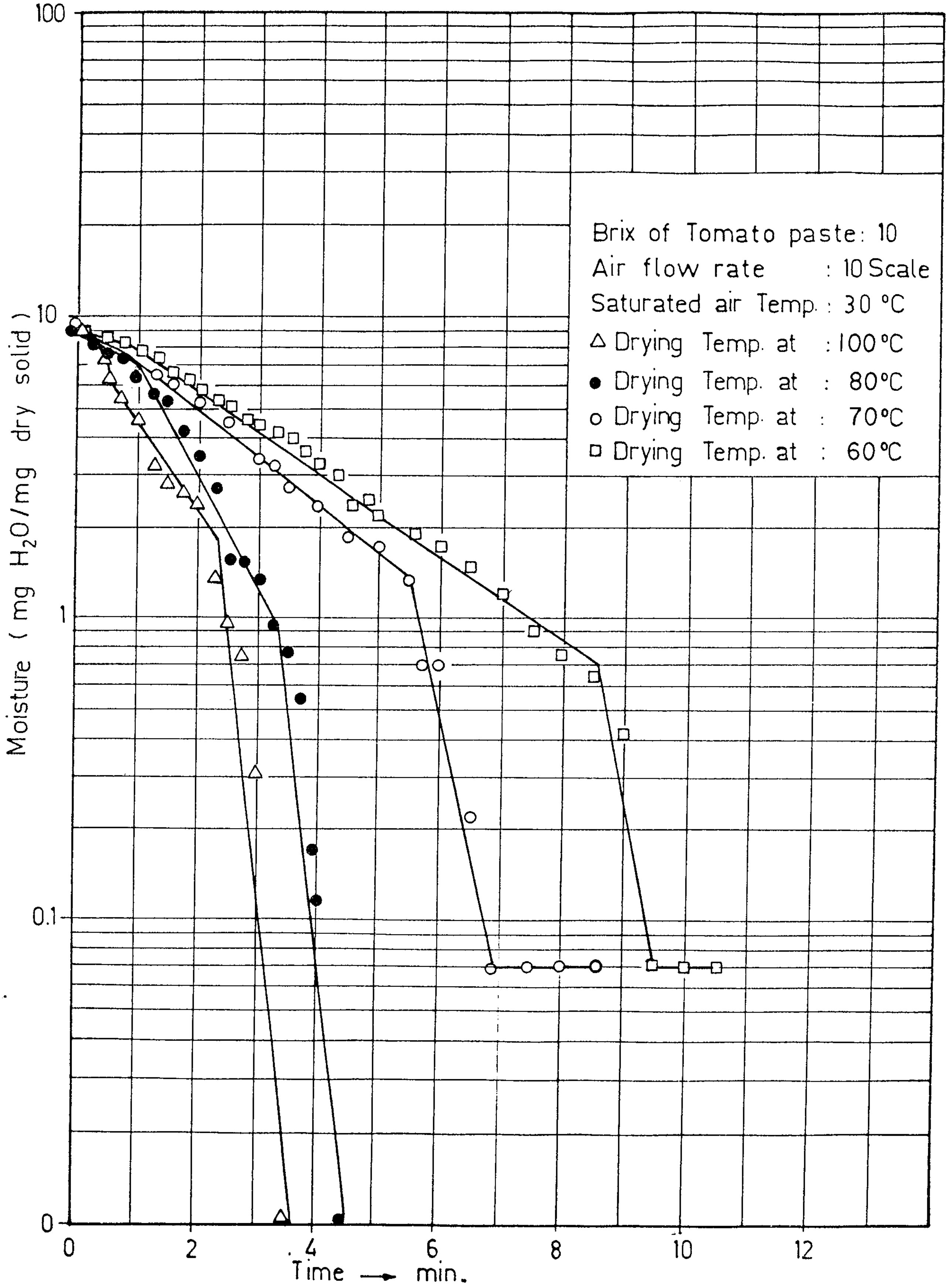


Figure 4.10 Droplet drying tomato paste : 10 Brix, u_s=11.9 ml/s H_s=30 °C

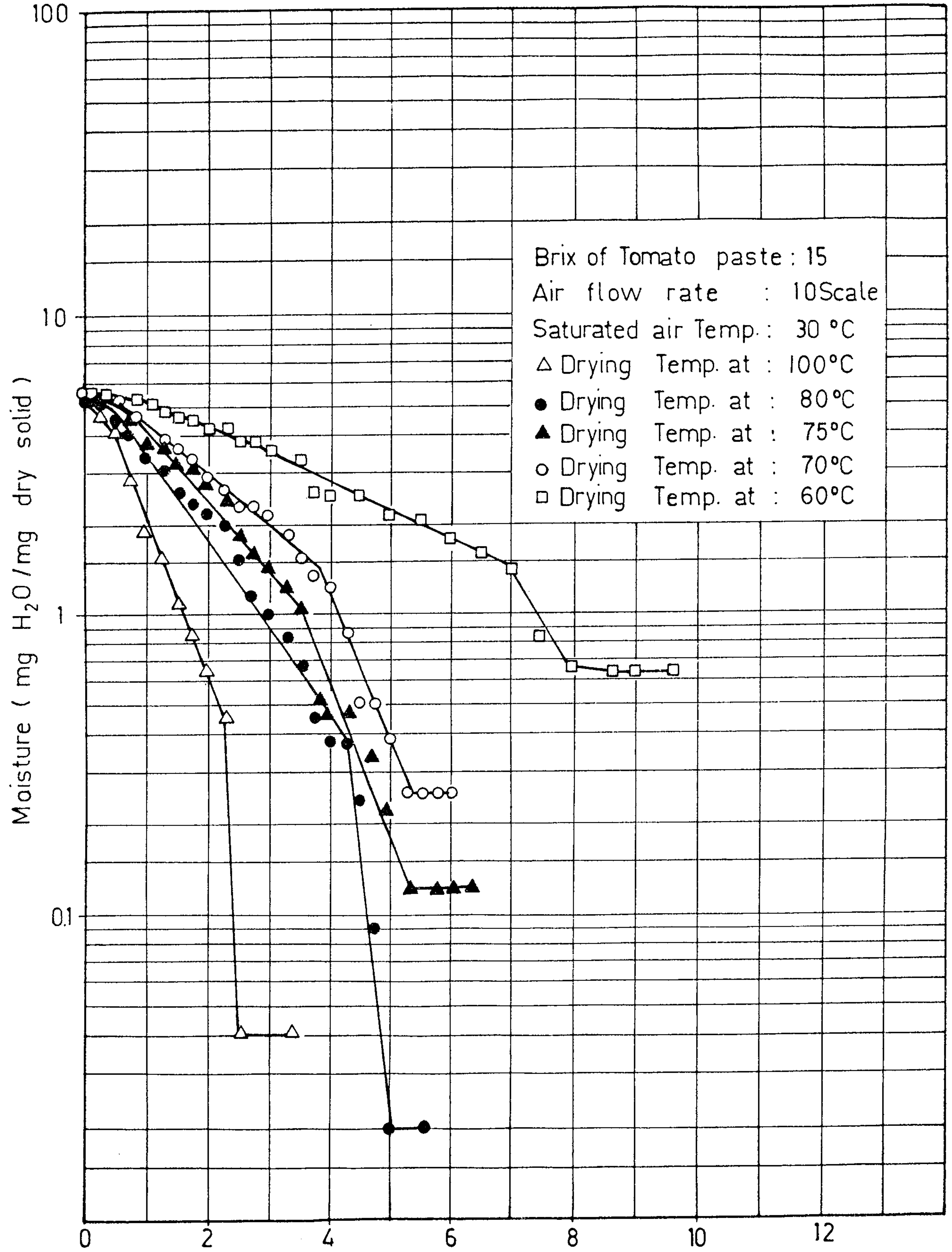


Figure 4.11 Droplet drying tomato paste: 15 Brix, u_s = 11.9 ml/s
H_s = 30°C

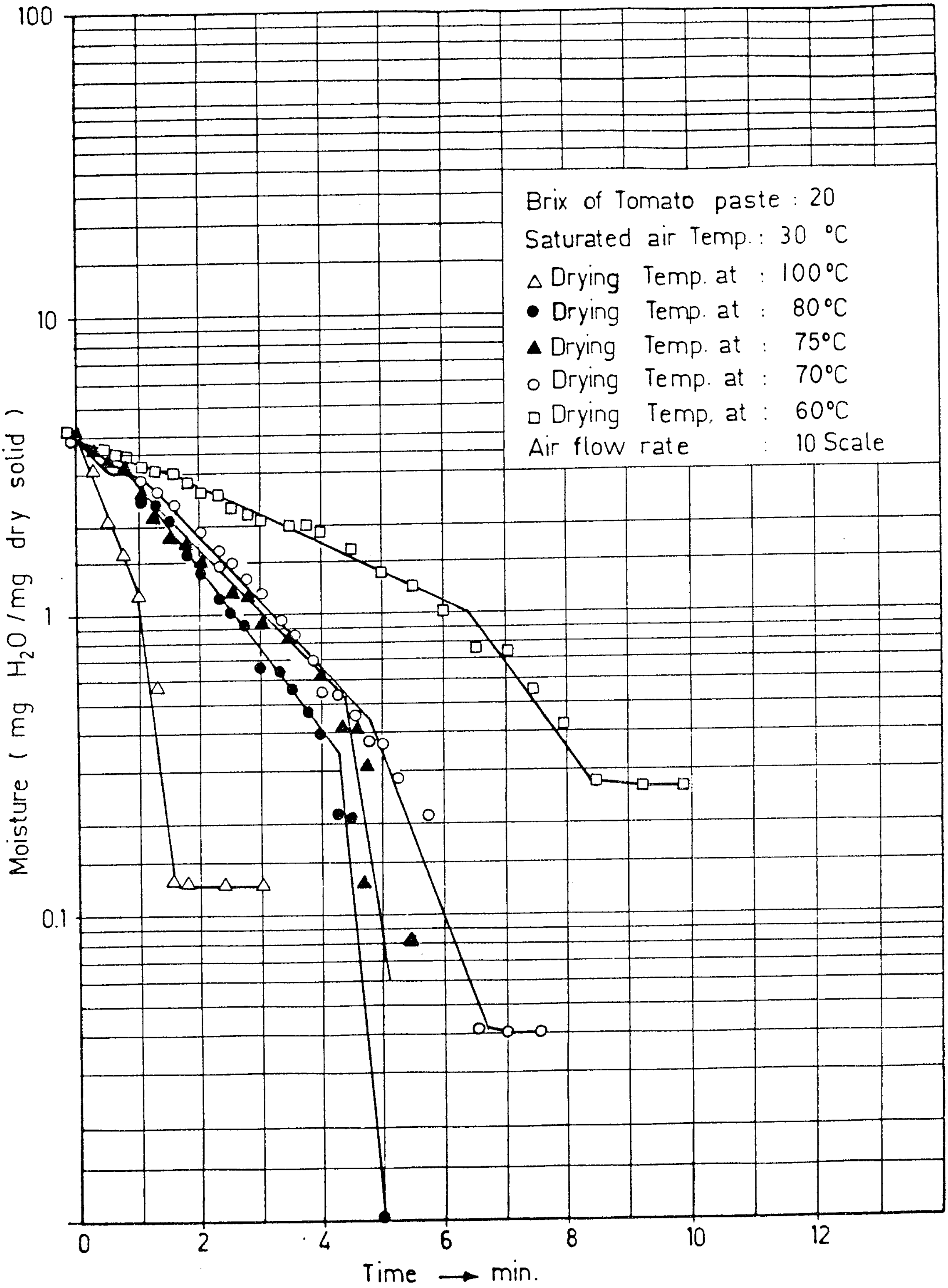


Figure 4.12 Droplet drying tomato paste : 20 Brix, u_S = 11.9 ml/s
H_S = 30 °C

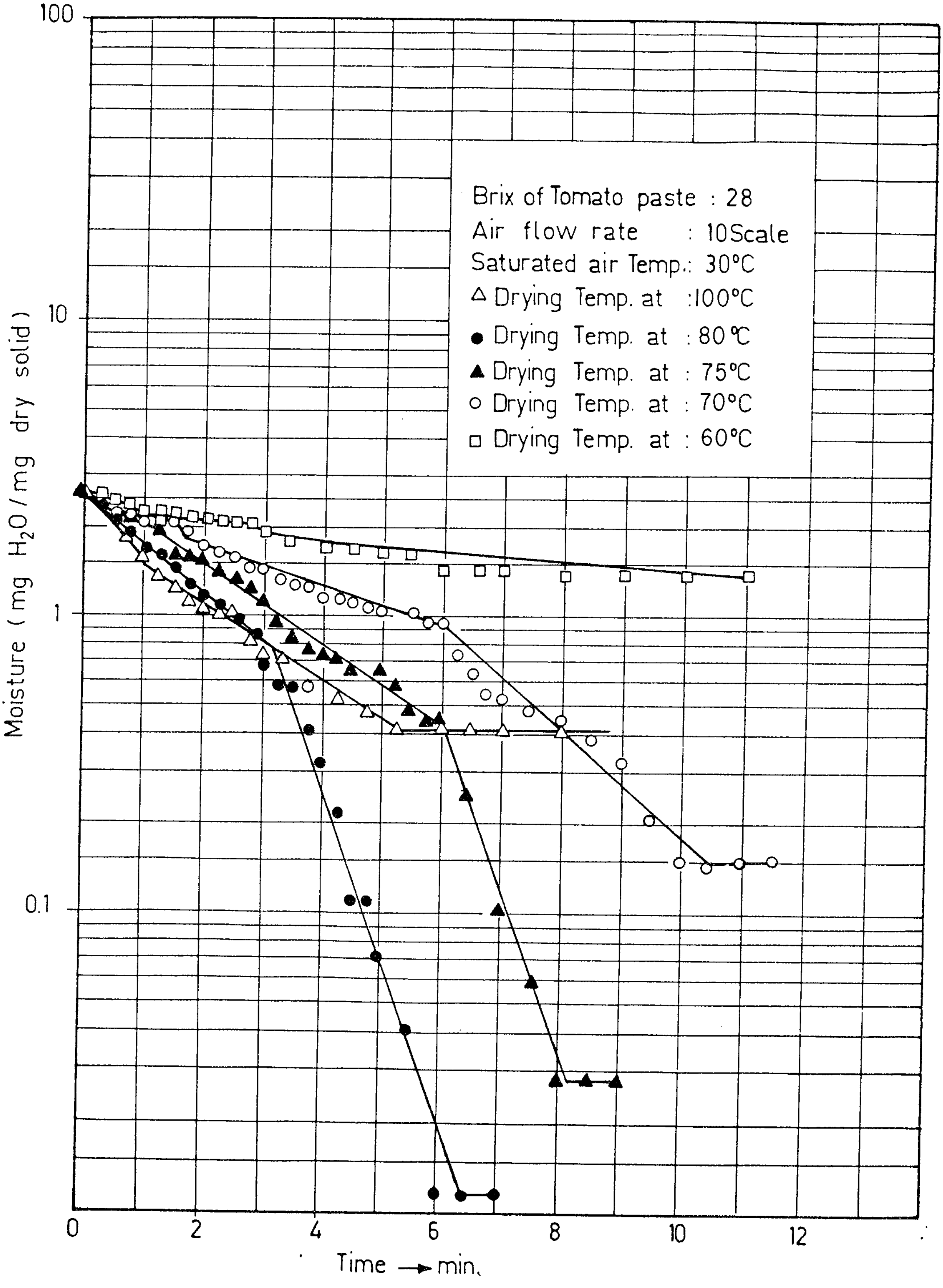


Figure 4.13 Droplet drying tomato paste : 28 Brix, $u_S = 11.9$ ml/s $H_S = 30\,^\circ C$

The formation of such a dry layer could not be prevented when the temperature of the saturated inlet air was increased from 20°C to 30°C. Nevertheless, at a low droplet concentration of 10 % wt, steep falling rates were observed. However,as the humidity of the inlet was increased the total period of drying was increased too, as expected. This effect may be attributed not only to the decreased driving force between the phases but also to the views suggested by Keey [25] and William-Gardener [66] .

According to these proposals, inelastic and impermeable crust will break open to release moisture and further evaporation will cause shrivelling because of the thermoplastic properties of the powder as in Fig. 4.5 and 4.10. Contrary to this observation, at 5% wt concentration a steep falling rate was observed for inlet air saturated at 30°C but not for that at 20°C which may be due to the different diameters of the droplets, [25] [66] , Figs. 4.4 , 4.9 and Tables Appendix A, A5 and A29.

With respect to the drying rates obtained at 80°C for different solid concentrations and humid air conditions, Figs. 4.4 - 4.13 , the following statements can be made ; more steep falling rates were seen for the inlet air saturated at 20°C due to impermeable crust formation and sudden breakage of the crust. However, as the humidity of the air was increased to that corresponding 30°C, the drying rate slowed down for 28 % wt of droplet concentration. This may be due to the assumption that the greater the humidity the smaller the crust formation. When the concentration of droplet was reduced to 20 % wt , the case hardening occurred at high humidity contents for saturated air temperature of 20°C.

It was further noted that as the temperature of the saturated air was increased from 20^{o}C to 30^{o}C, the steep falling rates were again observed as shown in Figs. 4.7 and 4.12. This may be due to the hygroscopic property of tomato droplet entering the falling stage at the very begining of dehydration, and remaining so until the layer adjacent to the surface reaches substantially zero moisture content, Samuel [67] . In the case of reduction of the concentration of the droplet to 15 % wt, the case hardening was observed at lower humidity contents and the drying rates slowed down increasing the saturated air inlet temperature as shown in Figs. 4.6 and 4.11. These results are all in agreement with the views expressed by Van Arsdel [65] and Keey [25] .

The reduction of droplet concentration to 10 % wt and 5 % wt resulted in the occurence of steep falling rates and the slowing down of the drying rates which was due to increasing inlet saturated air temperature Figs. 4.4, 4.5, 4.9 and 4.10. The slowing down of drying rates again might be due to the formation of an impermeable skin on the surface, [25] [65] . Parallel to the increase in the humidity of inlet air, the drying rates slowed down which was compatible with the theoretical explanations of William-Gardener [66] .

With regard to the dehydration of droplet at 75^{o}C for different concentrations and air humidity, the following results can be stated.

When the concentration of droplet was at 28 % wt, the case hardening was observed at high moisture content for 20^{o}C saturated air inlet temperature, but when the saturated air inlet temperature was increased to 30°C, the final case hardening occurred at lower moisture contents in the droplets, Figs. 4.8 and 4.13. Regarding the concentration of droplet at 20 % wt the same result as above was obtained. This is to indicate that the major portion of the migration of vapor took place before the formation of an impermeable skin on the surface of the droplet. The greater humidity content of the inlet air might be considered responsible and this is in contrast to the view pointed out by Van Arsdel [64] as shown in Figs. 4.7 and 4.12.

Furthermore, as the concentrations of droplets were reduced to 15 % wt, 10 % wt and 5 % wt at 75°C, the final case hardening phenomena was noticed at higher moisture contents Figs. 4.6, 4.11, 4.5, 4.10, 4.4 and 4.9 respectively. Nevertheless, when the saturated air inlet temperature was increased from 20°C to 30°C the drying rates of droplets slowed down and final case hardenings were detected at high moisture contents. This is in agreement with the views of Keey [25], Karel [68], Krisher and Kast [20].

Moreover, with respect to the droplet drying at 70°C for different concentrations and air humidities, the case hardening was observed at all stages of dehydration for different moisture content of the droplets as shown in Figs. 4.4-4.13.

It was also seen that at higher solid concentrations case hardening can be observed at high moisture contents such as 28 % wt and 20 % wt and that the reduction of droplet concentration was not effective on preventing the case hardening and no steep falling rates were observed even when humidity of inlet air at this stage was changed, Karel [68] , Samuel [67] and Brennan et.al. [10] . Dehydration in the falling rate period is not only an unsteady state process with respect to moisture gradients, but it is also a function of temperature as shown in Figs. 4.7, 4.8, 4.12 and 4.13.

Finally when the temperature was reduced to 60 °C at different concentrations of droplet and saturated air humidities of inlet air, the following results were obtained.

Although the final case hardening was obtained at the highest moisture content of droplet, approximately no difference was observed as to the moisture content in the final case hardening even when the saturated air inlet and concentrations, 28 % wt, 20 % wt, 15 % wt, 10 % wt and 5 % wt were changed as shown in Figs. 4.4-4.13.

The ceasing down of the drying rates might be due to an irreversible change within the body such as would be produced by a chemical reaction. Other physical and chemical aspects such as browning, permanent structural changes, loss of volatile components, and case hardening (caused by solute migration) are also important phenomena occurring during drying Charm [54] and Karel [64] . As soon as the first layer of solids appear on the surface of evaporation, the rate falls off and, when the crust is complete the rate becomes very slow [65] . To sum up, it can be concluded that when the above results were taken into consideration, a more uniform drying was observed at 15 % wt, 10 % wt and 5 % wt concentration levels at 20°C saturated air inlet temperature. Therefore, the relevant diffusion rates are studied only for these three concentrations in detail as follows with a view to giving complete understanding of case hardening.

4.5 Diffusional Phenomena in Air Drying of Tomato Concentrate at Different Concentrations

Fick's law of diffusion expressing moisture transfer out of spherical droplets was succesfully applied to describe the drying of tomato droplet concentrates. Parameters employed in this study were solid concentrations ranging 5-15 percent solids, drying air temperatures 105°C, 115°C, 125°C, 135°C and 160°C using saturated air at 20°C at constant air flow rate 11.90 ml/sec. The air outlet temperatures for entering into tunnel were 60°C, 70°C, 75°C, 80°C and 100°C respectively. It is assumed that the maximum temperature attained by the droplet is about equal to the exit temperature of air.

Drying rate curves were constructed and used for calculation of equilibrium moisture content for each drying stage and effective diffusivity of the moisture through droplet. The temperature dependency of moisture diffusivity was applied for different concentration and drying stages were assigned through EPSON PC/HX 7030H computer.

The Fick's equation that express diffusion of a liquid in a solid can be written, Dennis and Singh [69] .

$$\frac{dm}{d\Theta} = D_{eff} \left(\frac{d^2m}{dr^2} + \frac{jdm}{rdr} \right) \qquad 4.2$$

Where j is equal to "0" for an infinite slab, "1" for an infinite cylinder and "2" for a sphere.

The solution to the above equation was given by Crawe [21] ,Perry

[26] , Auerre et.al. [59] , Mazza and Lemaguar [61] . In case of sphere, the solution of the diffusion equation can be expressed as ;

$$\frac{\bar{m} - m_e}{m_o - m_e} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(\frac{-n^2\pi^2 D_{eff}}{r^2} \right) \Theta \qquad 4.3$$

4.6 Results and Discussion

Drying proceeded normally at first until the surface moisture and internal reservoir were being exhausted. When most of the cavities were emptied on the surface of the droplet, case hardening occured and therefore liquid was unable to rise to the surface from the interior.With the supply of water diminished, the rate of drying immediately decreased and vaporization rate ceased but the moisture content never reached zero. When the droplets shrank with impermeable surface, due to heat transfer towards the inside of the solid, vapor pressure of the water is increased which resulted with a new supply of moisture to the surface. Then the drying rate rose immediately and proceeded by steeper falling rates.

Drying data of different soluble solid contents at 5 %, 10 % and 15 % of the tomato droplet at different temperatures at constant air flow rate 11.90 ml/sec and constant relative humidity of 20°C are as given in Appendices A Table A1, A2 and A3. Thus, Fick's law of moisture diffusion may be used for modelling the spherical droplet drying periods Geankoplis [9] , using Equ.4.3.

$$m^* = \frac{\bar{m} - m_e}{m_o - m_e} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(\frac{-n^2\pi^2 D_{eff}}{r^2} \right) \Theta \qquad 4.4$$

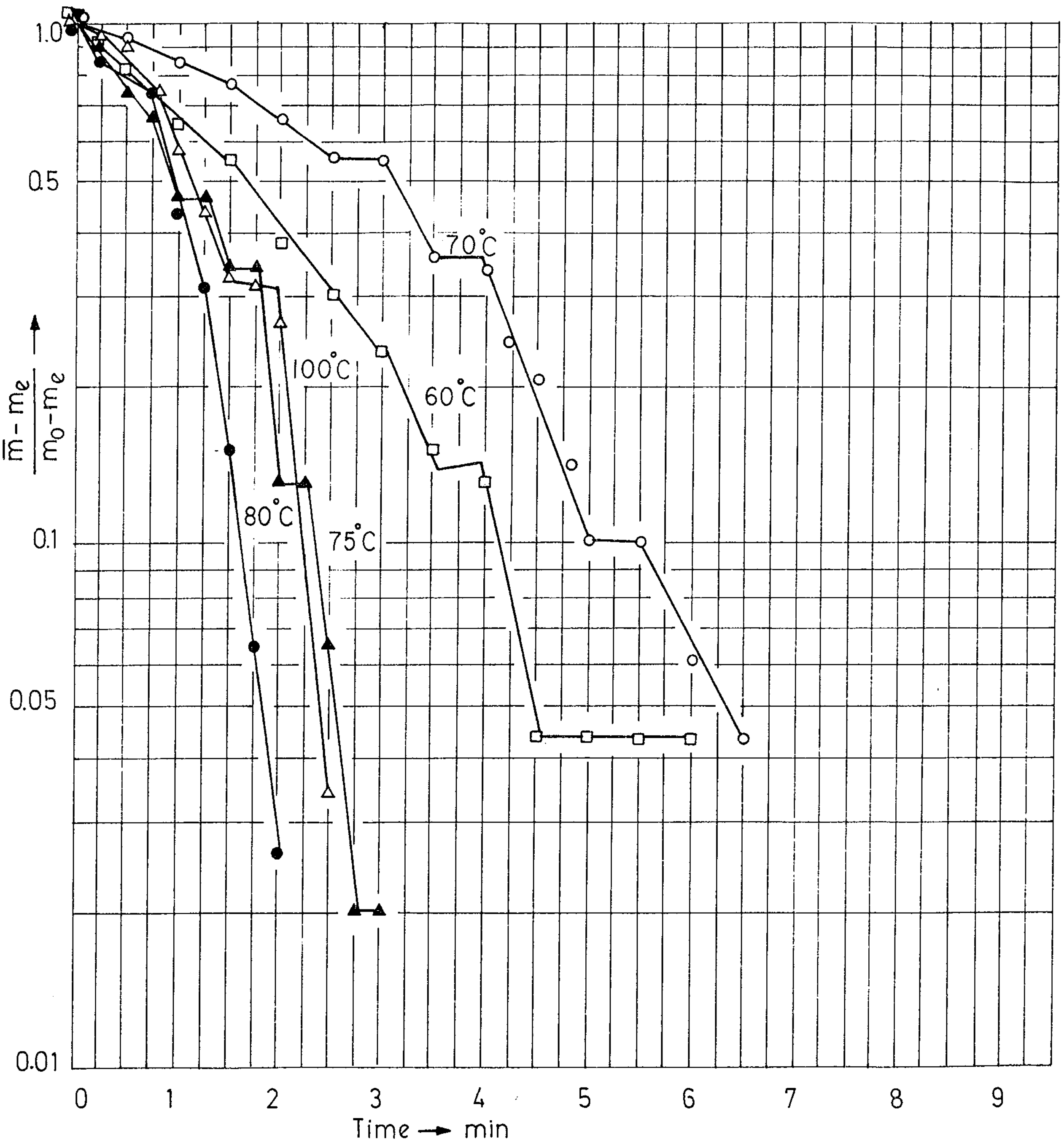


Figure :4.14 Droplet drying tomato paste : 5 Brix, U_S=11.9ml/sec, H_S = 20°C

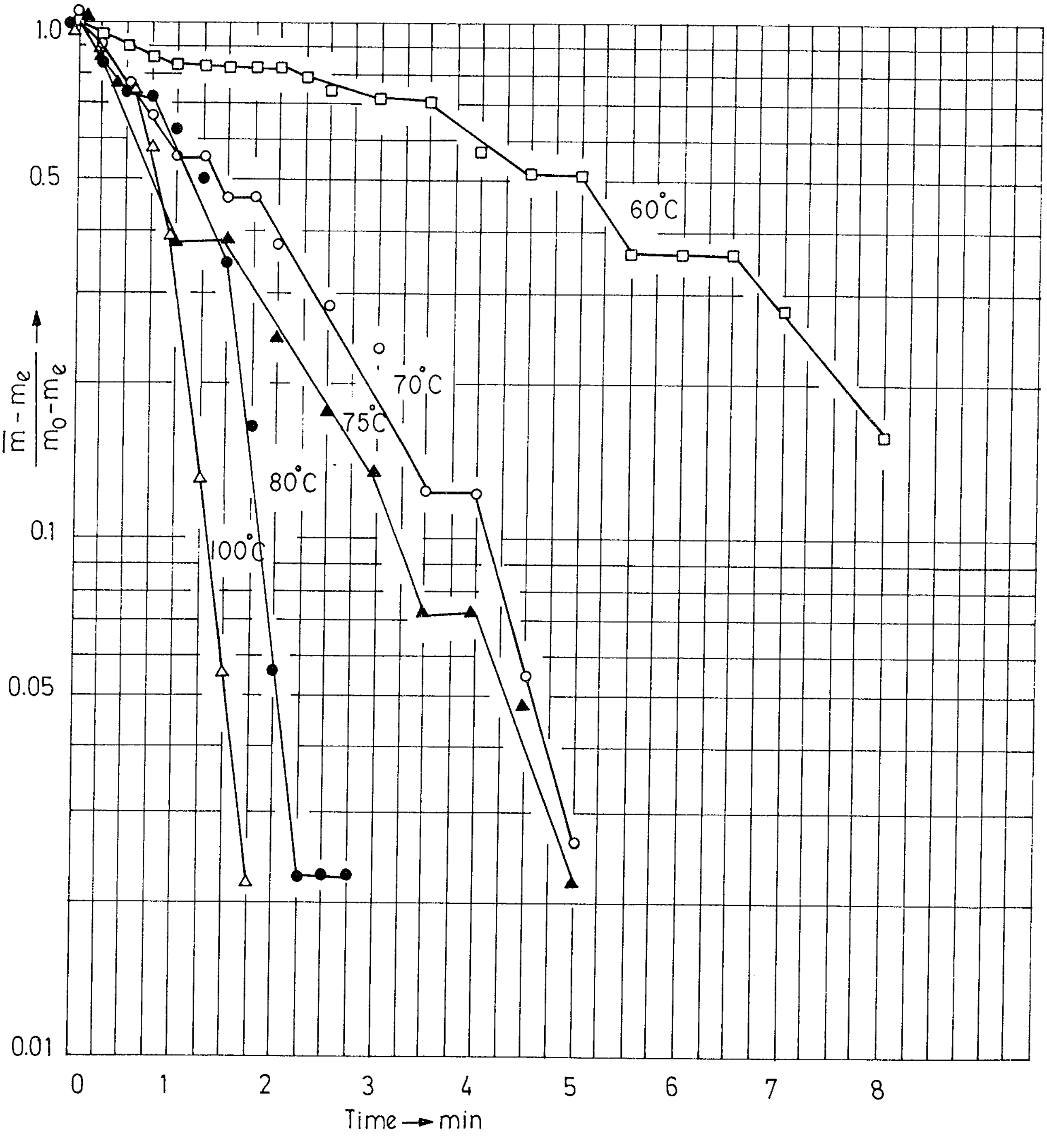


Figure: 4.15 Droplet drying tomato paste : 10 Brix U_s=11.9 ml/sec H_s= 20°C

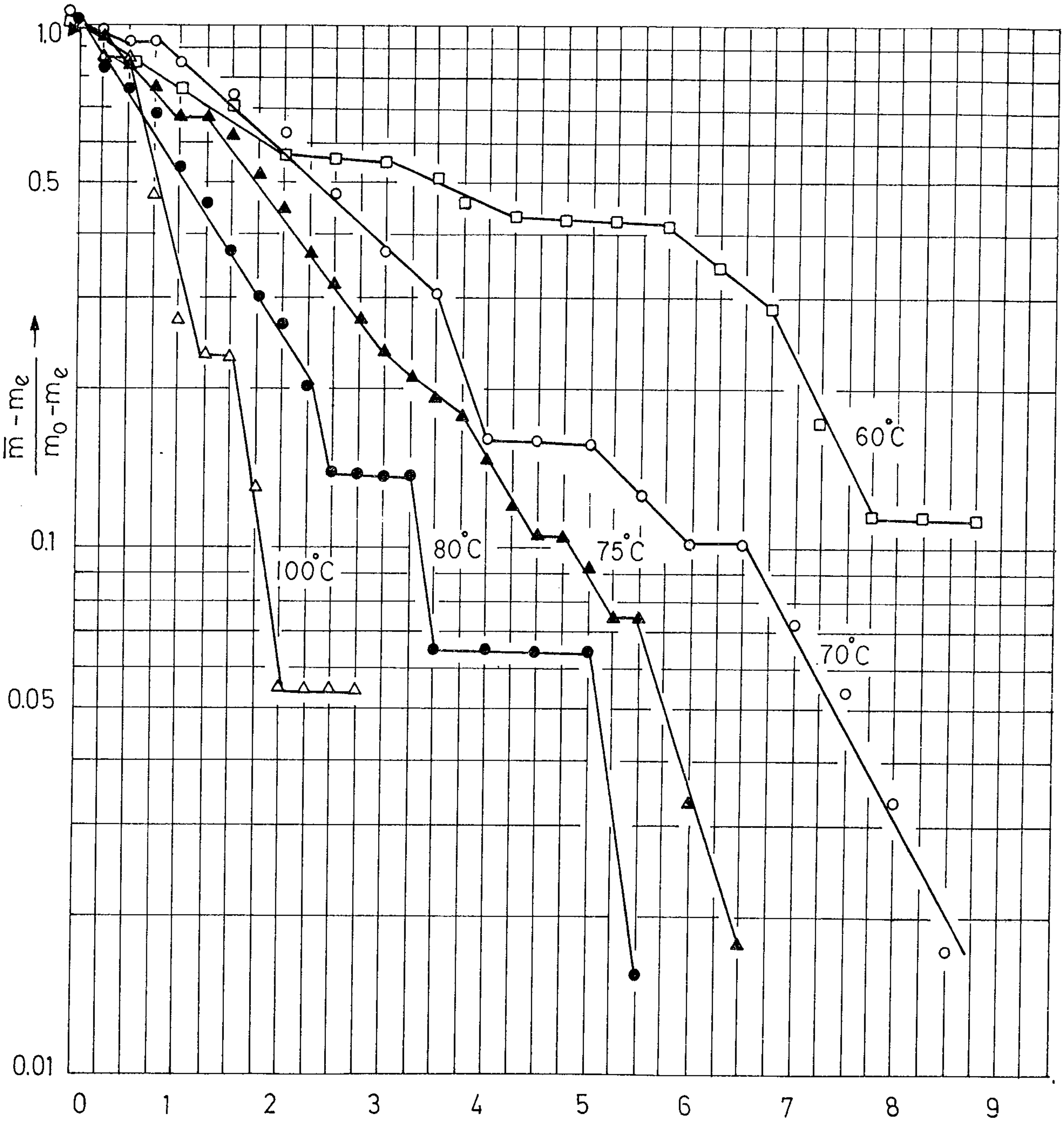


Figure: 4.16 Droplet drying tomato paste : 15 Brix
$H_s = 20\,^\circ C$, $U_s = 11.9$ ml/sec

The results of data estimated on dehydration in previous work were converted to $m^* = \dfrac{\bar{m} - m_e}{m_o - m_e}$ versus time as shown in Appendices A in Table A49, A50 and A51. The results of data obtained were plotted as $\log\ m^*$ versus time as shown in Figs. 4.14, 4.15 and 4.16 according to Equ. 4.4.

From the inspection of the figures the zones of steep falling rates and constant moisture can be seen, where the latter is an obvious indication of case hardening phenomena.

$$\log\ m^* = \log \frac{6}{\pi^2} - \frac{\pi^2 D_{eff}}{2.303\ r^2}\,\Theta \qquad 4.5$$

From Equation 4.5 the theoretical intercept should be $6/\pi^2=0.608$, whereas the intercept of various experimental drying curves were between 0.549-0.578 which was slightly smaller than the theoretical one. This difference was due principally to the fact that different concentrate concentration droplet does not have a uniform spherical shape, secondary due to curve fitting.

From the slope of curves the diffusion coefficients were estimated for each drying stage, Keey [25] , Toledo [50] and Charm [54] as shown on Tables 4.2, 4.3 and 4.4. In the estimation, since the radius of the droplet was not measured, the arithmetic average of the initial radius calculated from Equ. 4.1 and the radius of the glass sphere was employed. The diffusion coefficients thus evaluated were in the order of $10^{-9} m^2$/sec, where a range of 10^{-7} - 10^{-12} m^2/sec were reported for such diffusion coefficients in solids [50] .

Figs. 4.14, 4.15 and 4.16 show that the drying rate patterns were different from that reported for the onion, rice grain, grain

Table 4.2. Diffusion Coefficient Moisture of Tomato Droplet (5Brix)

U_s: 11.9 ml/sec H_s: 20°C

Drying time of stages(sec)	Drying Temp(°C)	Slope of curve	r x10^{-1} cm	D_{eff}x10^{-5} cm^2/sec	δ^2
75	60	0.2969	9.64	0.466	0.953
30	60	2.4512	9.64	3.853	1.000
150	70	0.2329	9.64	0.366	0.951
30	70	0.9113	9.64	1.432	0.994
60	70	1.686	9.64	2.650	0.982
60	70	0.9015	9.64	1.417	0.975
60	75	0.7304	9.36	1.082	0.950
15	75	1.229	9.36	1.822	1.000
15	75	3.651	9.36	5.412	1.000
30	75	3.549	9.36	5.261	0.950
45	80	0.366	8.78	0.477	0.975
75	80	2.624	8.78	3.419	0.976
45	100	0.371	9.11	0.521	0.860
45	100	1.147	9.11	1.609	0.979
30	100	4.618	9.11	6.470	0.906

Table 4.3. Diffusion Coefficient Moisture of Tomato droplet (10 Brix)

U_s : 11.9 ml/sec H_s : 20°C

Drying time of stages (sec)	Drying Temp(°C)	Slope of curve	r $\times 10^{-1}$ cm	$D_{eff} \times 10^{-5}$ cm^2/sec	δ^2
60	60	0.170	9.58	0.263	0.979
60	60	0.120	9.58	0.186	0.969
60	60	0.259	9.58	0.401	0.952
30	60	0.576	9.58	0.892	0.991
60	60	0.874	9.58	1.354	0.963
30	70	0.594	9.25	0.859	0.950
30	70	0.526	9.25	0.761	0.998
15	70	0.644	9.25	0.931	0.999
105	70	0.726	9.25	1.050	0.905
60	70	1.403	9.25	2.030	0.999
60	75	0.941	9.43	1.415	0.930
120	75	0.777	9.43	1.168	0.960
60	75	0.944	9.43	1.420	0.922
30	80	0.502	9.25	0.726	0.935
45	80	0.929	9.25	1.344	0.962
45	80	3.500	9.25	5.064	0.992
30	100	0.540	9.02	0.743	0.985
60	100	1.326	9.02	1.824	0.978
45	100	3.716	9.02	5.111	0.993

Table 4.4. Diffusion Coefficient Moisture of Tomato Droplet (15 Brix)

U_s: 11.9 ml/sec H_s: 20°C

Drying time of stages (sec)	Drying Temp(°C)	Slope of curve	r $\times 10^{-1}$ cm	$D_{eff} \times 10^{-5}$ cm^2/sec	δ^2
60	60	0.182	9.348	0.267	0.991
75	60	0.196	9.348	0.287	0.986
60	60	0.223	9.348	0.327	0.952
60	60	0.916	9.348	1.352	0.995
45	70	0.295	9.937	0.490	0.975
90	70	0.501	9.937	0.834	0.997
30	70	1.260	9.937	2.090	1.000
60	70	0.220	9.937	0.371	0.975
120	70	1.384	9.937	2.306	0.998
60	75	0.467	9.960	0.782	0.990
135	75	0.580	9.960	0.972	0.992
45	75	0.666	9.960	1.108	0.986
30	75	0.811	9.960	1.358	1.009
60	75	1.384	9.960	2.318	0.999
135	80	0.706	10.410	1.226	0.989
15	80	3.244	10.410	5.637	0.999
15	80	2.773	10.410	4.819	0.999
45	100	1.774	8.560	2.191	0.959
30	100	2.773	8.560	3.425	1.000

sorgum and paraboiled rice, Auerre et.al. [59] , Suare et.al. [60] , Mazza and Lemaguar [61] and Topar [22] . The difference may be due to the thermoplastic property of the tomato droplet plus the structural difference.

The effectiveness of increasing the drying air temperatures on acceleration of dehydration of different total concentrate cocentration of tomato droplet was illustrated in Figs. 4.14, 4.15 and 4.16. The drying rates have more than one falling rate and case hardening periods and this is in agreement with hygroscopic drying stages of materials, Jackson and Lamb [70] , Dennis and Singh [69] and Geankoplis [9] .

As can be observed from drying curves and diffusivities, a general interpretation can be made as, at the beginning of drying stages removal of moisture from droplets has a slow diffusion, in other words, a diffusivity of low value. Following this stage, case hardening occurs and during this period almost a dry solid forms at outside layer nearly acting like impermeable skin preventing further drying of droplets. The diffusivity of droplets were equal to zero at this stage. As the heating proceeds the pressure inside droplet increases breaking down the outer layer forming solid passages.

This caused the removal of moisture giving rise to steep falling rates in the following drying stages. The related diffusivity formed again and the same procedure as above was repeated until the end of drying time.

Hence, it can be concluded that the total mass transfer in all the drying experiments was due to the internal moisture diffusion within the droplet and the diffusivity was increasing as a function of temperature and so formed solid passages. Further it can be stated that the so formed solid passages increase with concentrate concentration.

These results were in agreement with theoretical explanation of the hygroscopic drying materials which considered that drying stages occurred with more than one falling stage and case hardening, Charm [54] , Keey [25] and Van Arsdel [24] . The overall diffusivity at each drying stage was in parabolic characteristics which was also in agreement with drying stages of hygroscopic materials, Karel [64] and Toledo [50] . In contrast, the diffusivity of droplet for 15 % wt concentration at 100^{o}C drying temperature was lower than 80^{o}C drying temperature which was not in agreement with the general proposal. This may be due to thermoplastic property of the tomato droplet which became softer at high temperature drying preventing the formation of impermeable skin and thus giving the low diffusivity.

4.7 Conclusions

The case hardening behaviour is believed to be valid for all such materials exhibiting thermoplastic and hygroscopic character mainly due to sugar present in the material.

Therefore it can be recommended that, to have more uniform drying condition, small droplets and medium drying temperatures should be practiced.

CHAPTER 5

SPRAY DRYING OF TOMATO PASTE

5.1 Introduction

Any improvement in the method of food dehydration would require a better understanding of the drying condition and how this is effected by different variables, Ernst et.al. [71] and Keey [25] .

In recent years, many types of drying techniques have been developed for dehydration of tomato paste, Goose [3] , Ginnette et. al. [27] , Heigh [28] , Masters [17] and Lazar [31] one of the most important of which is spray drying. With respect to these views we are concerned to find out a promising condition during spray drying of tomato paste. To serve for the purpose a spray drier was employed.

5.2 Materials and Methods

5.2.1 Experimental Set-up

A Buchi model-190 laboratory spray dryer manufactured by Buchi company was used. The vertical downward co-current flow type dryer consists of nozzle, an electrical heater, a glass drying chamber to which a glass cyclone and a receiver are connected to recover dried particles. Solution is fed by a peristaltic pump and an exhauster fan supplies the secondary air which are both manually adjustable. Further details of the equipment is given in Fig. 5.1. The electrical heater heating the air entering through the air inlet to the drying chamber is manually adjustable to a maximum temperature of 220^{o}C. The temperature of the air at the inlet and outlet to the drying chamber are measured by thermo-couples originally installed on the equipment.

The pressure type of stainless steel nozzle of diameter 0.70 mm is pressurized at 4.5 atm and has self cleaning system. The rate of air entering into it is adjustable in the range 200-800 lt/h.

5.2.2 Feeding the Solution (concentrate)

The peristaltic pump was located on top of the drying chamber and was used to supply the feed solution at an adjusted steady rate into the nozzle. The feed rates of the tomato concentrates were set by a graduated switch present on the control panel of the equipment.

Prior to starting the experiments, the feed rate adjustment switch was calibrated according to the concentrate concentrations, Fig. 5.2a Appendix B. The pump receives and supplies the concentrate through a 2 mm plastic tubing.

5.2.3 Air Supply

The movement of air through the drying chamber was performed by an exhaust fan. The speed of the fan was adjustable manually and the power of the fan was 200 V/50 Hz/2600 Watt. The feed rate of air was

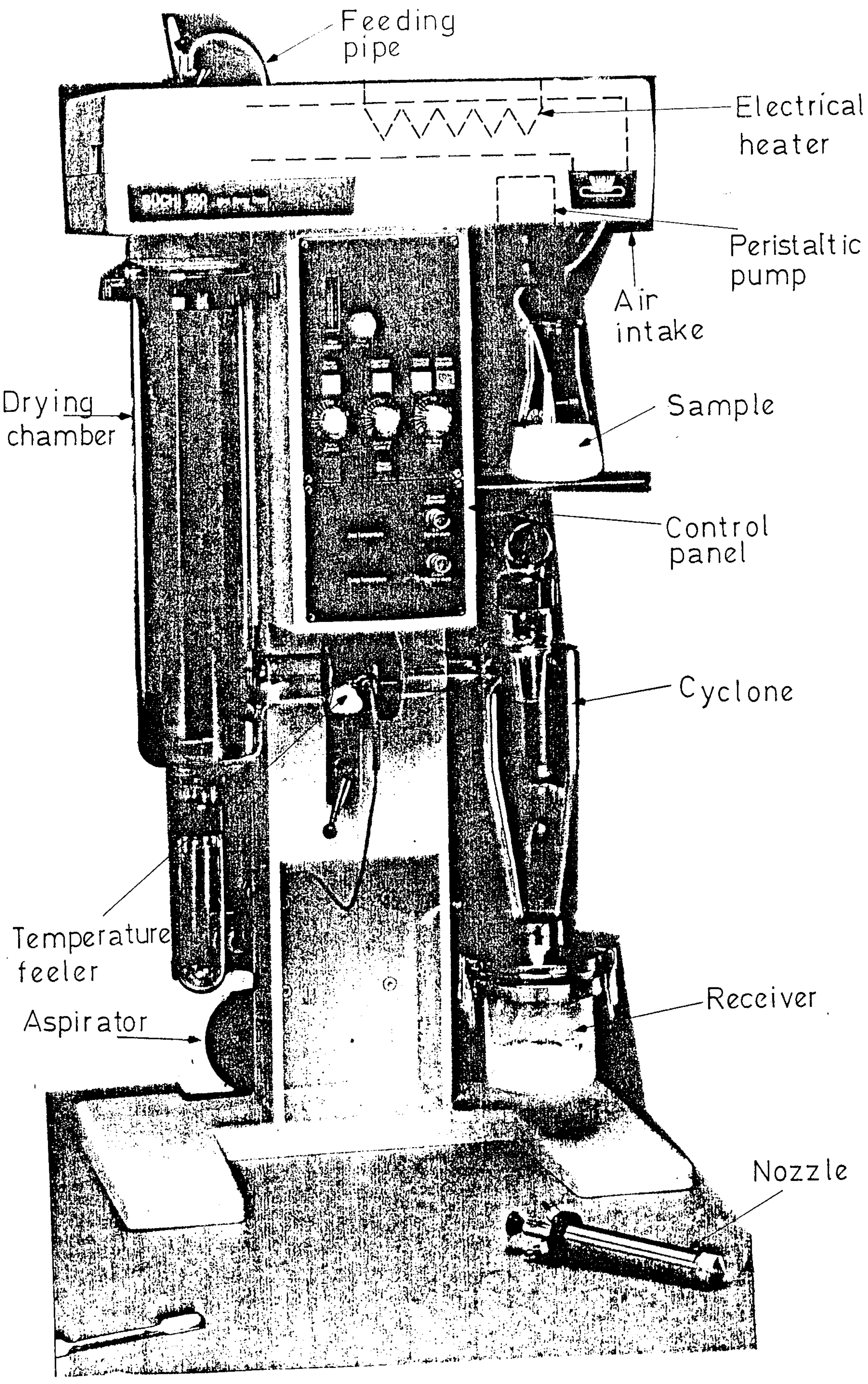


Figure 5.1 The spray dryer, Büchi type model-190

measured by calibration data of which is given in Fig. 5.2b Appendix B.

5.2.4 Additives

There are many types of additives recommended for use during dehydration of food materials, food report 1970 [36] , and Peleg et.al. [37] . In this work the following additives were selected as drying aids.

Carboxymethyl cellulose : C.M.C. (Adıyaman-Turkey)
Magnesium stearate : MgS (Merck)
Common salt : NaCl (Billur tuz)
Corn starch : C.S (Piyale)

The properties of the additives which were used in these experimental runs are given as follows, Pearson [72] .

The corn starch was received from Piyale A.Ş. and its property related with moisture content, protein and fat were estimated. The moisture content with vacuum oven method at 60°C, the protein content by kjeldahl method and the fat content with ether extraction method were assayed as shown in Table 5.1.

The salt used in these experimental runs was received from Billur Tuz A.Ş. The amount of moisture content in the salt was estimated at 130°C. The amount of NaCl was determined by titration with silver nitrate and the amount of Iodine in NaCl was detected by titration with sodium thiosulphate as shown in Table 5.1.

Table 5.1 Property of additives

	Moisture %	Protein Nx5.7	Ash %	NaCl %	I_2 ppm
Corn starch	12.10	0.40	0.1	-	-
Salt	0.72	-	-	99.10	20.1

The magnesium stearate (MgS), $C_{36}H_{70}MgO_4$ in pure form and having the molecular weight 391.2 was given by Merck company. The carboxyl methyl cellulose was received from Adıyaman C.M.C. Company. The rheological property of the C.M.C. for different concentrations was determined according to British Standards [73] , as shown in Appendix B Fig. 5.3.

The sample of CS, NaCl and C.M.C. were wetted in the warm water for different concentrations and kept overnight. Then they were filtrated and added into the tomato paste for required amount of additive of dry solid basis. But the MgS was mixed directly with tomato paste.

5.3 Experimental Procedure

The parameters involved in the experimentation procedures were set as,

a) Preparation of sample, setting the spray dryer and feeding the solution
b) Mixing additives into the feeding solution
c) Examining the properties of the products,(moisture, color and reconstitution)
d) Determination of yield or product for each run

The feed material was prepared from double concentrated canned tomato paste which was received from Demko Gıda Sanayii A.Ş. The tomato paste was diluted with sufficient distilled water to adjust the desired concentrations of 5 %, 10 %, 15 %, 20 %, and 28 % wt.

Due to rheological phenomena , it was not possible to spray the paste into the dryer properly by means of a nozzle for concentrations of about 28 % wt and above.

In each drying run, the inlet and outlet air temperatures were allowed to stabilize over a period of 15-20 minutes with distilled water introduced. After that the feed material prepared at known concentration in a glass beaker was fed into the dryer using the peristaltic pump. The duration of the main operation was about 50-90 min. for each run.

At the end of each run the glass beaker was weighed and the percentage of the solids was redetermined which was then utilized to calculate the total solids supplied to the dryer. Also the powder recovered in the receiver and the deposits on the walls of the chamber were brushed down and weighed separately. Then the yield was calculated on a total solid basis as the dry solid inlet which is recovered.

The dried samples were kept in air-tight bottles and their moisture content, colour, bulk density and reconstitution characteristics were determined in duplicate as follows.

The moisture in the dried powder was determined by weighing 1.9-2.0 g of sample in a round flat bottom metal dish about 5 cm in diameter.

The dish was placed on a shelf in the vacuum oven and the sample was dried to constant weight for 16 hours at 60°C, Pearson [72] .

The colour of the feed and the dried samples were determined by means of Lovibond Schofield Tintometer. The paste and powder were diluted with distilled water to 5 % wt solids by Abbé refractometer (Model B, F.G. Bode Co.). The results were estimated by Lovibond Tintometer expressed in International Units of colour in dominate, Kirk-Othmer [74] , Gordon and Angela [75] and Hunter and Yeatman [42] .

The bulk density of the powder was determined in the following way ; about 12-15 g of dried tomato powder was transferred to a 10 ml graduated cylinder, shaken for about 2-3 minutes and then the volume contained in the cylinder weighed. Bulk density was expressed in kg/m^3, Masters[16] and Pearson [76] .

For reconstitution , the dried powder was diluted to 5 % wt solid under constant stirring, the sample was set aside for 90 sec. and then stirred again for 20 sec. or 30 sec. A few drops of this sample is put on a white tile, covered with a glass plate and undissolved or burned particles are observed visually, Reeve and Wong [40] .

In the major phase of the work, four tomato concentrate concentrations 5 %, 10 %, 15 % and 20 % wt, seven inlet temperatures, 125°, 135°, 140°, 145°, 150°, 160° and 170°C ; six air flow rates through the nozzle 200, 400, 500, 600, 700, 800 lt/h , and five air supply rates to chamber 12, 16, 20, 24 and 28 m^3/h were studied as parameters. Also different feed rates of solution were considered.

In addition to the above parameters, different concentrations of NaCl, MgS, CMC and their combinations as additives, the effect of counter-current cooling of the drying chamber externally and direct cooling of the product by installation of glass pipe of varying diameters (8, 10, 12, 14, 15, 16, 20 mm) ; at different positions into the drying chamber were investigated. Thus, at this stage of the experimentation altogether 220 experimental runs were performed.

5.4 Results

The effect of the parameters of tomato paste concentration in the feed, the temperature and the rate of inlet air into the drying chamber, the amount of air supplied to the nozzle, presence of additives, indirect and direct cooling of the chamber on the yield are given in Figs. 5.4-5.22 and Tables in Appendix B, B_1-B_{13} . The interpretation of the data with respect to these parameters are as below ;

5.4.1 Temperature, concentration and feed rate

In the experimental runs 1.1-1.7 Appendix B conducted for 5 % wt concentrate concentration, no product was collected in the receiver even when the air inlet temperature was increased to 170°C for setting the peristaltic pump to 5.2 ml/min feed rate Fig.5.4. When the feed rate was reduced from 5.2 ml/min to 3.7 ml/min, about 11 % yield was obtained. However, when the feed rate was increased to 6.5 ml/min no product was received at the studied temperatures of the air supplied into drying chamber Fig. 5.5 and 5.6.

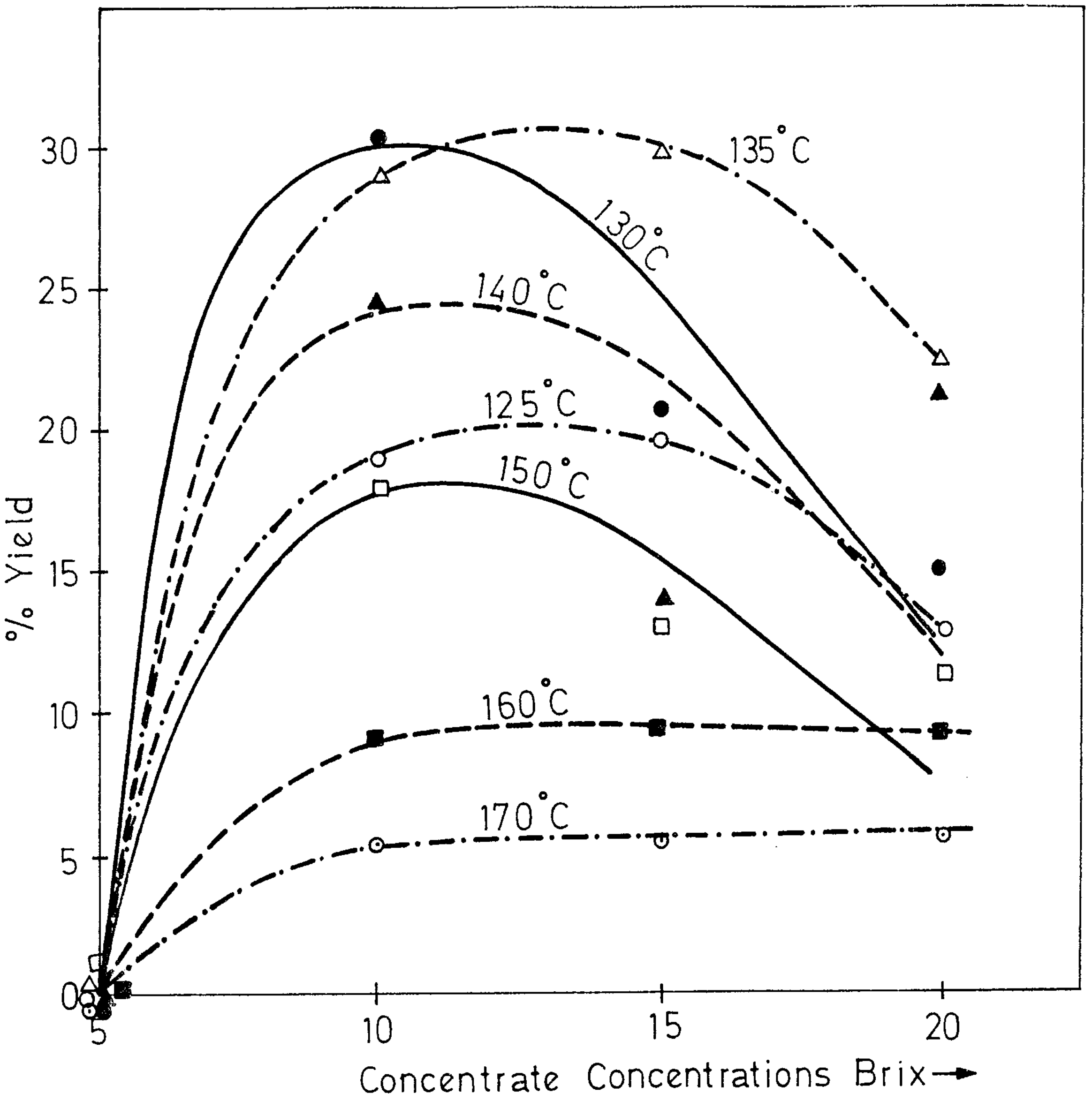


Figure 5.4 Yield at different drying temperatures and concentrations at 6 scale setting of the peristaltic pump for feed rate, 700 lt/h air flow rate through nozzle and 24 m^3/h through drying chamber.

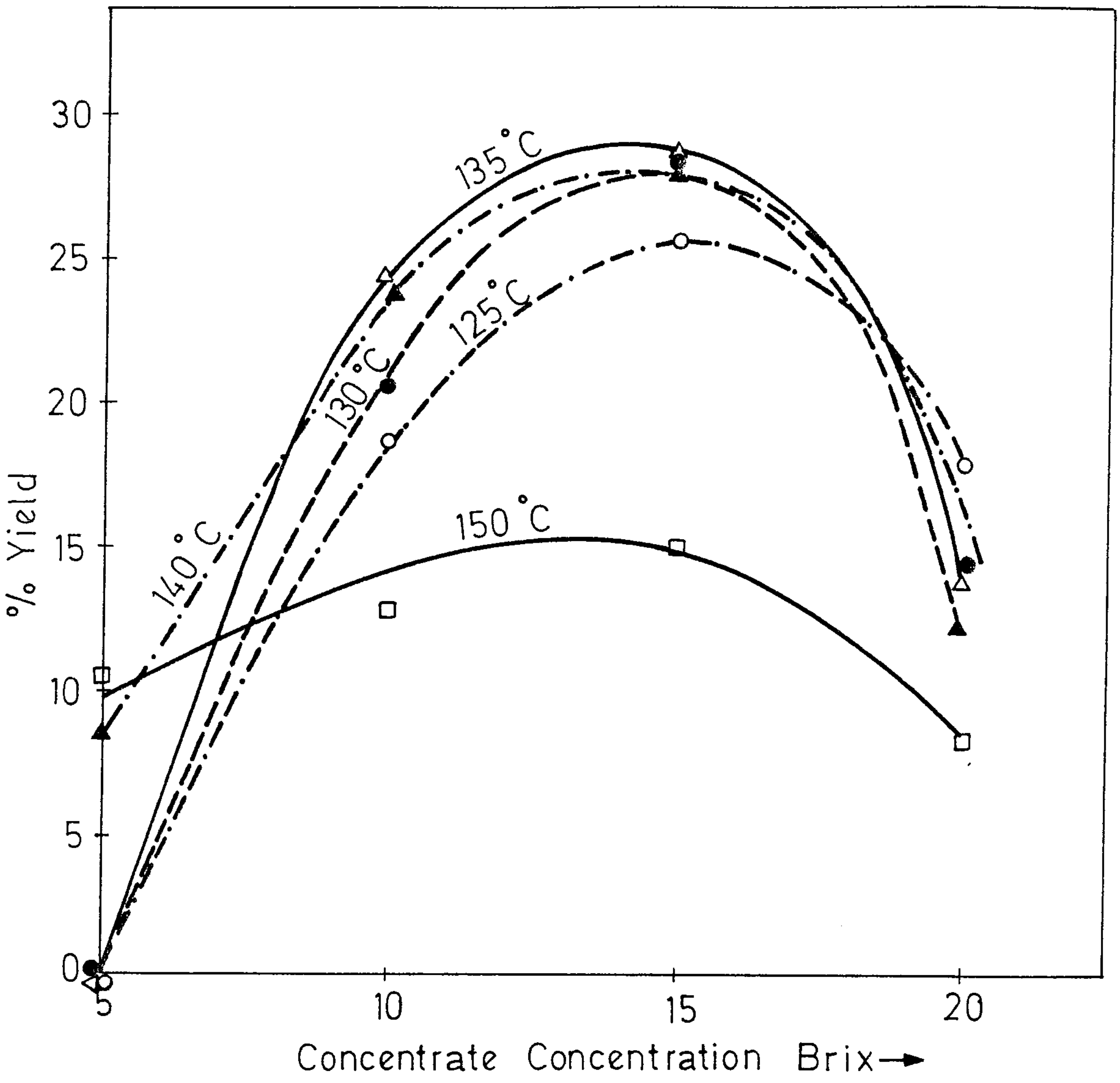


Figure 5.5 Yield at different drying temperatures and concentrations at 4 scale setting of the peristaltic pump for feed rate, 700 lt/h air inlet through nozzle and 24 m^3/h through drying chamber.

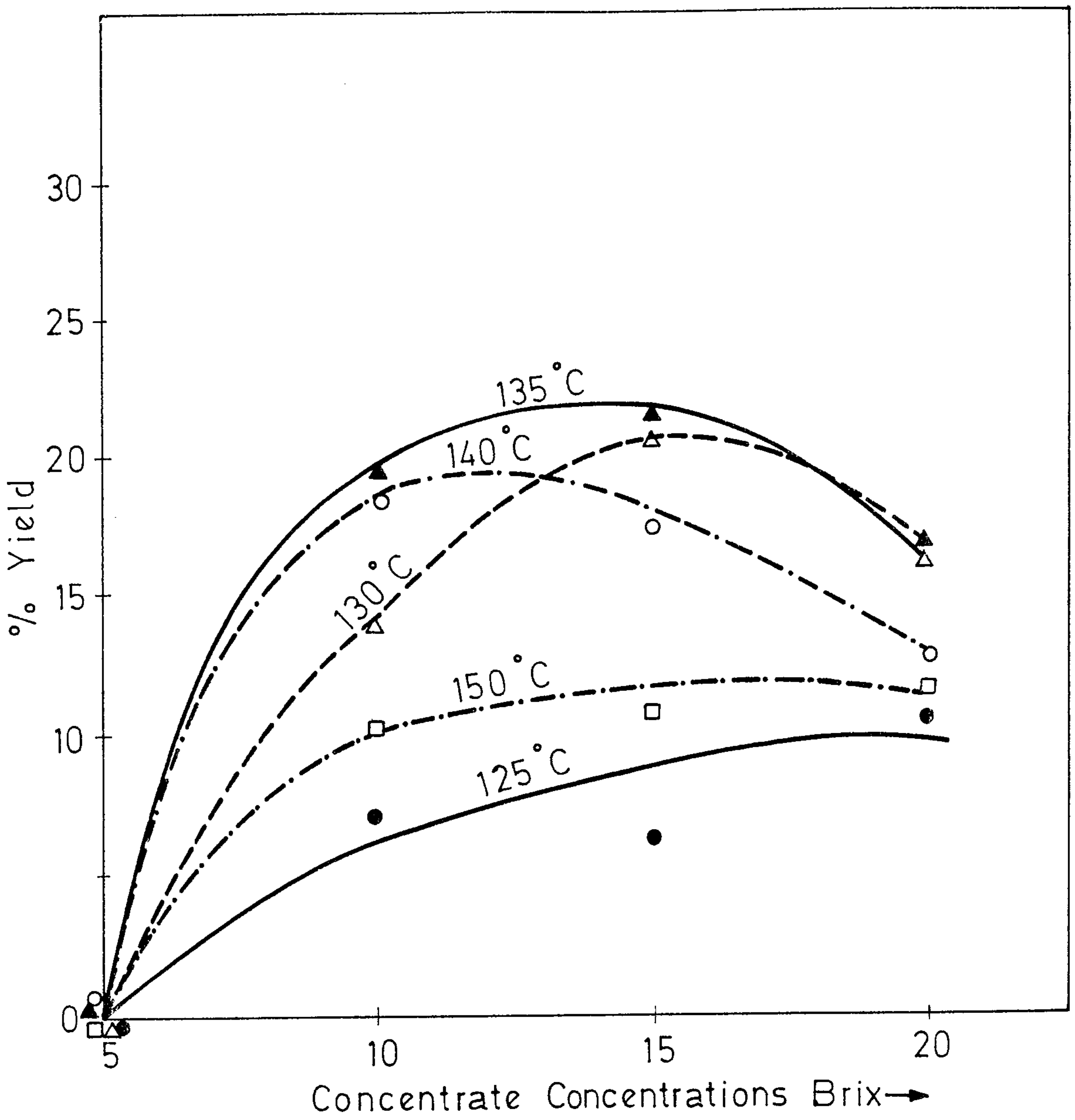


Figure 5.6 Yield at different drying temperatures and concentrations at 8 scale setting of the peristaltic pump for feed rate, 700 lt/h air flow rate through nozzle and 24 m^3/h through drying chamber.

As the concentration of the tomato paste was increased to 10 % wt, the yield reached up to 30.9 % at 130°C for the feed rate of 3.8 ml/min. Increasing and reducing feed rate to 5.0 ml/min and 2.8 ml/min did not effect the yield and when the air inlet temperature was increased to 170°C, the yield was reduced to 5.6 % Figs. 5.4, 5.5, 5.6 and 5.7.

For the 15 % wt solid content of the feed tomato paste the maximum yield found to be about 30.3 % at 135°C for feed rate 2.5 ml/min. By increasing and reducing the feed rate to 1.8 ml/min and 3.3 ml/min with setting of the peristaltic pump, the maximum yields were estimated to be 28.0 % and 21.5 % respectively at 135°C as shown in Figs. 5.5, 5.6 and 5.8. With respect to temperature above and below 135°C, the yields were reduced even at lower and higher feed rates. When the same conditions as above were applied to 20 % wt feed, the maximum yield obtained was about 23.0 % at 135°C as shown in Figs. 5.4 and 5.9.

Furthermore the effect of air flow rate through nozzle and the air flow rate through drying chamber at 135°C and 140°C on the yield was investigated as shown in Figs. 5.10 and 5.11. The optimum condition for the yield was estimated to be 700 lt/h air flow rate through nozzle and 24 m^3/h air flow rate through drying chamber for setting the peristaltic pump to be 2.5 ml/min feed rate.

In the light of the obtained results it is possible to draw a reliable conclusion for the optimum yield of product :

i. The drying temperature of the air inlet should be at about 135°C

ii. The feed rate of tomato concentrate should be 2.5 ml/min (6 scale setting the peristaltic pump) for 15 % wt concentrate concentration of tomato paste

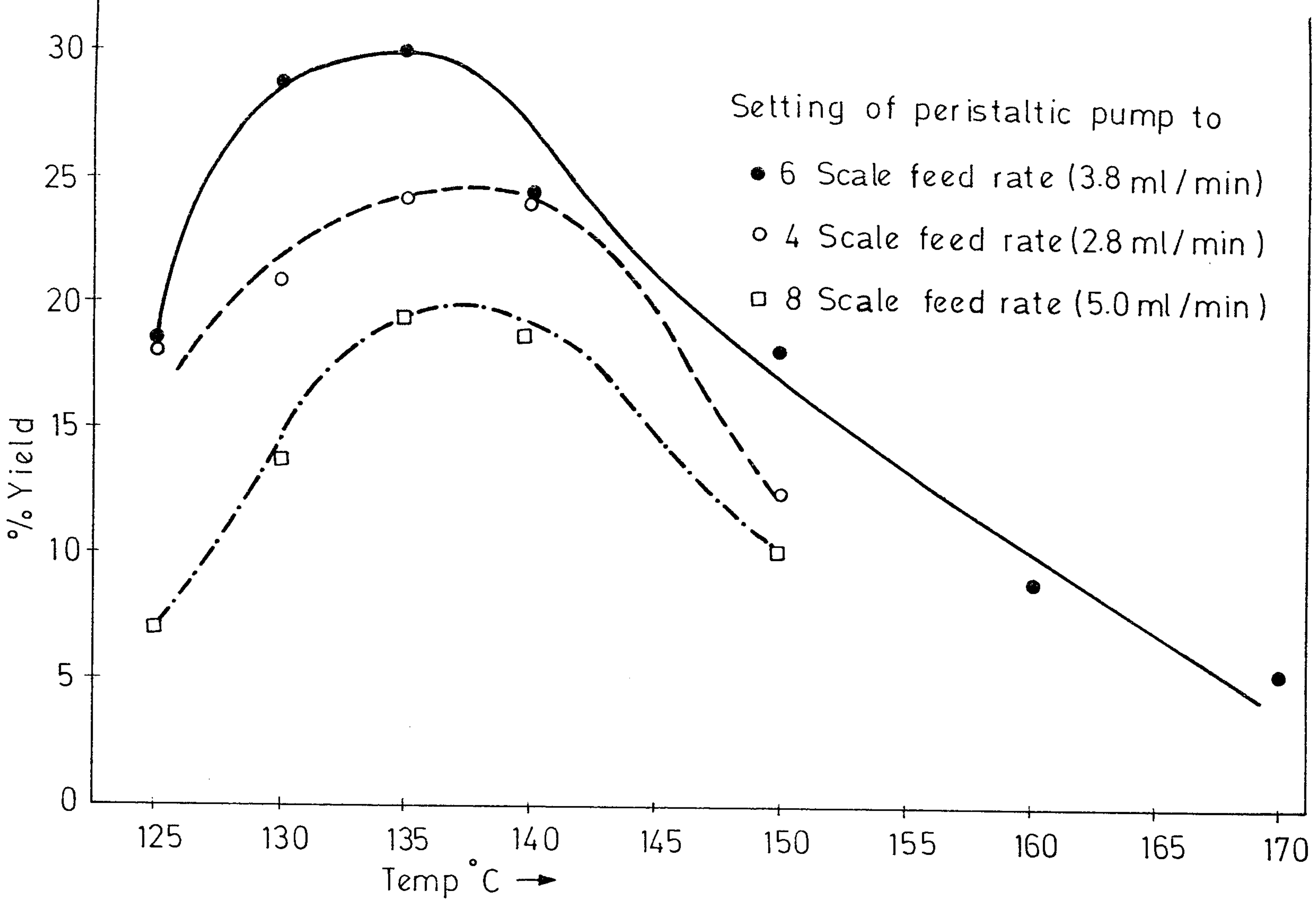


Figure 5.7 Yield of 10 Brix tomato paste related with temp and feed rates.

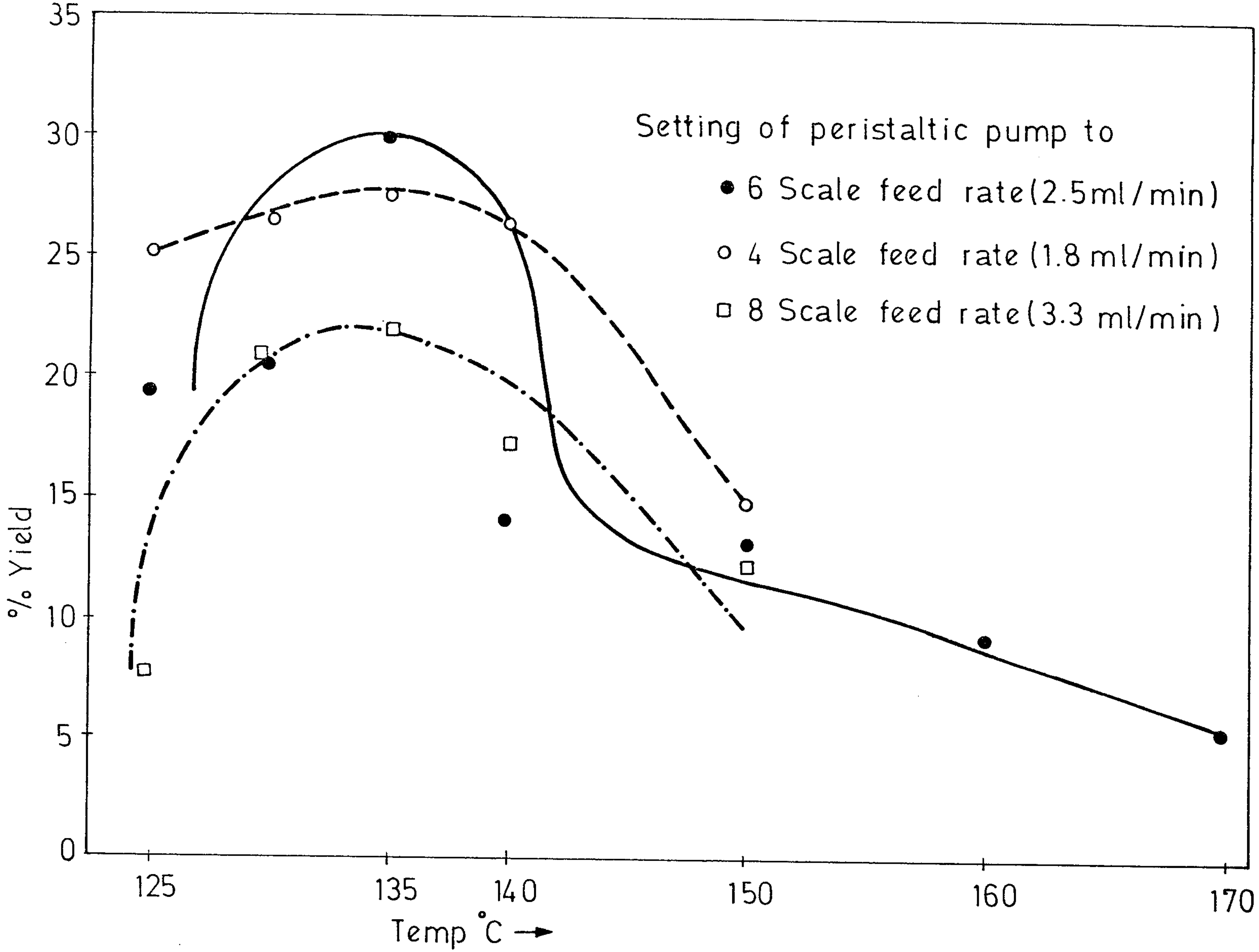


Figure 5.8 Yield of 15 Brix tomato paste related with temp and feed rates.

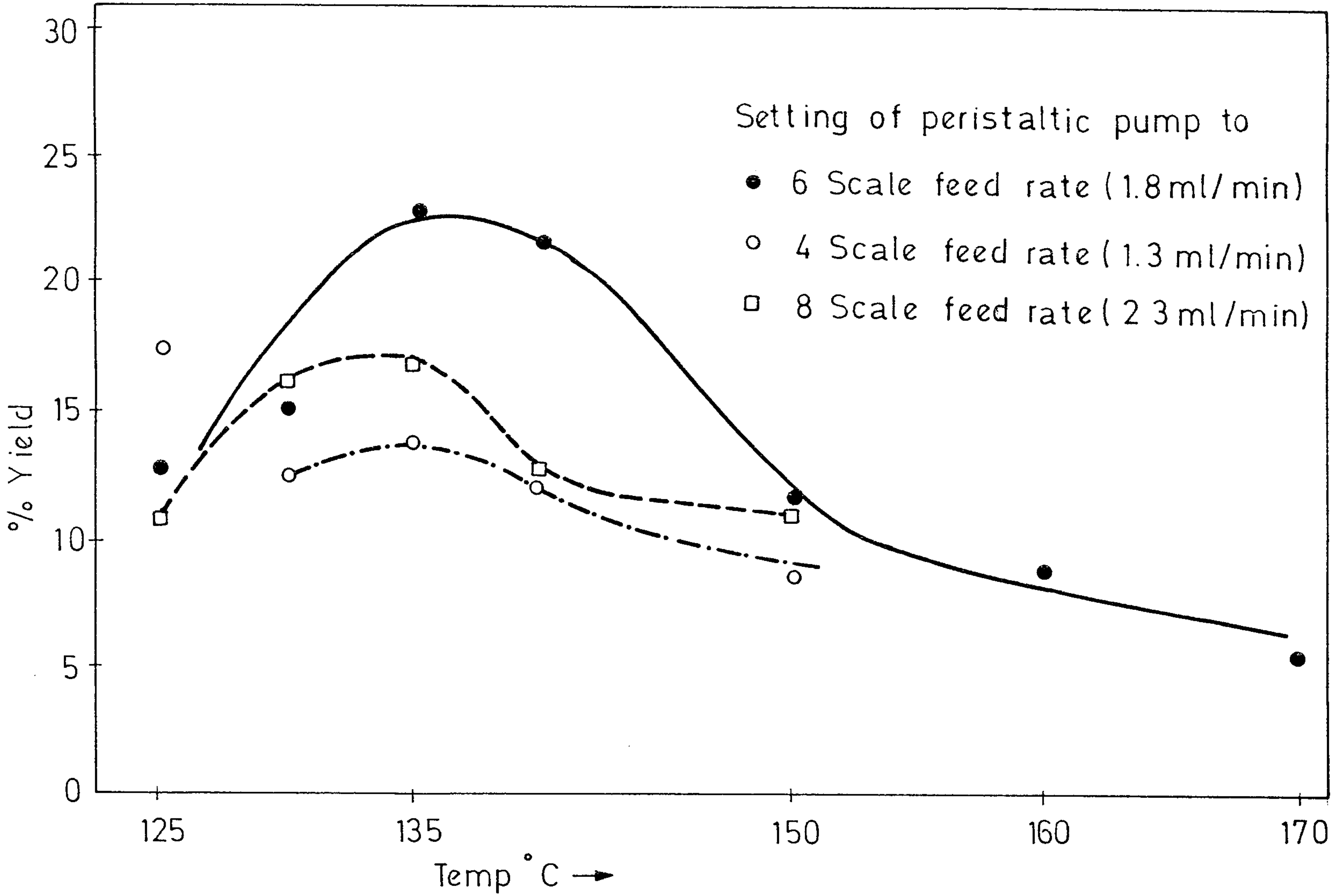


Figure 5.9 Yield of 20 Brix tomato paste related with temp and feed rates.

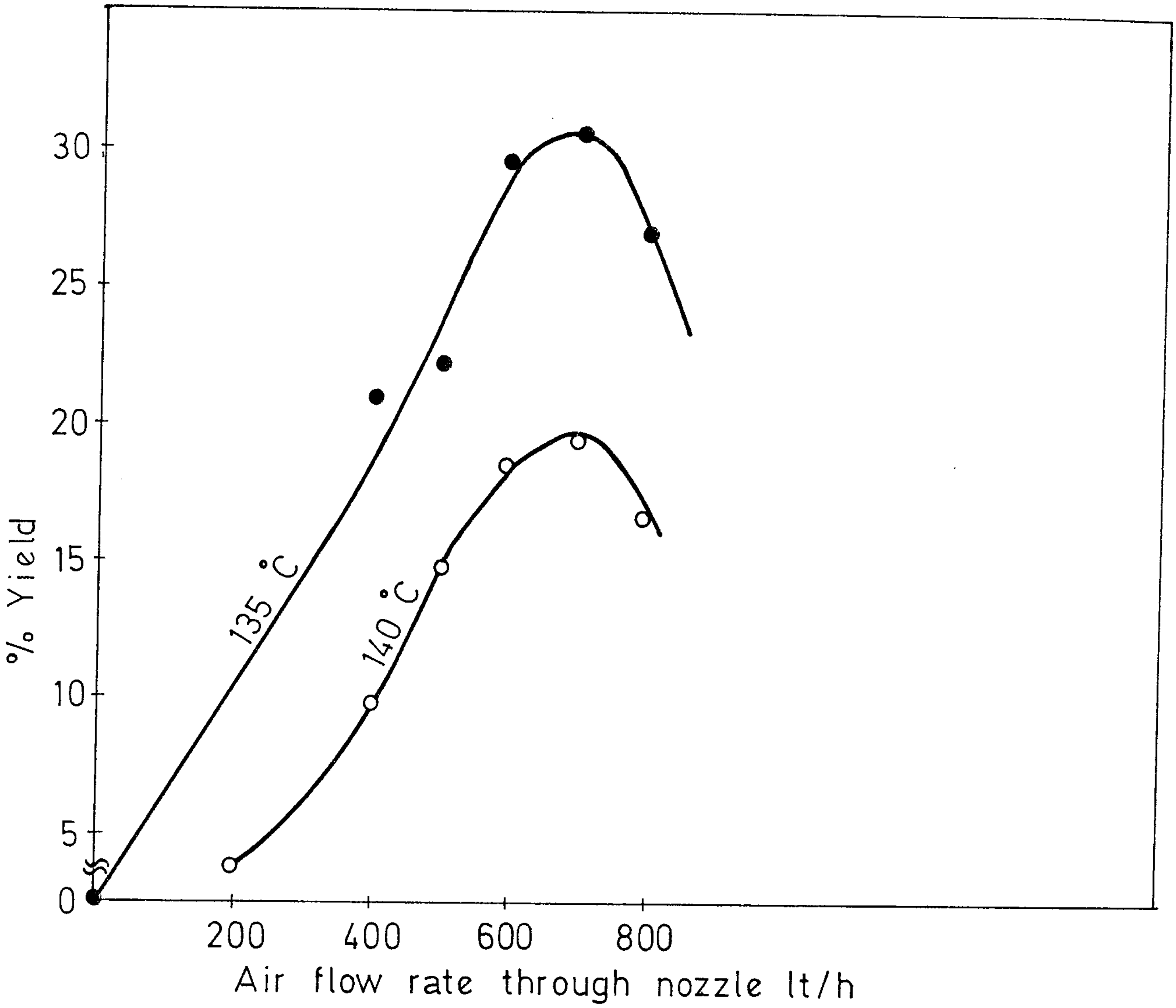


Figure 5.10 Yield of product related to air flow rate through nozzle, 2.5 ml/min feed rate (6 scale setting of the peristaltic pump) and 24 m^3/h air flow rate through drying chamber for 15 Brix of tomato paste.

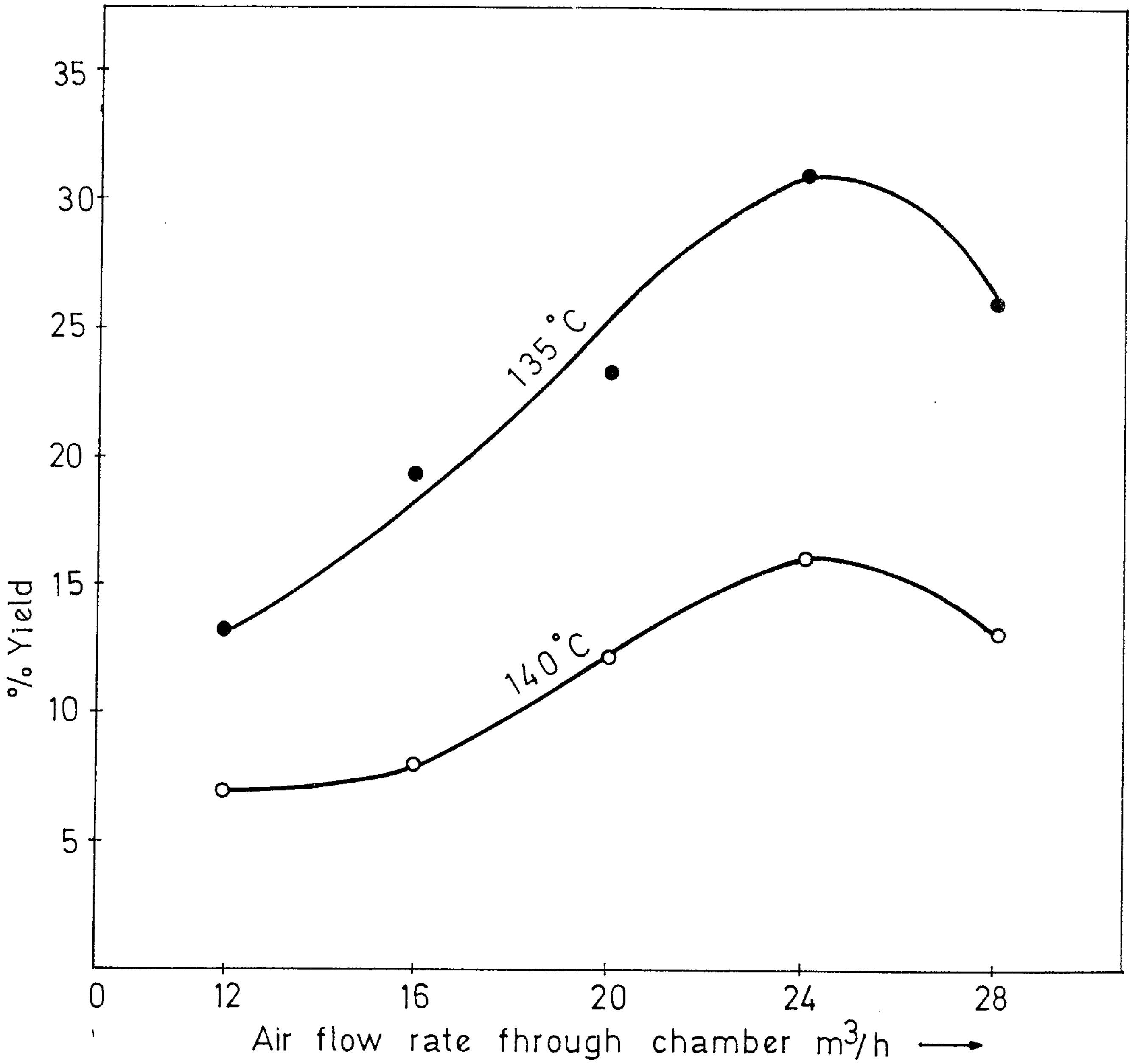


Figure 5.11 Air flow rate through nozzle 700 lt/h, 2.5 ml/min feed rate (6 scale setting of the peristaltic pump) for 15 Brix concentrate concentration of tomato paste.

iii. The air flow rate through nozzle has to be 700 lt/h and air flow rate through drying chamber should be 24 m^3/h. If the conditions were different than those values, the yield was observed to reduce on this laboratory spray-dryer.

Moisture content in the powder was estimated as shown in Fig.5.12. As the temperature of air inlet increased, the amount of moisture was observed to fall down to 1.4 % at 170°C for 15 % wt solids feed. The moisture content of the solids for these trials were estimated using the sticky heavy deposition on the chamber wall of the drying chamber and that collected in the receiver. It is likely that due to thermoplastic property of the powder, the yield was reduced at high drying temperatures.

5.4.2 Additives and air rate through the nozzle

Addition of common salt (NaCl), magnesium stearate (MgS) and CMC at different concentrations expressed as the percent of the total dry solids in the concentrate were investigated together with the parameters of 15 % wt solid with feed rate of 2.50 ml/min (6 scale setting of peristaltic pump) and 500, 700 lt/h air flow through nozzle. As can be seen from Fig. 5.13, the yield in the runs with high concentration of NaCl were effective whereas the effect of C.M.C. and MgS were not significant.

Regarding the air inlet temperature into drying chamber and air flow rate through the nozzle employing the above additives, the yeilds were observed to have reduced at 150°C but a little more promising result was obtained at 140°C . When 2.5% CMC was added. Hence with

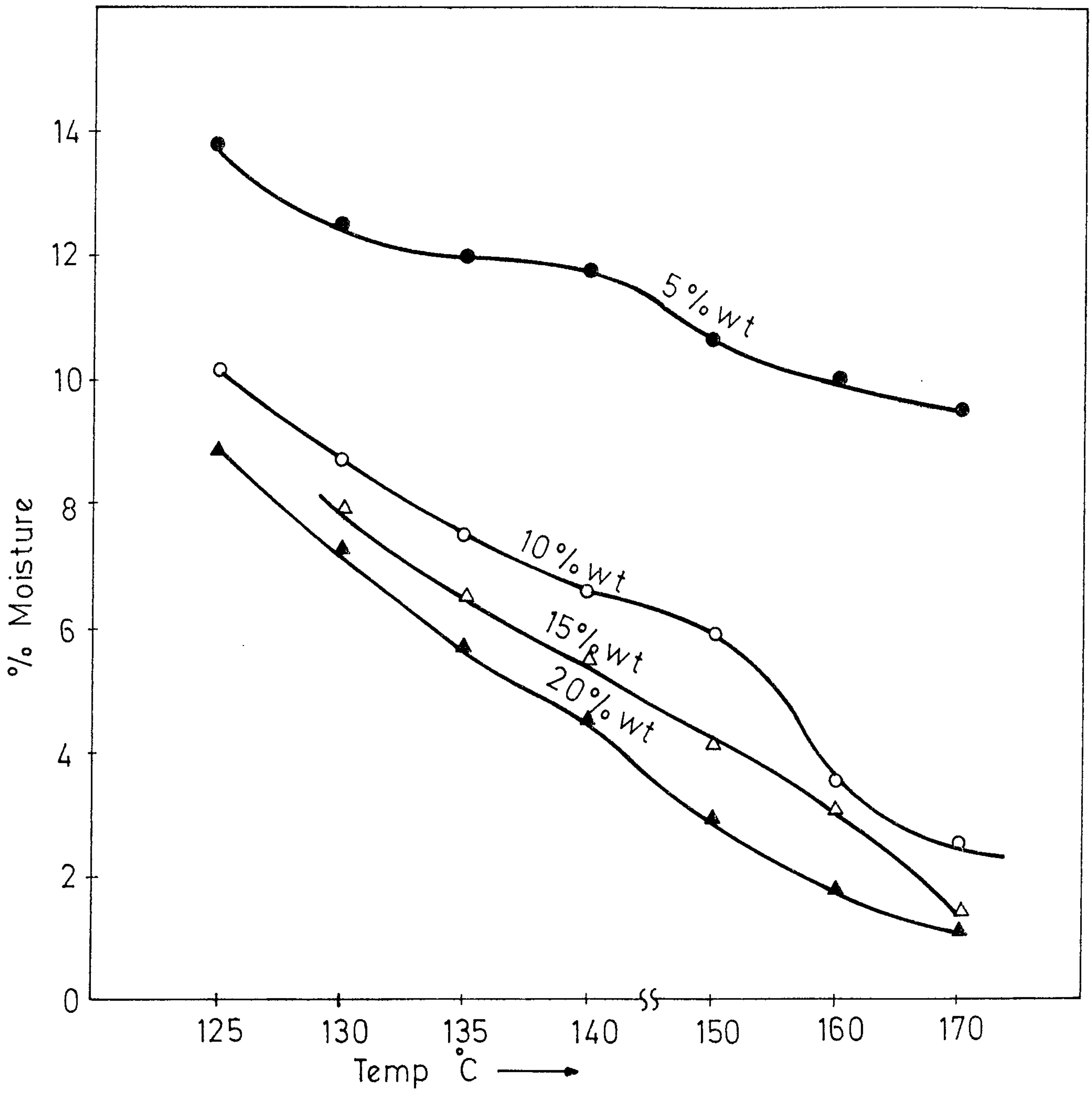


Figure 5.12 Moisture content in the powder related with temp. and concentrations at 6 scale setting of the peristaltic pump for feed rate and 24 m^3/h air flow rate through drying chamber and 700 lt/h through nozzle.

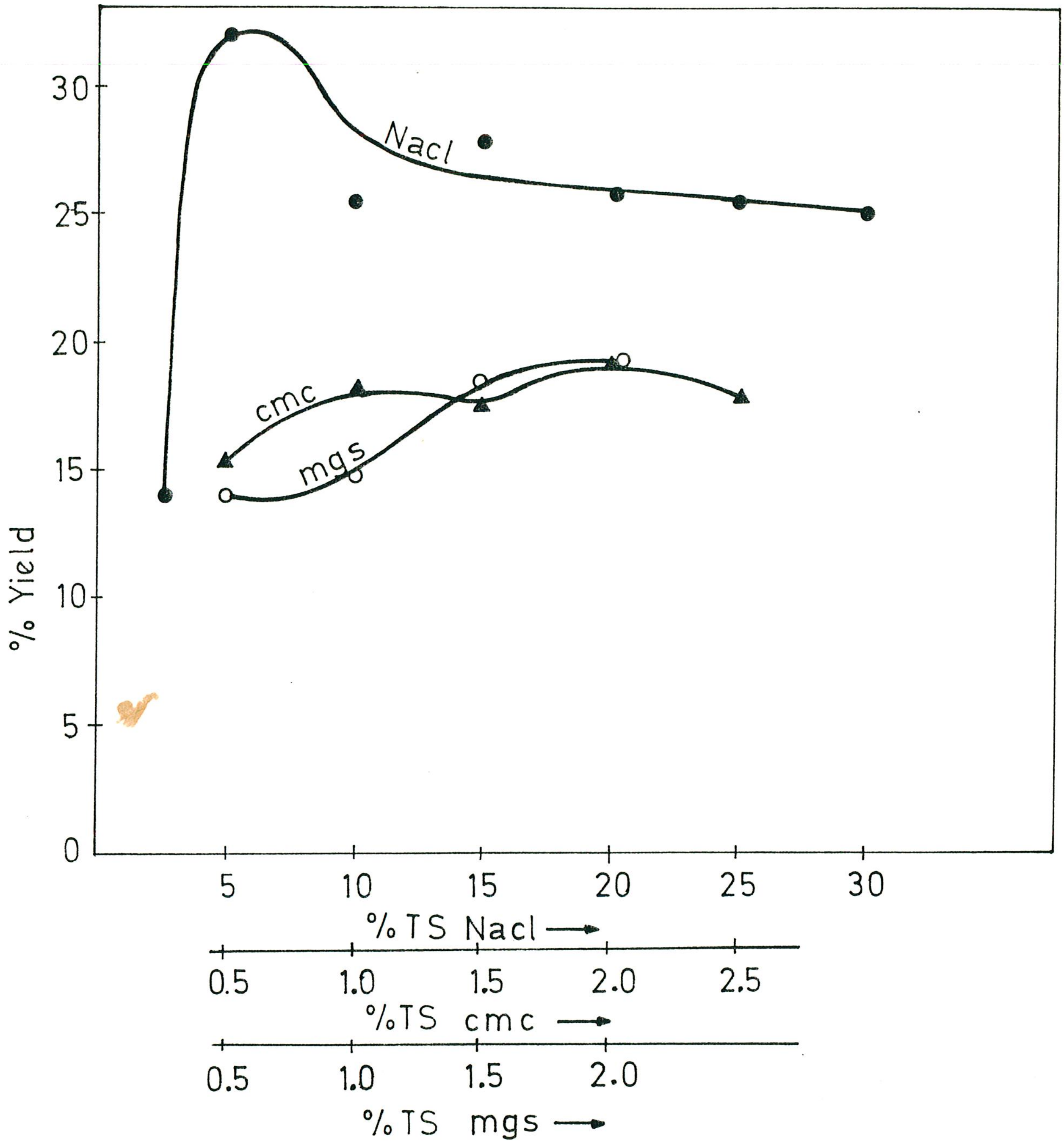


Figure 5.13 Yield of product related with additives at 135°C, at 700 lt/h air flow through nozzle and 24 m^3/h through drying chamber , feed rate 2.50 ml/min (6 scale setting of the peristaltic pump) for 15 Brix tomato concentrate concentration.

the reduction of temperature to 135^{o}C, the yield was increased up to 33.10 % for 700 lt/h air flow rate through nozzle and 5 % T.S. NaCl Fig. 5.14. When the yield was compared with the cases at different drying temperatures with additives at 500 lt/h and 700 lt/h air flow rate through nozzle ; it was noticed that the yield was more favorable at the 700 lt/h than 500 lt/h.

Furthermore the effect of mixture of additives on the yield was investigated at 135^{o}C and 700 lt/h air flow rate through nozzle as shown in Fig. 5.15. The yield increased up to 35.1 % when the mixture of 2.5 % TS CMC + 1.5 % TS NaCl was used , however the mixture of MgS + NaCl was ineffective on the yield . The mixture of additives related with drying temperatures on the yield were investigated and the results were shown in Fig. 5.16. The yield was observed to fall down at high drying temperatures and the mixture of MgS + NaCl was not effective on the yield.

Finally the effect of air flow rate through nozzle related with yield was investigated at different temperatures as shown in Fig. 5.17. Again at the 500 lt/h air flow rate through nozzle the yield reduced.

Thus, the results obtained so far with the existing spray dryer indicated that it is possible to restrict the employed parameters to the following values for further work in addition to those specified above :

a) Additives C.M.C. and NaCl should be used together at low concentrations.

b) Air flow rate through nozzle should be 700 lt/h

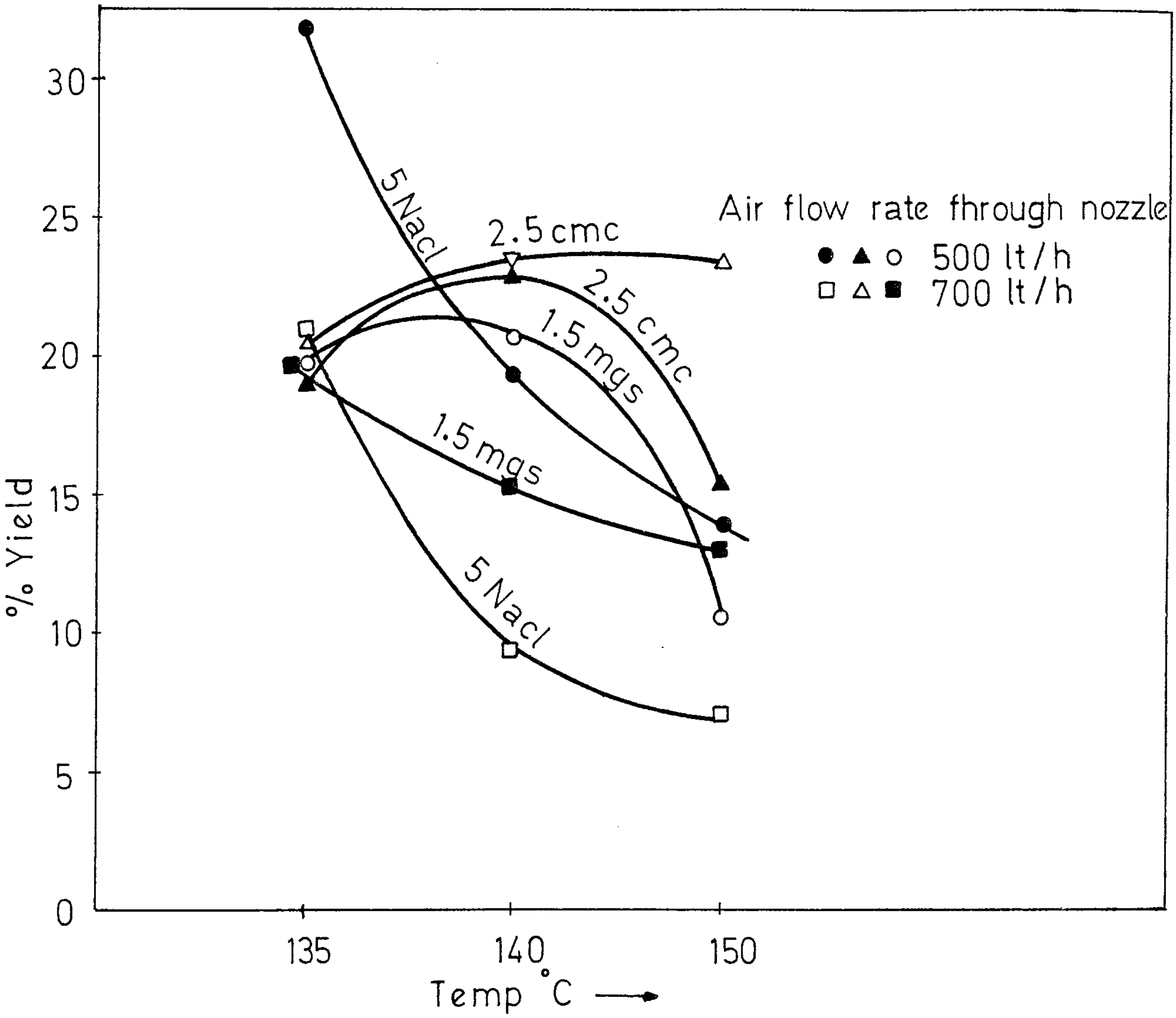


Figure 5.14 Yield related with different temperatures, additives and air flow rate through nozzle ; applied in terms of 24 m^3/h air flow rate through drying chamber at 2.5 ml/min feed rate (6 scale setting of the peristaltic pump) for 15 Brix concentrate concentration of tomato paste.

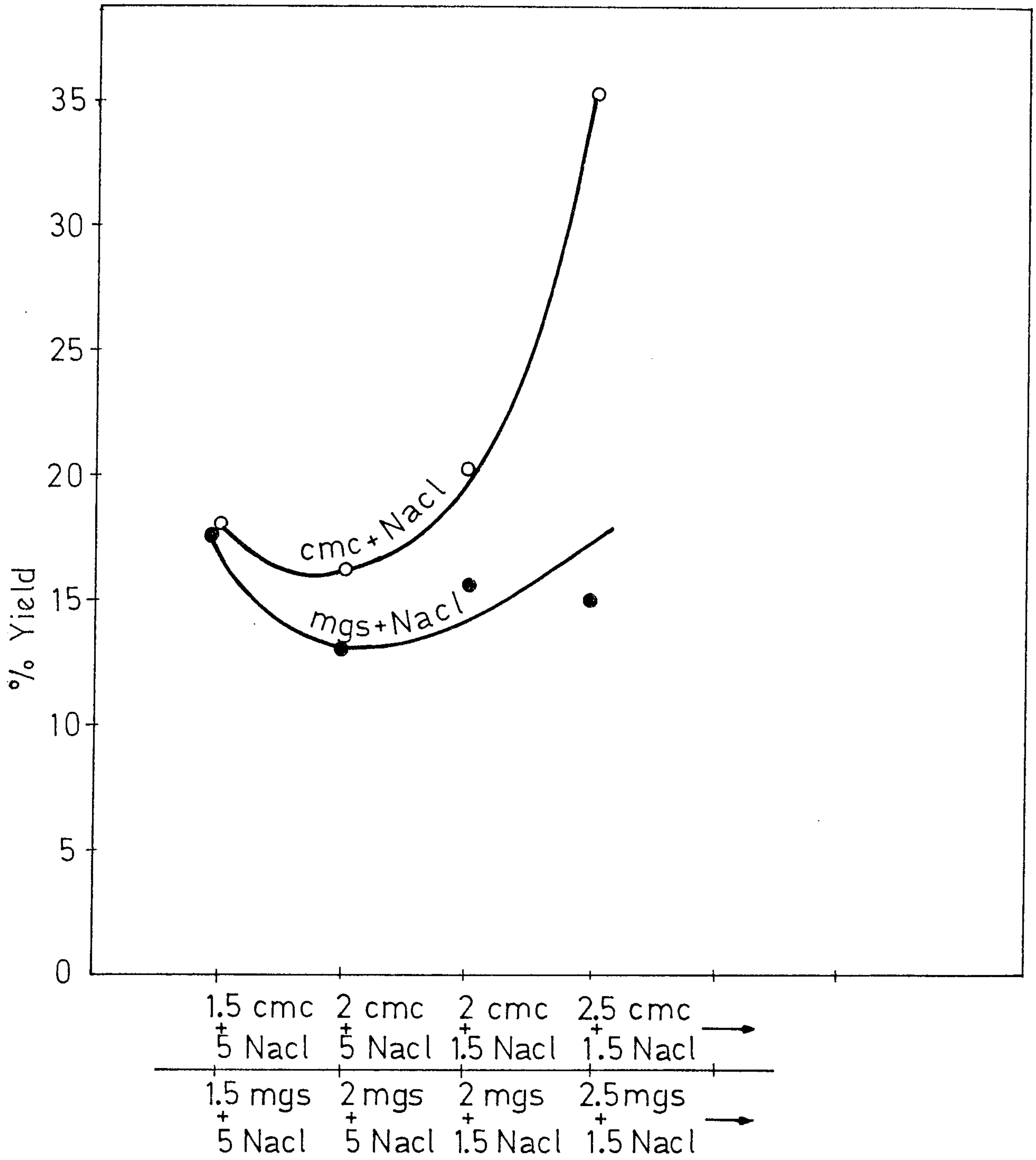


Figure 5.15 Yield related with mixture of additives at 135°C drying temperature 700 lt/h air flow rate through nozzle and 24 m^3/h through drying chamber at 2.5 ml/min feed rate (6 scale setting of the peristaltic pump) for 15 Brix concentrate concentration tomato paste.

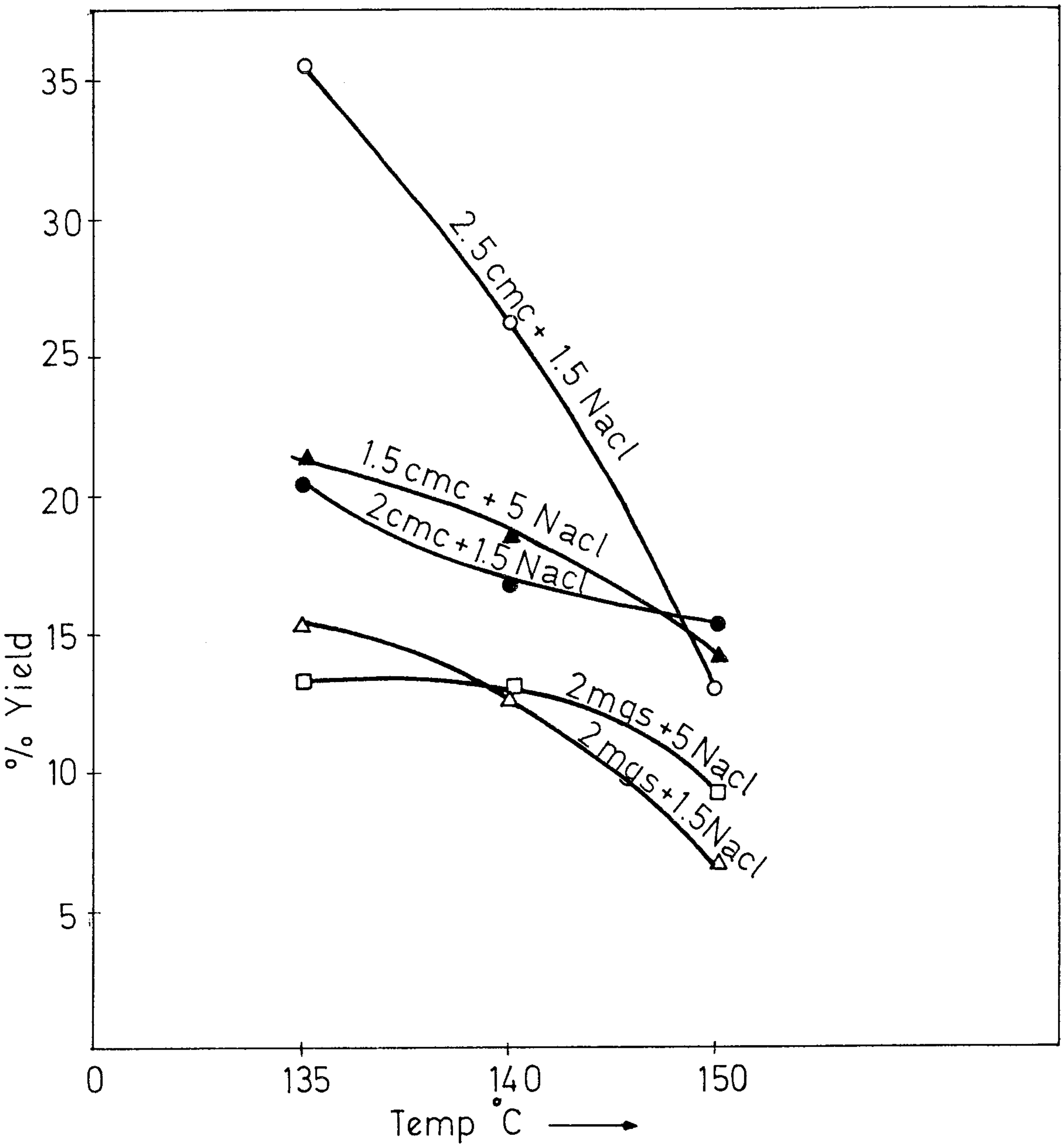


Figure 5.16 Yield related with different temperatures and additives 700 lt/h air flow rate through nozzle and 24 m^3/h through drying chamber, at 2.5 ml/min feed rate (6 scale setting of the peristaltic pump) for 15 Brix concentrate concentration tomato paste.

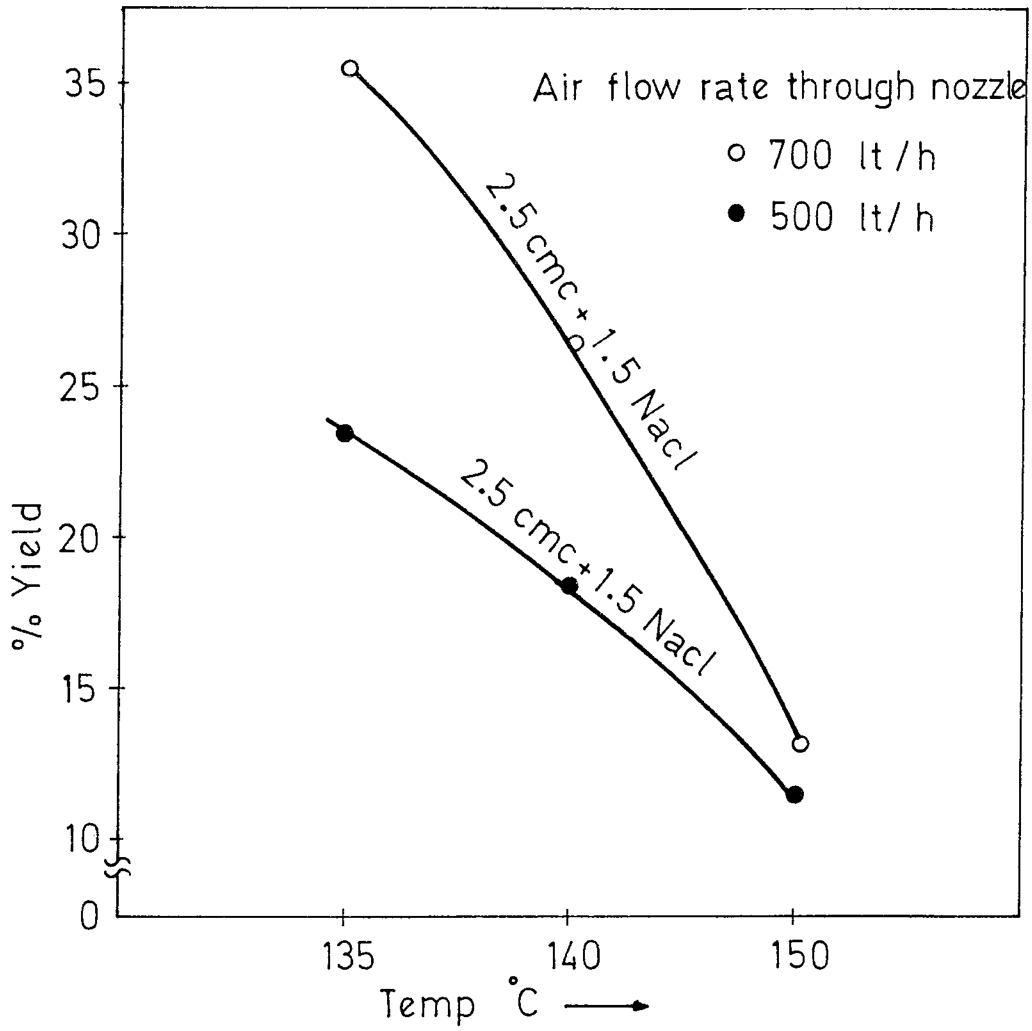


Figure 5.17 Yield related with different air flow rates through nozzle, 24 m^3/h air flow rate through drying chamber, 2.5 ml/min feed rate (6 scale setting of the peristaltic pump) for 15 Brix concentrate concentration tomato paste.

c) Drying temperature should be kept around 135°C.

5.4.3 Cooling the chamber indirectly by a jacket

Experiments were carried out using a cooling jacket placed on the external surface of the drying chamber. The jacket was constructed from PVC of 140 mm inner diameter with a length of 400 mm as shown in Fig. 5.18. It is connected to the air inlet of the drying chamber so that the air admitted through the clearance provided at the skirt, cools the drying chamber as it flows counter-currently (upward) in the annulus between the jacket and the chamber surface.

The effect of indirect cooling on the yield practiced with and without additives was as shown in Fig. 5.19. From the inspection of results the maximum yield obtained was about 37.2 % at 135°C when a proportion of additives CMC and NaCl was used as 2.5 ; 1.5 percent of dry solid basis of feed solution. A gradual reduction in the yield was recorded if the temperature of the inlet air was increased above 135°C. When indirect cooling was applied without additives, the maximum yield obtained was about 23.5 % at 140°C. Furthermore, employment of high concentrations of additive-mixtures was seen to be almost ineffective on the yield.

The above results implied that, neither the high concentration of additives nor the temperatures above 135°C favors the yield.

However, cooling the chamber wall turned out to be quite effective on the yield and therefore further means of cooling the drying chamber was studied.

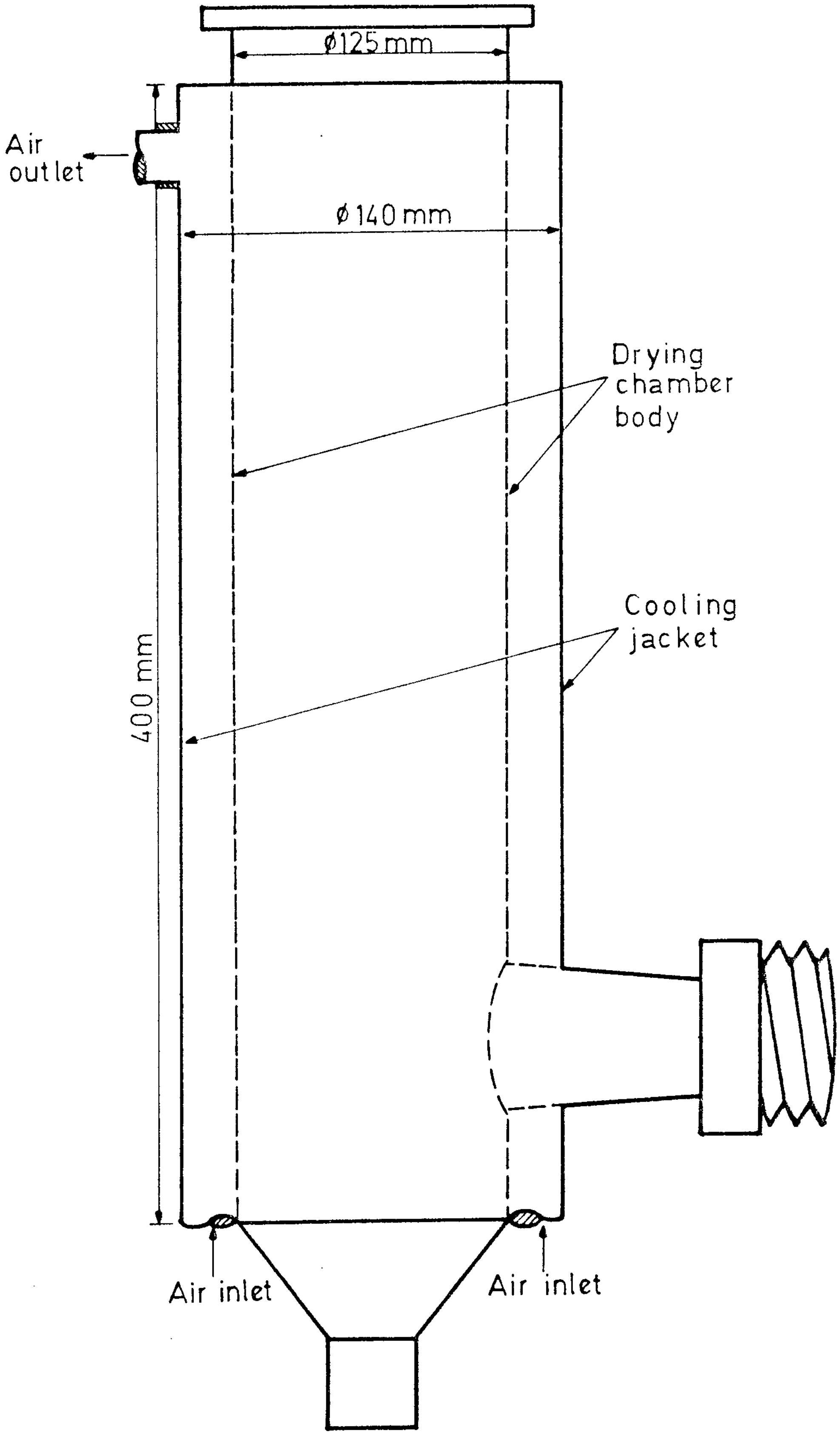


Figure 5.18 Cooling the chamber indirectly by a jacket

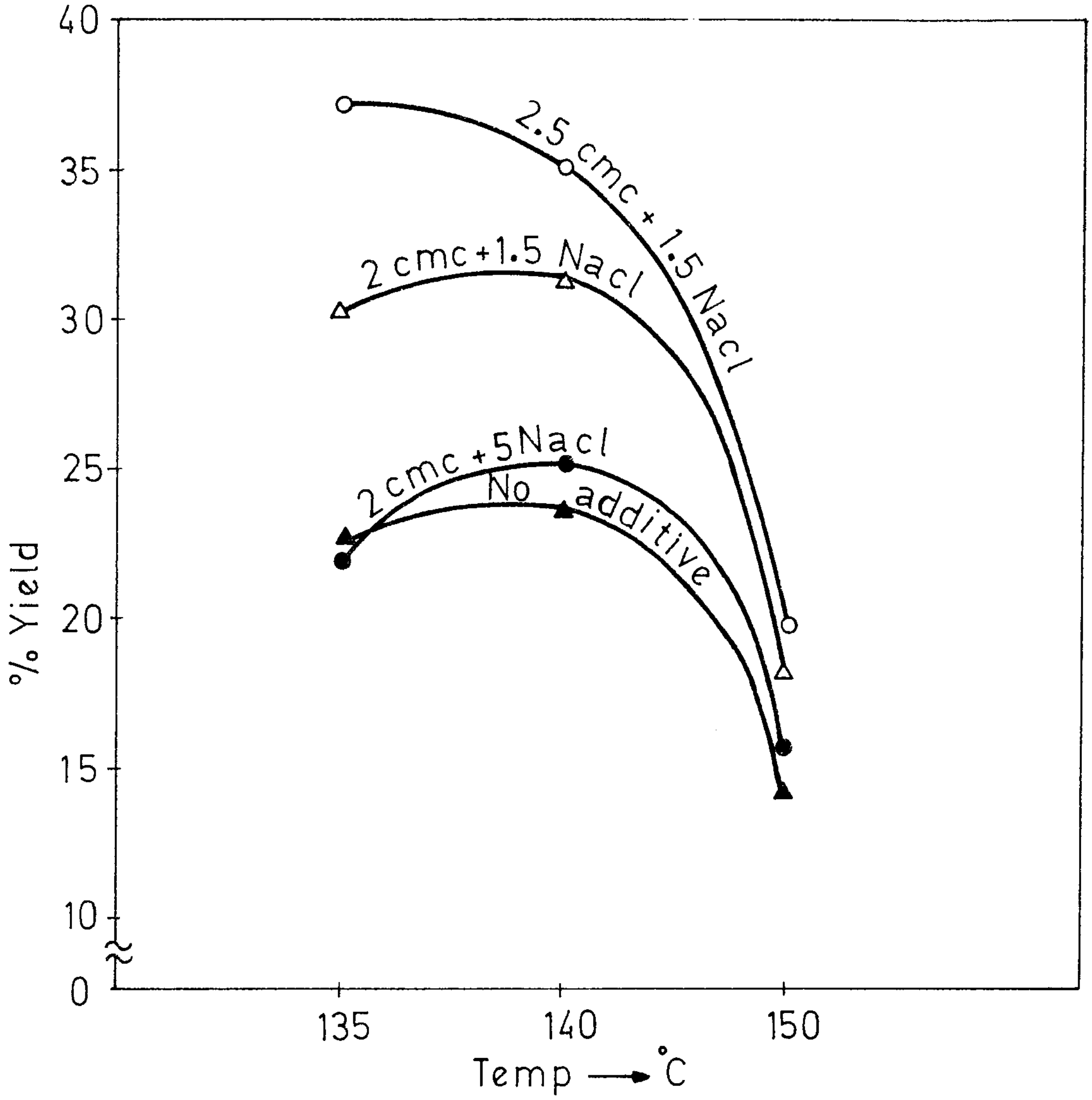


Figure 5.19 Yield related with indirect cooling expressed as temperature of the air inlet to the chamber, air flow rate 24 m^3/h and 700 lt/h through nozzle, feed rate 2.5 ml/min for 15 Brix tomato concentrate.

5.4.4 Direct cooling of the chamber by bleeding air

A modification made on the drying chamber with a cooling jacket used in the experiments above was the insertion of a glass pipe through the bottom for direct cooling. The aim was to increase the yield by decreasing the temperature of the system and hence the powder Fig. 5.20. The diameter of the inserted pipes were selected as 8, 10, 12, 13, 14, 15, 16 and 20 mm. Their mouths were adjusted to different levels from the bottom of the chamber for each run in the range of 10 to 310 mm. The net thermal effect of providing direct cooling during drying was about 13 to 15^{o}C drop in the temperature of the exit air as in Appendix B.

According to the results shown in Figs. 5.21, 5.22 and 5.23 this arrangement made it possible to increase the yield up to about 47 %. This maximum value corresponds to the placement of the tip of the 12 mm cooling pipe at 30 mm from the bottom of the chamber both for high and low concentrations of the mixture of additives at 140^{o}C in order to be able to sec the maximum yield at 140^{o}C for fixed positions above 30 mm, different diameters of cooling pipes were used and the maximum yield was obtained for 12 and 15 mm diameter pipes. They were about 45 to 46.5 % Figs. 5.21 and 5.22. As the pipe diameter increased above 15 mm and reduced below 12 mm, the yield reduced to about 20 % and 30.2 % for 20 and 8 mm respectively. In addition to this, when the position of the cooling pipe was kept variable for 12 mm diameter for different temperatures of 145^{o}, 143^{o} and 142 ^{o}C, the maximum yield obtained was about 45 % at the position of 90 mm as shown in Fig. 5.23.

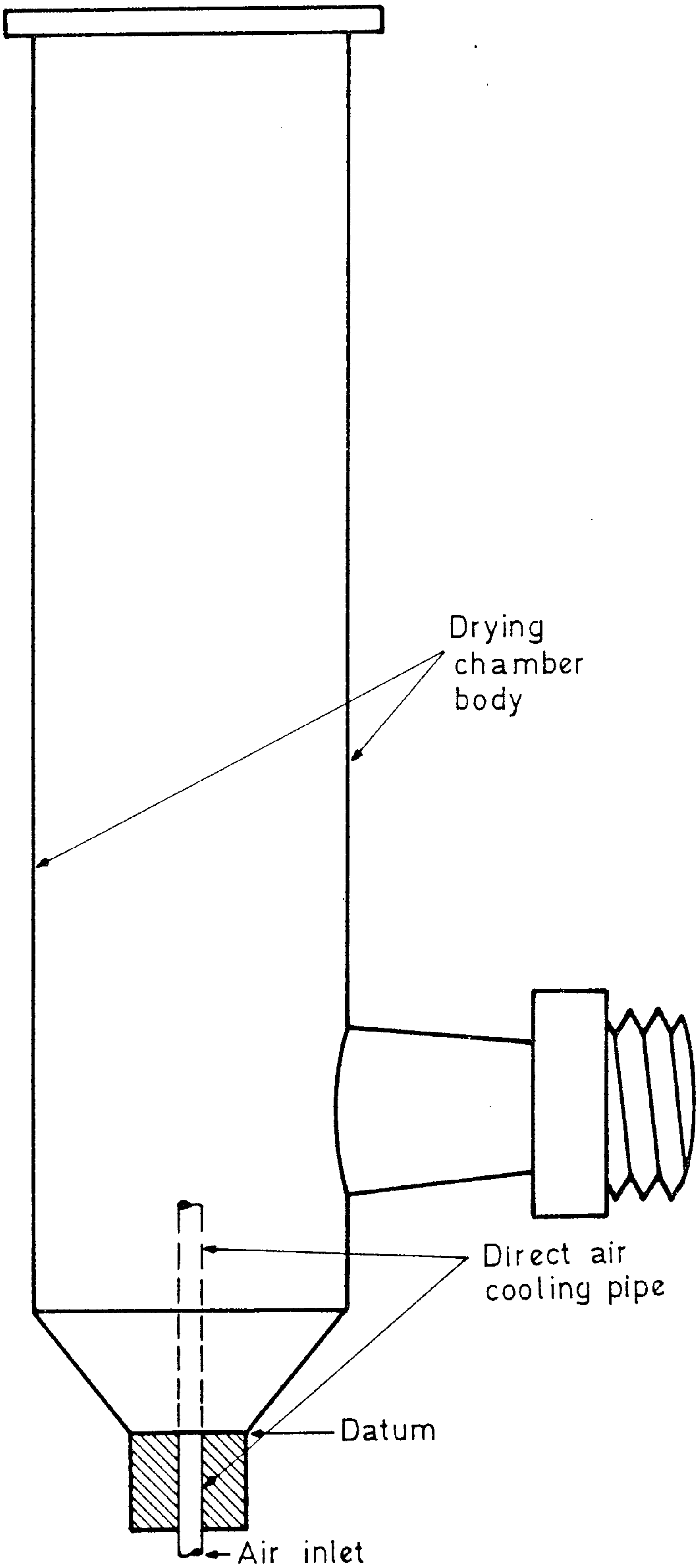


Figure 5.20 Direct cooling of the chamber by bleeding air

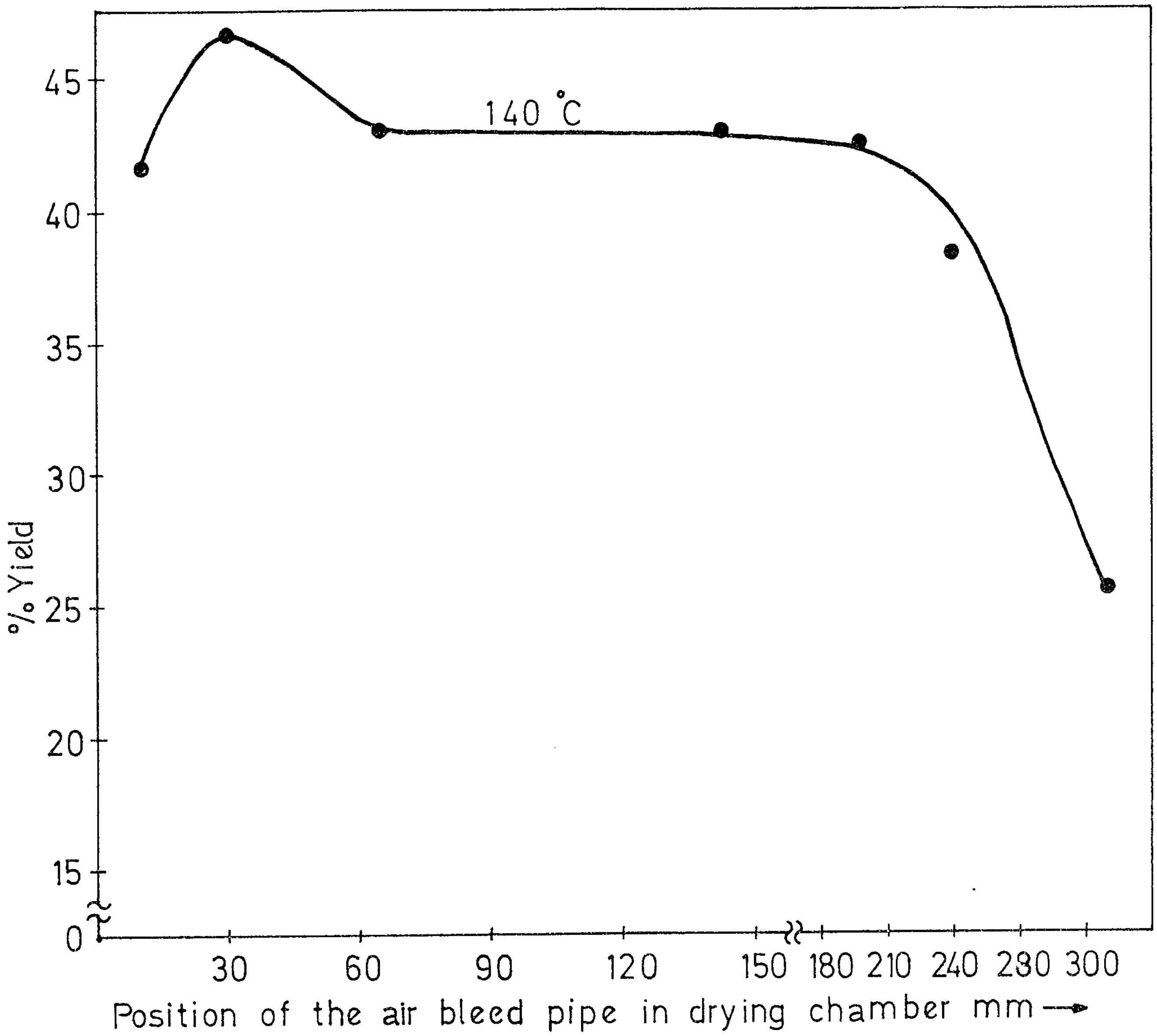


Figure 5.21 Yield of tomato powder when direct cooling is practiced for the mixture of additives of 1.5% TS NaCl + 2.5% TS CMC, 12 mm Ø glass pipe fixed inside the drying chamber at 140°C drying temperature, feed rate 2.5 ml/min, concentrate concentration 15 Brix, air flow rate 24 m^3/h and 700 lt/h through nozzle .

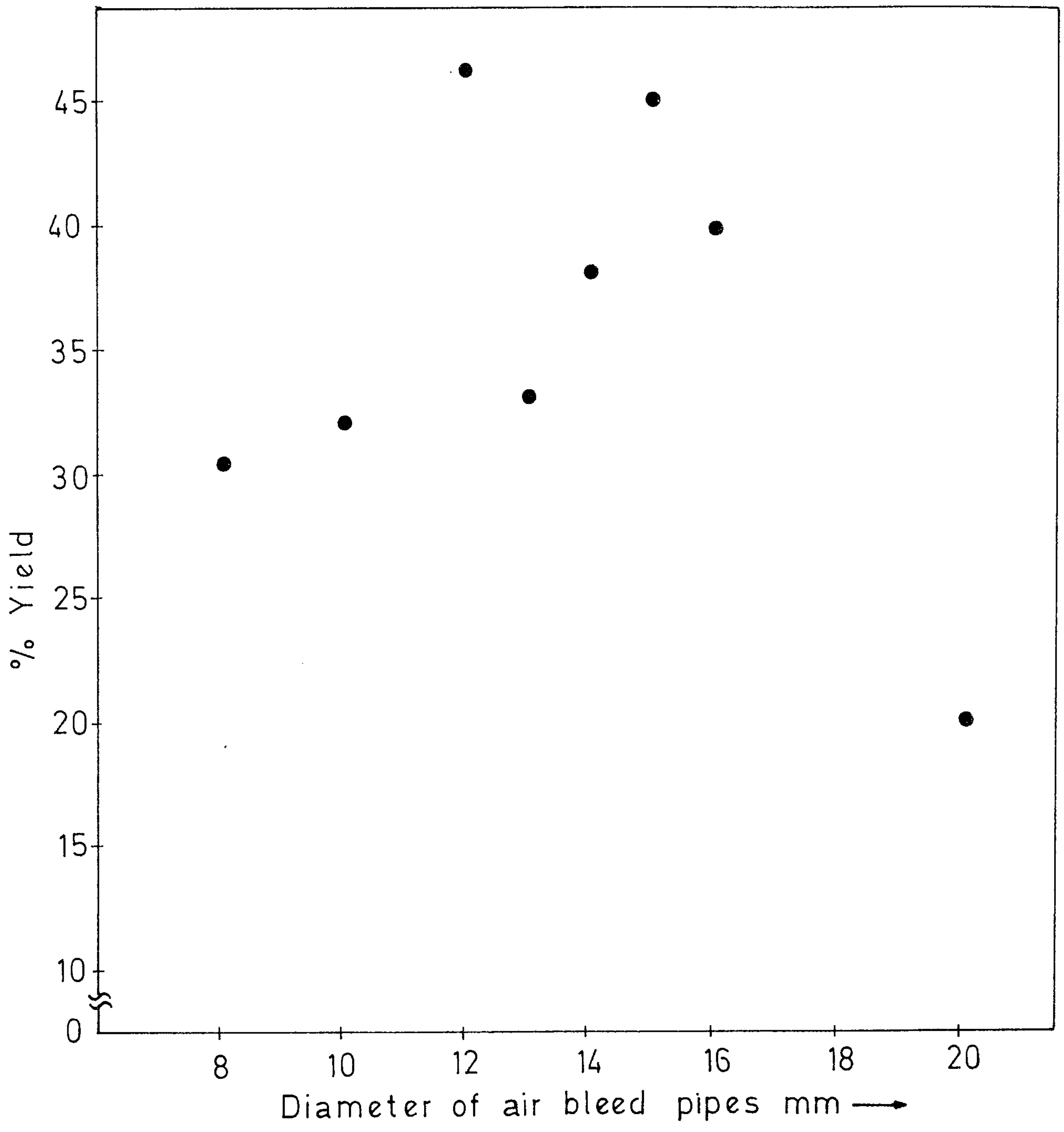


Figure 5.22 Yield at 140°C for different diameters of air bleed pipes, additives (1.5 % TS CMC + 2 % TS NaCl) at fixed position of 30 mm inside drying chamber, air flow rate 24 m^3/h and 700 lt/h through nozzle, feed rate 2.5 ml/min for 15 Brix tomato concentrate.

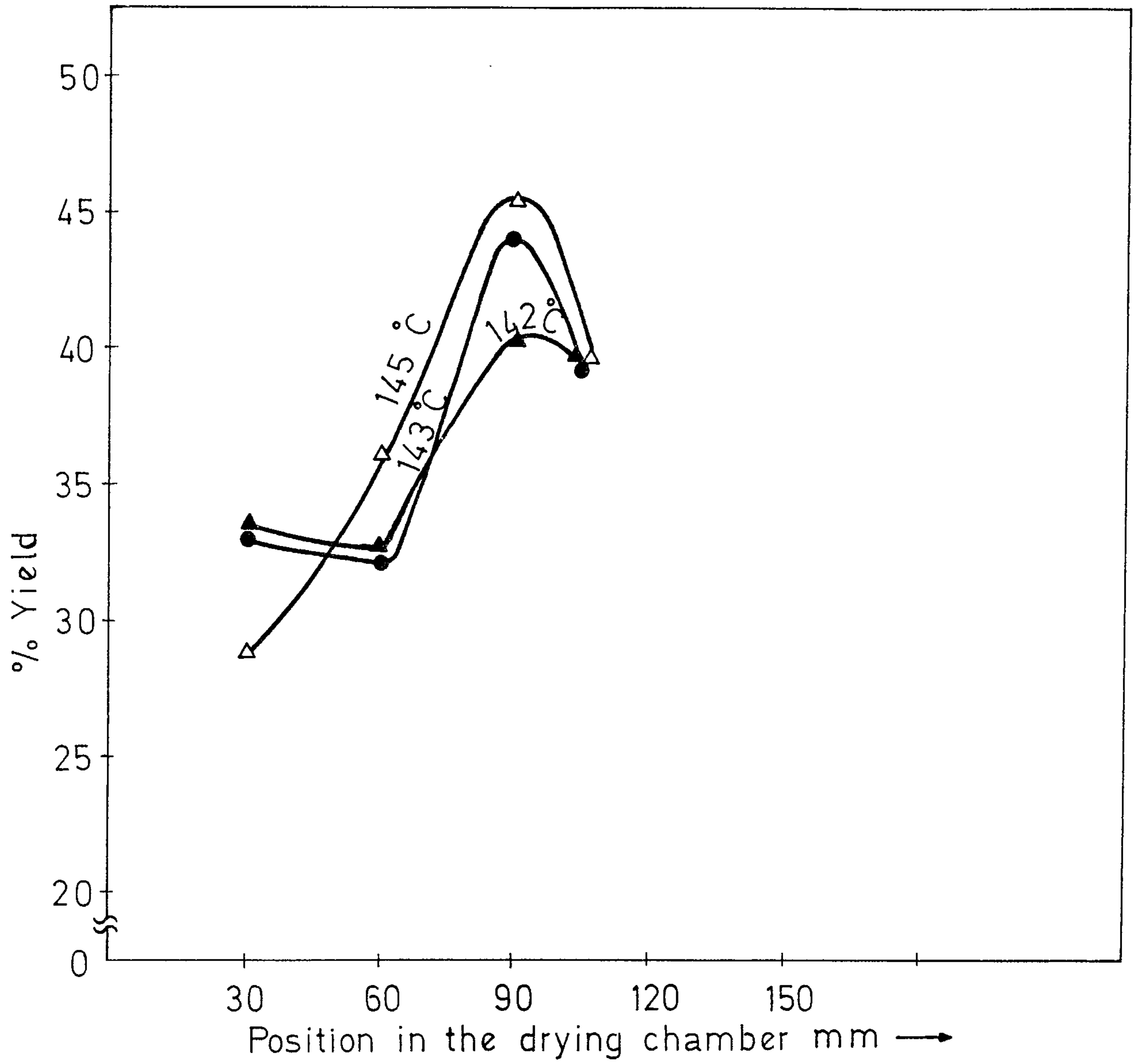


Figure 5.23 Air flow rate 24 m^3/h and 700 lt/h through nozzle feed rate 2.5 ml/min for 12 mm pipe inlet into drying chamber, for low concentration additives, concentrate concentration of tomato paste 15 Brix.

In this set of experimentation, again the positive effect of maintaining higher air rate at the nozzle on the yield was assured.

The moisture content in the powder related with pipe diameters is shown in Fig. 5.24, the amount of moisture content in the powder was related with pipe diameter and air inlet into the drying chamber.

5.5 Discussion

It has been known that spray-drying of viscous materials containing a proportion of a hygroscopic substance (e.g. sugar) is often associated with the problems of wall deposition due to thermoplastic properties, Mazza and Lemaquar [61], Islam and Flink [62] and Karel [68].

In accordance with this fact, the present study indicated that the product yield is governed by the combined effects of the drying temperature, presence of additives, concentration of the feed, provisions for cooling of the drying chamber and the air flow rate through the nozzle. The following discussion is about the results obtained with respect to these variables.

i) Drying Temperature

There were heavy wall depositions due to the tacky, hygroscopic and thermoplastic product formed, which was difficult to remove and clean from the cyclone and the drying chamber wall during spray drying of the paste without additives. Many researchers have worked on preventing the wall deposition during spray drying of tomato paste, as mentioned in chapter 2, section 2.8,[31][32][33][23] .

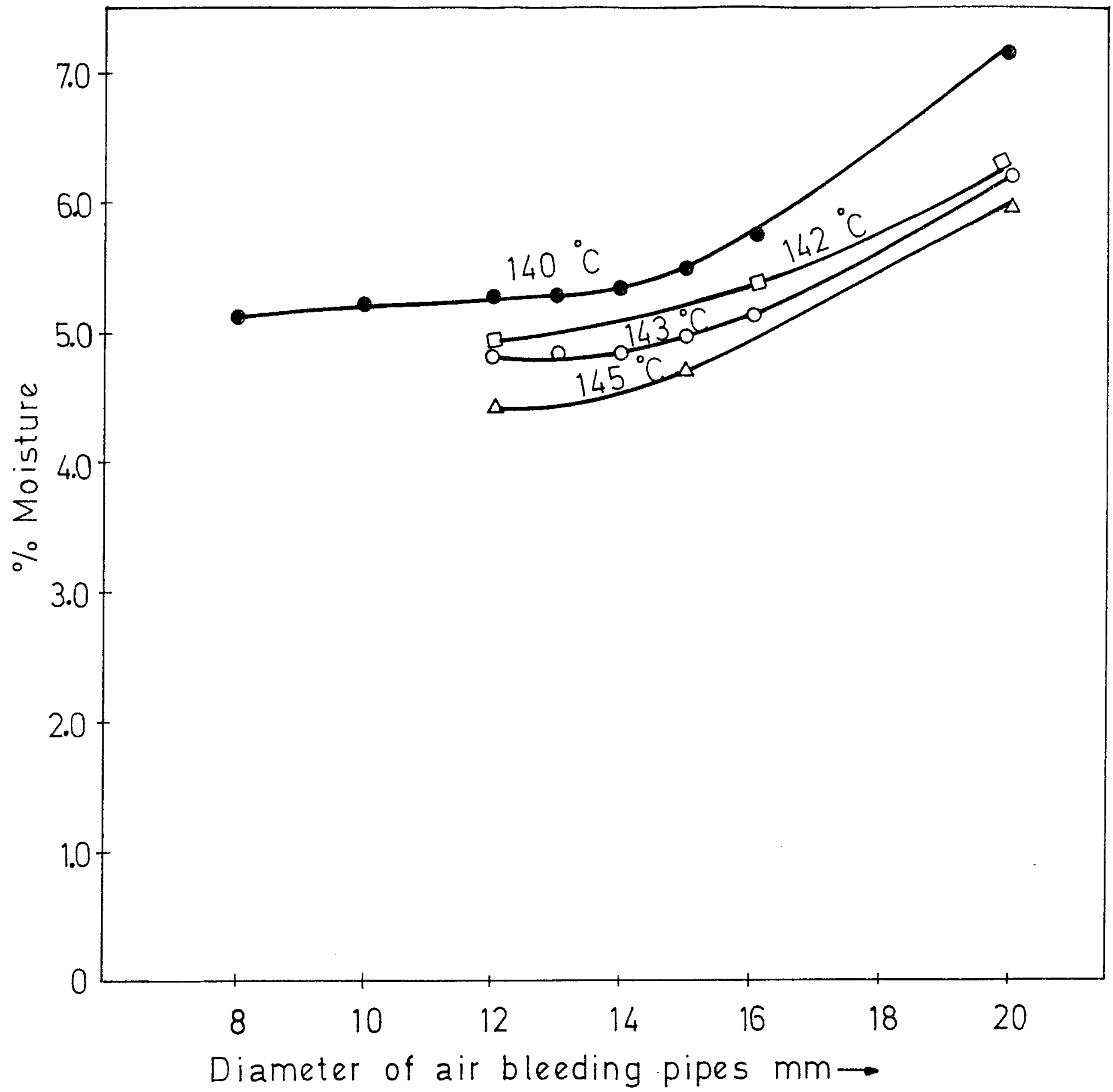


Figure 5.24 Moisture content in the powder related with temp. and diameter of the pipes for air bleeding through direct cooling chamber.

In our experimental runs the yield was reduced when air inlet temperature was above 140^{o}C and the amount of air flow through nozzle was lower and higher than 700 lt/h as shown in Figs. 5.7, 5.8, 5.9, 5.10, 5.14. Ideal spray drying temperature for tomato paste was recommended to be 77-150^{o}C, Masters [18] and Christensen [23] . The wall deposition encountered in the processing of the tomato powder was not only because of the stickiness but also effected by the wall temperature which acts on the thermoplastic properties. This fact was also pointed out by Kaufman et. al. [30], Lazar and Rumsey [78] , Masters [8] and Karl et.al. [32].

When the drying temperature was at 160^{o}C and 170^{o}C, the yield was reduced to a lower value for different concentrations as shown in Fig. 5.4. The reduction of yield is believed to be associated with thermoplastic property of tomato powder and diffusivity of moisture removal from droplets which was estimated in Chapter 4. At these temperatures the powder may form into Millard reaction form which increases the stickiness on the chamber wall, Lazar and Rumsey [78] . The yield related with air flow rate through the nozzle is considered to depend on the problem of non-uniform atomization Spraco [19] , Van Arsdel et.al. [24] , Keey [25] , Christensen [77] , Heldman and Singh [69] .

ii) Presence of Additives

Fruit juice and vegetable extract presents considerable difficulties in the production of free flowing powder when spray dried because of the naturally occurring sugars, acids etc. which produce products that are relatively hygroscopic. This hygroscopicity spray drier it was not possible to use a feed above 15 % wt properly due to the nozzle of the spray drier.

iv) Cooling Drying Chamber

By the application of a cooling jacket it was possible to increase the yield up to 37 % as in Fig. 5.19. Lazar et.al.[31], Karl et.al.[32] , Masters [8] , Christensen [23][77] applied indirect cooling system with cool-wall technique for spray drying of tomato paste in a stainless chamber. Lazar [31] , obtained a yield of about 60-65 %, and the others obtained about 85-90 % applying the cool wall technique. The difference between our studies may be attributed to the differences in the materials of construction used for the drying chamber and the diameter of drying chamber.

In the cool wall technique discussed in section 2.8. 5.2. the drying air was supplied from the cooling air passing through the wall jacket supplemented by atmospheric air intake. The removal of the remaining moisture from tomato particles became more difficult as the concentration increased during drying of tomato droplet which was also confirmed in chapter 4. For the removal of the remaining moisture from tomato layer which broke away from chamber wall and fell, greater resistance to mass transfer was apparent, Goose [3] . Furthermore application of this method might cause heat degradation of vitamin C as estimated in Chapter 3 and supported by the researchers interested in this phase,[18][31] [23] [32] .

In another phase of this study cooling by bleeding air through a pipe inserted into the drying chamber at different pipe diameter and positions was practiced as shown in Figs. 5.20 and 5.21. Under these circumstances the yield obtained was about 47 % for 1.5 % TS CMC with mixture of 2 % TS Nacl as shown in Fig. 5.22. It is believed that, the small diameter of the experimental spray dryer used is the most influencing design variable governing any further increase in yield.

In our experimental runs reduction of the outlet temperature to 52-65°C, by direct cooling to prevent wall deposition was tried. Although the wall deposition on the receiver was avoided, again due to small diameter of our spray dryer chamber, the wall deposition could not be overcome,

v) Air Flow Rate

As to the air flow rate through the nozzle, its effect on the yield decreased at the flow rate below and above 700 lt/h Fig. 5.10. It has been pointed out that one of the primary causes of the deposition on the chamber wall during spray drying tomato paste occurs due to the particle size of the powder, Christensen [77] and Keey [25] . In accordance with this view it can be stated that the decrease or increase in the particle size is partially due to the air flow rate through nozzle and thus it may reduce the yield. The position of the air flow in the drying chamber was recommended to be 90° flow in order to reduce wall deposition on the chamber wall, Christensen [77] . In our experimental runs we tried to keep at 90° angle of the nozzle for air flow into the drying chamber by replacement of perforated cap on the surface of air inlet into drying chamber. It was observed that the product stuck to the bottom of drying chamber before being dried which might be related with length of the drying not being adequate for our purpose.

The yield related with air flow rate through drying chamber is shown in Fig. 5.11. When the air flow rate was below and above 24 m^3/h, the yield was reduced and the optimum condition was estimated to be 24 m^3/h. For further runs this flow rate will be selected as optimum condition.

For spray drying tomato paste with cool wall chambers of 500 m^3/h, 1200m^3/h and 2000 m^3/h air was used by Lazar et.al. [31] , Karl et.al. [32] and Christensen [77] , but these values were not compatible with our laboratory spray dryer. Mainly the amount of air flow rate depends on the type and capacity of spray dryer, residence time in the chamber, drying temperature and amount of feed rate, Masters [17][18] and Keey [25] .

The moisture content of spray dried tomato powder was determined as shown in Figs. 5.12 and 5.14. The moisture content of the powder was found to be effected by three main factors;

A - inlet air temp.

B - feed concentration

C - feed rate.

The lower moisture content was obtained with higher inlet air temperature and low feed rate tomato paste which was in agreement with dehydration law Geankoplis [19], Toledo [50] and Keey [25] . Obviously as the temperature of inlet air temperature and the feed concentration increased and the feed rate reduced the moisture content of the powder was reduced.

Reconstitution of the powder was observed to be promising at drying temperatures between 125-150°C whereas at 160 and 170°C some burnt particles were noticed. This is in agreement with the recommendations of Lazar [31] , Karl et.al. [32] , Masters [8] , Christensen [23] and Goose [1] , who suggested that drying temperatures of tomato paste should be between 70-150°C. In experimental runs in Chapter 4, altough it was observed that the value of diffusivity of droplet increased with air inlet temperatures, the above effect may be due to the Maillard-type of reaction in which particles took a plastic form which made it difficult to remove the dried layer from the chamber wall, Lazar and Rumsey [78] , Topar [22] and Heigh [28] .

The effect of temperature on the colour of the powder was estimated by Lovibond Tintometer and the results were expressed in International unit of colour in dominate Figs. 5.25, 5.26 and Table B14, B15 in Appendix B. The effect of drying temperatures on the Vitamin C of the powder was estimated by the method described in Chapter 3 as tabulated in Table B20 Appendix B. The amount of ascorbic acid losses were lower than that observed in direct heating method results of Chapter 3. This must be related with heating time and temperature as depicted by Equ. 3.15. It was observed that the effect of temperature on the colour was more obvious than Vitamin C, therefore it appears to be a better method to use colour as a reference on the nutritional changes of tomato powder. As the temperature of air entering into the drying chamber was increased above 150°C the colour of the powder became unacceptable

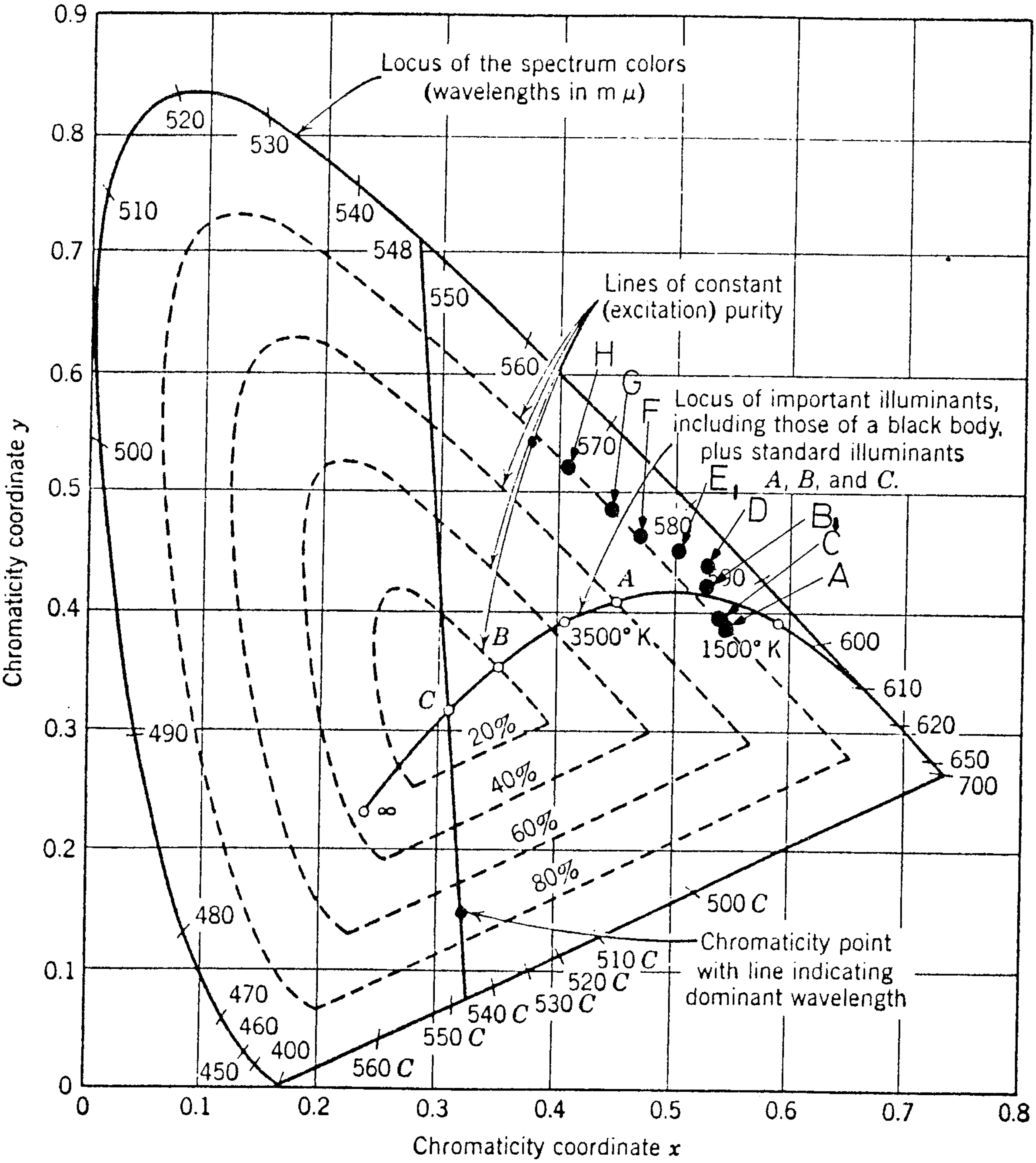


Fig.5.25. Chromaticity diagram for the CIE standard observer and illuminant C. Symbol represents ; A, tomato paste, B_1, C, D, E_1, F, G and H the run numbers, 1.8, 1.9, 1.10, 1.11, 1.12, 1.13 and 1.14 respectively.

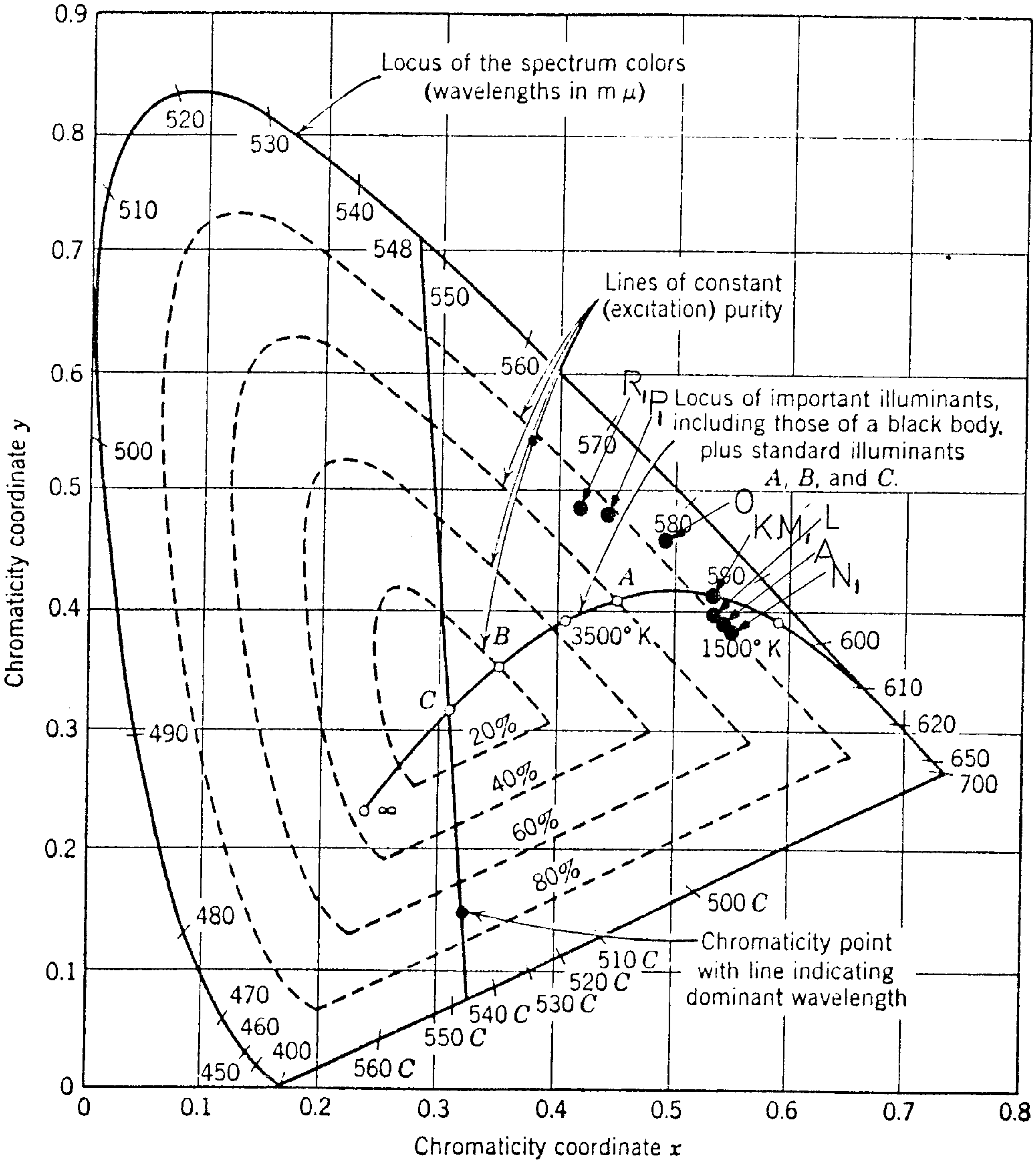


Fig.5.26. Chromaticity diagram for the CIE standard observer and illuminant C. Symbol represents ; A, tomato paste, K, .L, M_1 N_1 O, P_1 and R_1 the run numbers, 5.11, 7.14, 7.11, 8.13, 8.1, 1.19 and 1.20 respectively.

as shown in Figs. 5.25, 5.26. This is also in agreement with the suggestions on drying temperatures by Lazar [31] , Karl et.al. [32] , Christensen [23] , Masters [8] , Ginnette [27] , Heigh [28] , Kaufman et.al. [30] , Lazar and Rumsey [78]and Przbyla [29] . The oxidation of Lycopene is likely to be related with temperature which may give rise to unacceptable colour at high temperatures Cole and Kapur [82] and Linder et.al. [43] .

5.6 Conclusion

In the light of the results obtained in an experimental spray dryer the following items can be concluded :

1. It is not possible to produce a free-flowing, non-sticky tomato powder by a common spray drier and "cool wall" chamber. Therefore a special type of drying chamber should be designed for spray drying of such thermoplastic and hygroscopic materials.

2. The additives employed were found to have varying effects on the physical properties of the powder. A particular additive does not improve the yield to an acceptable value, but some promising results were obtained when a mixture of additives were used with direct cooling system. The most satisfactory of these was addition of 1.5 % TS CMC 2 % TS NaCl which gave yield of 47 %.

3. Increasing the air inlet temperature above 1500°C has an undesired effect on the colour of product causing some particles to burn. Thus, to preserve the colour of the product and Vitamin C at an acceptable value, air inlet temperature must be kept below 150°C.

CHAPTER 6

DESIGN OF A SCRAPED DRYING CHAMBER FOR SPRAY DRYING OF TOMATO PASTE

6.1 Introduction

The drying of tomato paste is a problem of great practical importance and has been studied extensively. A number of researchers have developed various types of drying techniques such as, spray drying, drum drying, foam-mat drying and vacuum drying Goose [1], Heing [28], Ginnette et.al. [27] and Kaufman, Taylor and Tulburt [30] and sonic technology in food drying Swientek [83].

One of the most important methods is spray drying which has two basic types of applications, Masters [16].

a. spray drying utilizing moderate drying temperatures
b. spray drying utilizing low drying temperatures

For this purpose many types of drying chambers have been developed to overcome the thermoplastic and hygroscopic property of tomato paste during spray drying. Examples are the Birs tower, the cooling jacket chamber and the cooling chamber with direct cold air current inside the drying chamber, Brennan et.al. [10] , Heid and Manyard [34] , Lazar et.al. [31] and Masters [8] . Still there are many unsolved difficulties of the spray drying techniques such as the wall temperature of the spray drier chamber. It may become high enough to form a sticky powder through over heating, and may even reach to the point of burn-out, Goose [3] . Application at low temperatures induce some spoilage problems which might have risen as the temperature employed may not have been sufficient to destroy all of the micro-organisms such as Bacillus stearothermophilus, Bacillus coagulans and Bacillus thermoacidurans, Frazer [15] , Nickerson and Sinskey [13] and Brock [12] . Furhermore the cost of such equipment is quite high.

Therefore, in order to overcome these drawbacks of spray-drying process as applied to tomato paste, it is considered to be fruitful to place a rotating scraper blade on the interior wall.

The aim in installation of a scraper in the drying chamber was to remove the adhered layer on the chamber wall to allow free flowing of particles and also to increase the yield.

6.2 Designing Scraped Surface Type of Drying Chamber

The geometry of scraped surface drying chamber was determined according to the dimensions of Büchi type 90 of spray dryer given in Appendix B. The dimensions and configuration of the scraper chamber elements, namely, the dryer body, the bearing conveyor, the lower bearing, the upper conveyor bearing, the lower scraper bearing and scraper bearing and scraper knives were then determined afterwards.

The details of the drawings are shown in Figs. 6.1, 6.2, 6.3, 6.4 and 6.5.

As to the design of the scraped surface drying chamber, at first wooden models of above mentioned parts were prepared except for the knives and then they were moulded as cast iron at Küsget Gaziantep. In the next stage these moulded parts were proceessed according to the required sizes at the workshops of METU Gaziantep Campus, Mechanical Engineering Dept. Later on the processed inner surface of the drying chamber was coated with hard chronium in Ankara Organize Sanayii.

The material used in the construction of the scraper knives was stainless steell. The upper end of the scraper knives was connected to the upper conveyor bearing, and the lower end of it was connected to the lower scraper bearing so as to sweep the inner surface of the drying chamber wall at an angle of 90^{0}. This was made possible by placing steel springs in the beds of the upper conveyor bearings and lower scraper bearings.

The upper conveyor bearing was made of teflon details of which were shown in Fig. 6.5. The central part of the lower scraper bearing was connected to the central part of the lower bearing by means of a shaft the other end of which was connected to a rim.

This rim was connected to a smaller rim, the other end of which was connected to an electric motor (0.375 kw) which in turns was connected to an adjustable speed electrical panel procured from Sam-El Company İzmir. The whole body of the scraped surface chamber was placed on a table with adjustable feet. The details of the mounted equipment is shown in Fig. 6.6.

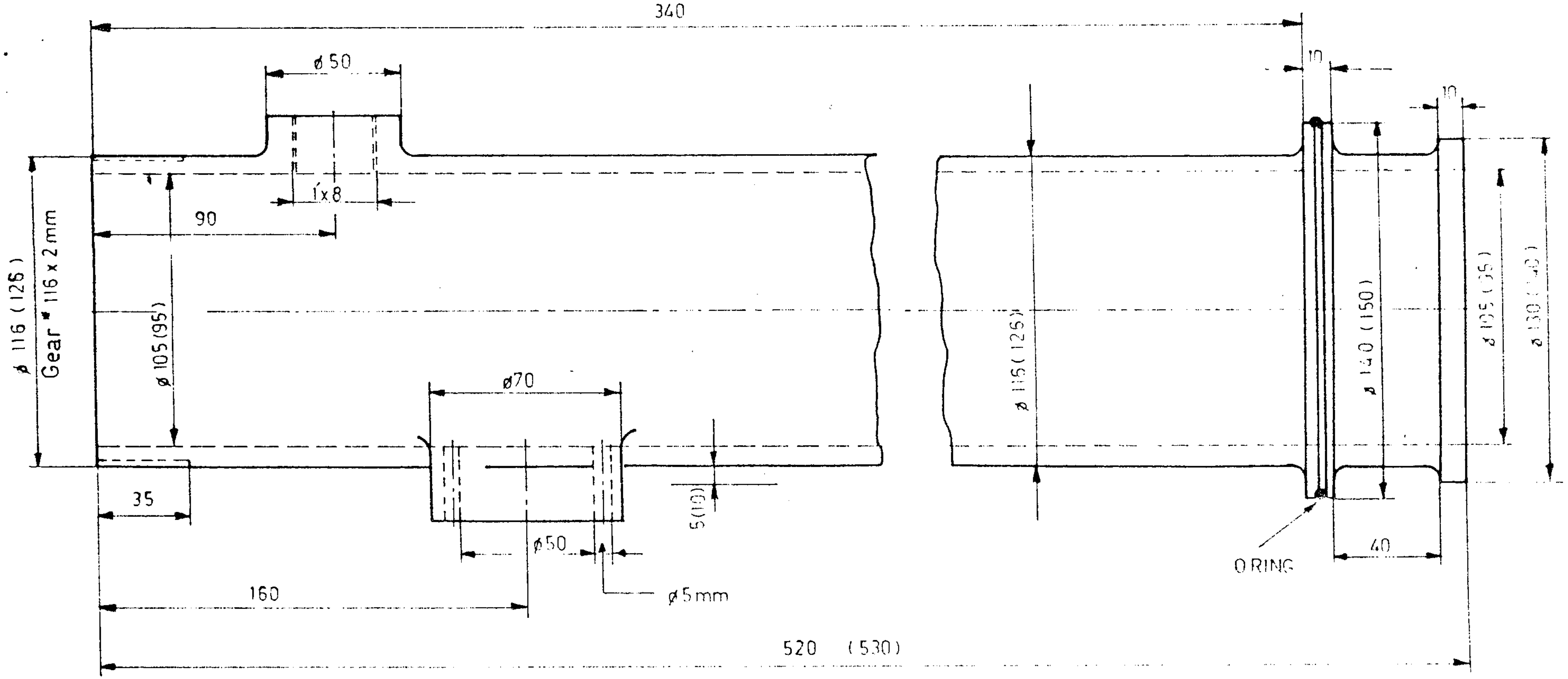


Figure 6.1 The drying chamber
Scale 1/2

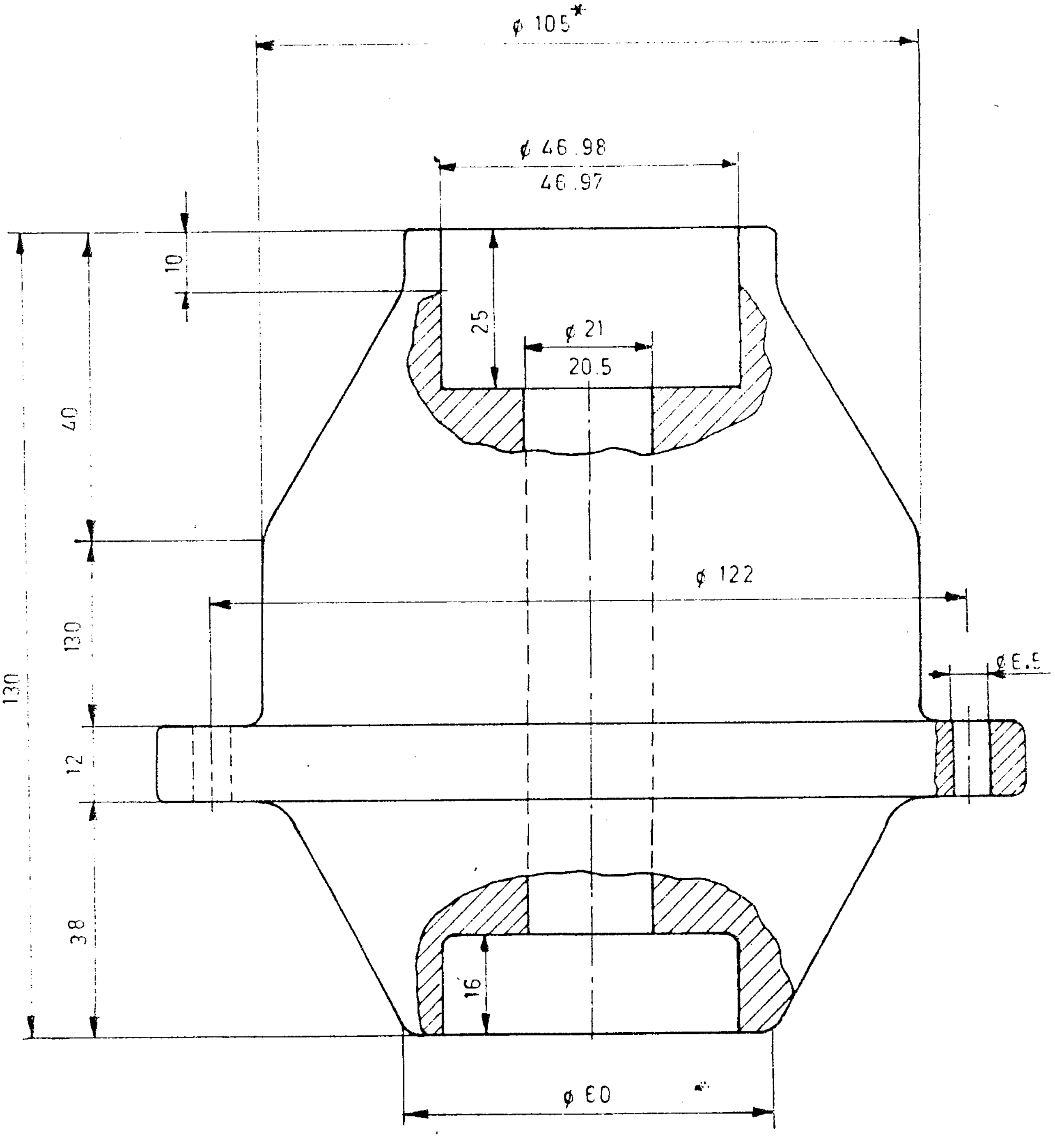


Figure 6.2 The bearing conveyor
Scale : 1/1

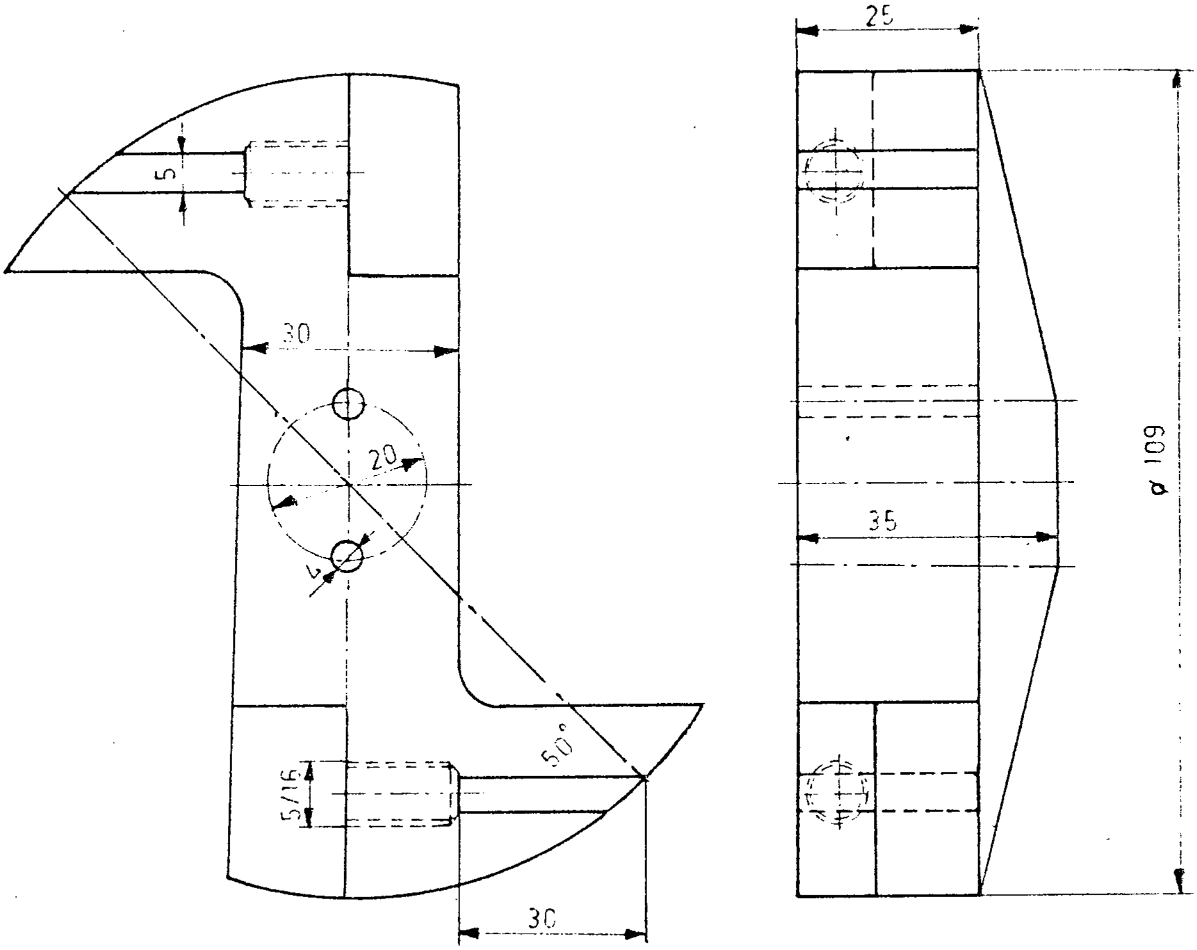


Figure 6.4 The lower scraper bearing

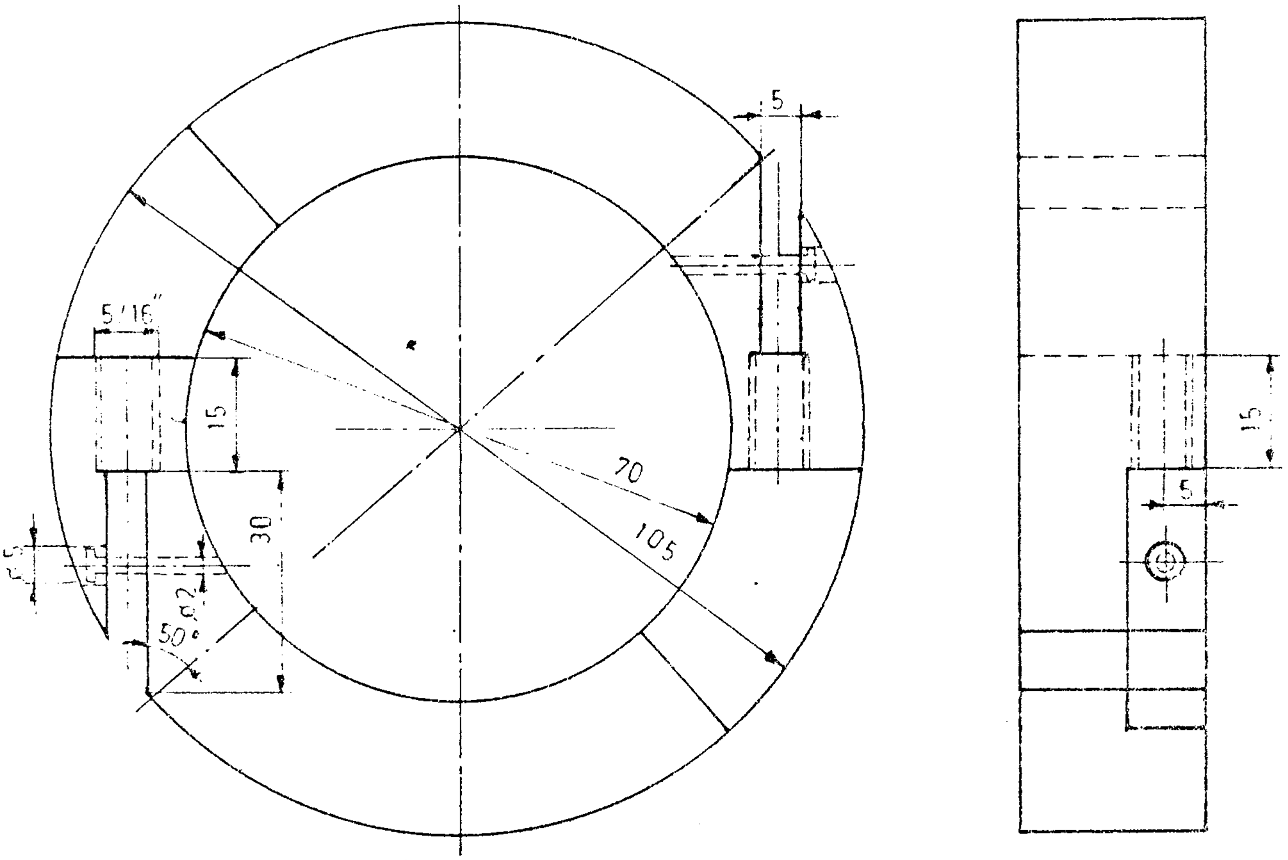


Figure 6.5 The upper conveyer bearing

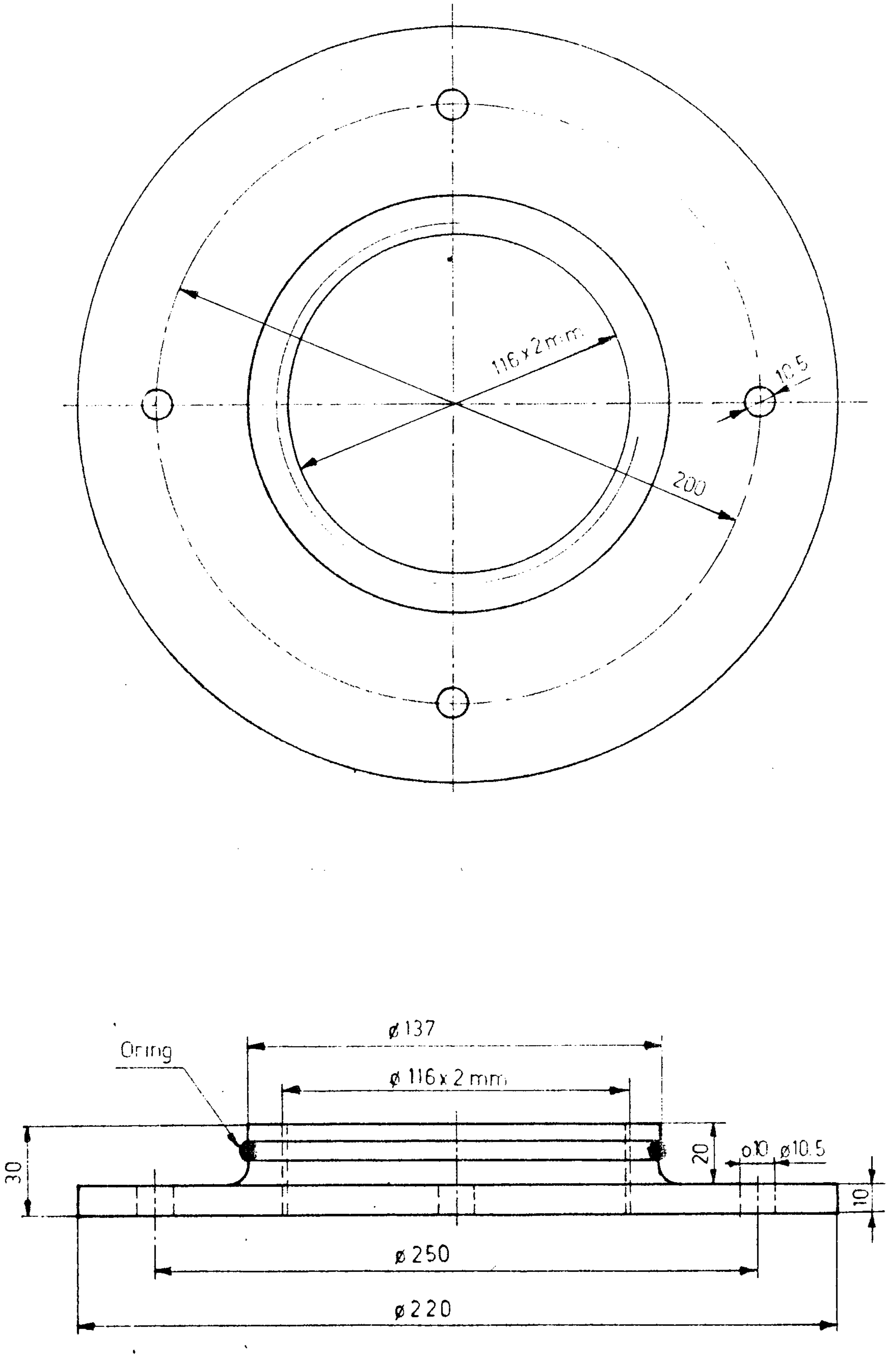


Figure 6.3 The lower bearing

To the lower end of the shaft between two blades on the lower scraper bearing a perforated plate was placed. This is to form a fluidized bed of the scraped powder for further drying and to prevent them from falling down to the bottom of the drying chamber.

Also at the bottom end of the drying chamber body, 12.52 mm diameter hole was made which enabled the introduction of cold air through the fluidized bed and by circulating inside the drying chamber reduced the temperature of spray dried powder.

6.3 Material and Methods

Samples of 28-30 % wt solids commercial tomato paste were received from Demko Gıda Sanayii A.Ş. The adjustment of dilution was made as in previous studies in Chapter 3. Since excluding the spray drying chamber, the other facilities of the Büchi spray dryer were kept unchanged, the procedure used for adjustment of the rates was identical to that given in Chapter 5.

6.4 Results

As described in the previous sections, the experimental procedure was carried out according to five subsequent parameters;the effect of inlet air temperature, additive concentrations, air flow rate through the nozzle, the feed rate of tomato paste and direct cooling of the drying chamber were practiced. The data obtained from the studies of these parameters on the yield were evaluated as follows :

i. Effect of temperature related with additives

The experimental findings under constant feed rate, type of additives, air flow rate through the nozzle and drying chamber are

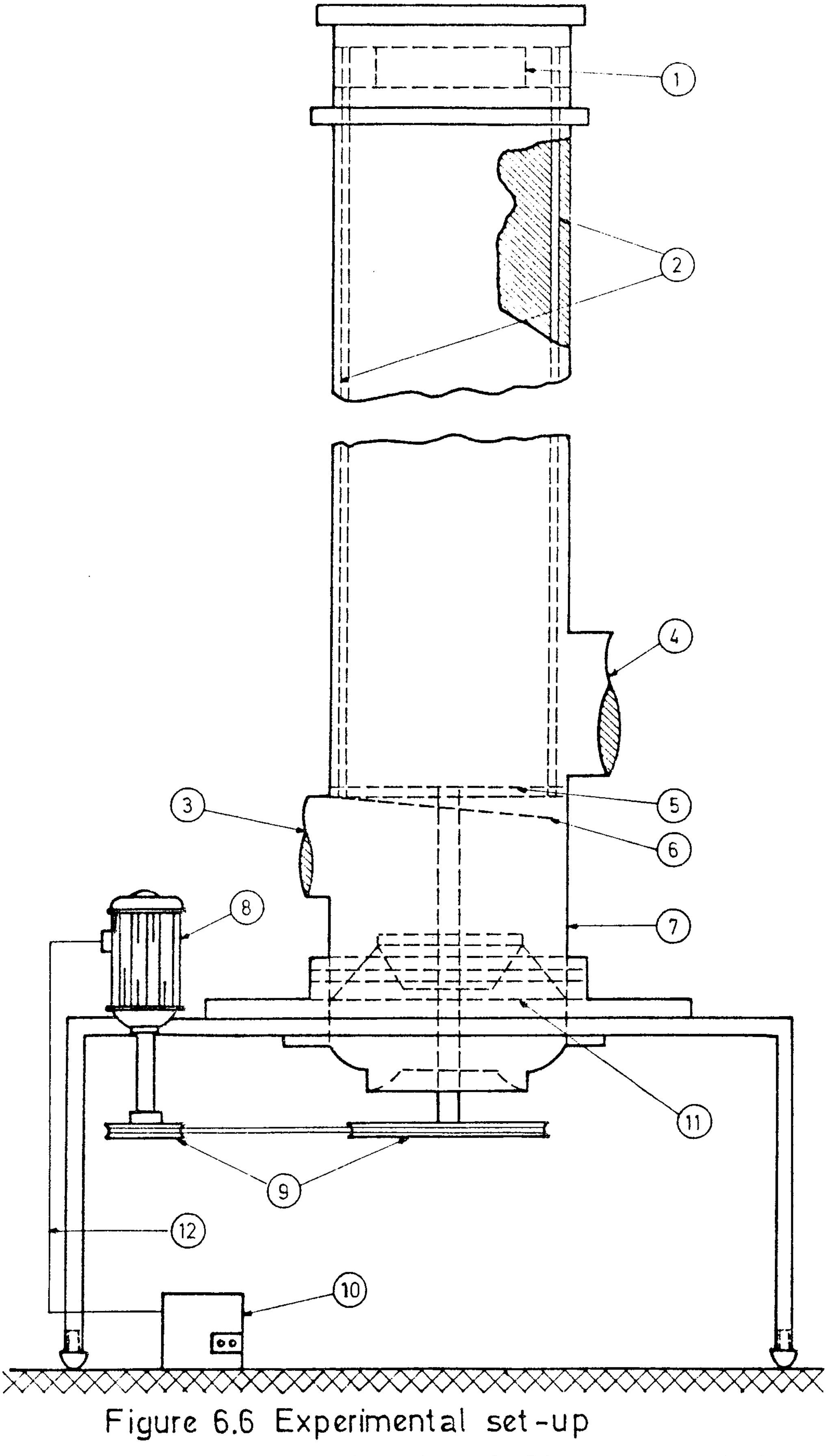


Figure 6.6 Experimental set-up

1_The upper conveyor bearing 2_The scraper knives 3_Cooling air inlet 4_Connection line to cyclone 5_The lower scraper bearing 6_Fluidized bed 7_Drying chamber body 8_Motor 9_Speed connection system 10_Speed controller, adjusment electrical panel 11_The lower bearing 12_Electrical cable connection.

shown in Fig. 6.7. As a general trend it was observed that as the temperature of the inlet air into the drying chamber was increased, the yield was reduced. The yield which was 17.0 % at 150^{o}C was observed to increase gradually as temperature is reduced and at 115^{o}C, the maximum yield of 51.0 % was obtained with the mixture of additives as 1.5 % TS CMC and 2 % TS NaCl.

When the amount of NaCl in additive mixture was kept constant and that of CMC was reduced from 1.5 % TS to 0.5 % TS, it was noticed that the yield did not show a parallel trend to the previous run. However again at 115^{o}C, the maximum yield was observed corresponding to 40.9 %.

ii. Effect of air flow rate

The conditions giving the above maximum yield as 40.9 % was considered as a reference for further investigations. This condition was applied to different air flow rates through the nozzle, drying temperatures and with and without additives as shown in Fig. 6.8. It was observed that the yield reduced as the air flow rate through the nozzle was reduced and air inlet through drying chamber increased. The maximum yield obtained at 115^{o}C was 51.7 % with 600 lt/h air flow rate through nozzle and the minimum yield obtained at 140^{o}C was 16.0 % with 400 lt/h air flow rate through the nozzle. It was noticed that the addition of additives and the amount of air flow rate through nozzle were more effective on the yield than wtihout additives.

From the results indicated, it can be concluded that the yield gradually reduced as the amount of mixture of additives of C.M.C. was reduced and the air inlet temperature was increased to above 115^{o}C.

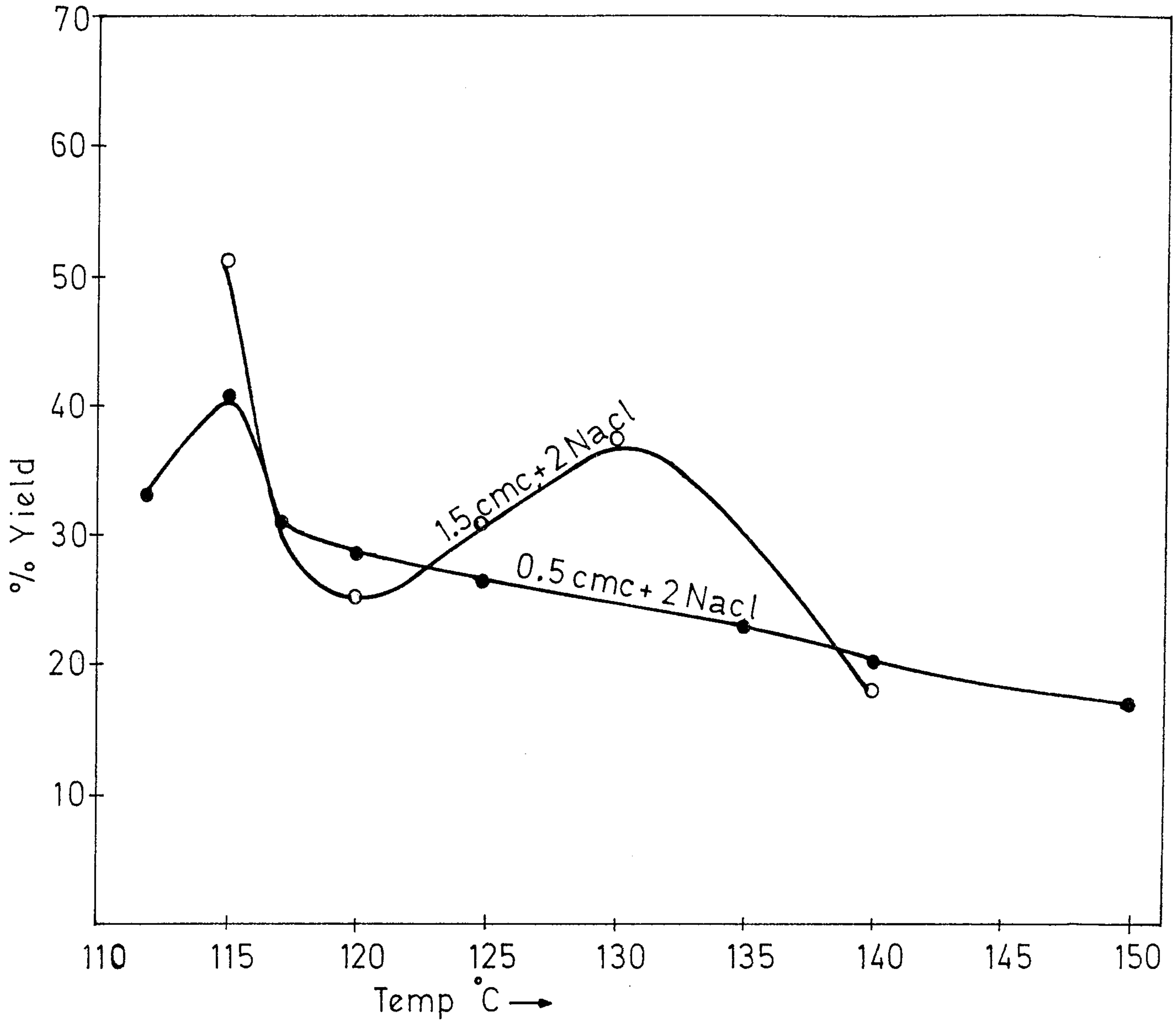


Figure 6.7 Yield of product related with temp. and additives at 12 rpm scraper speed, Air flow rate through nozzle 700 lt/h and 24 m^3/h drying chamber , Feed rate 2.5 ml/min.

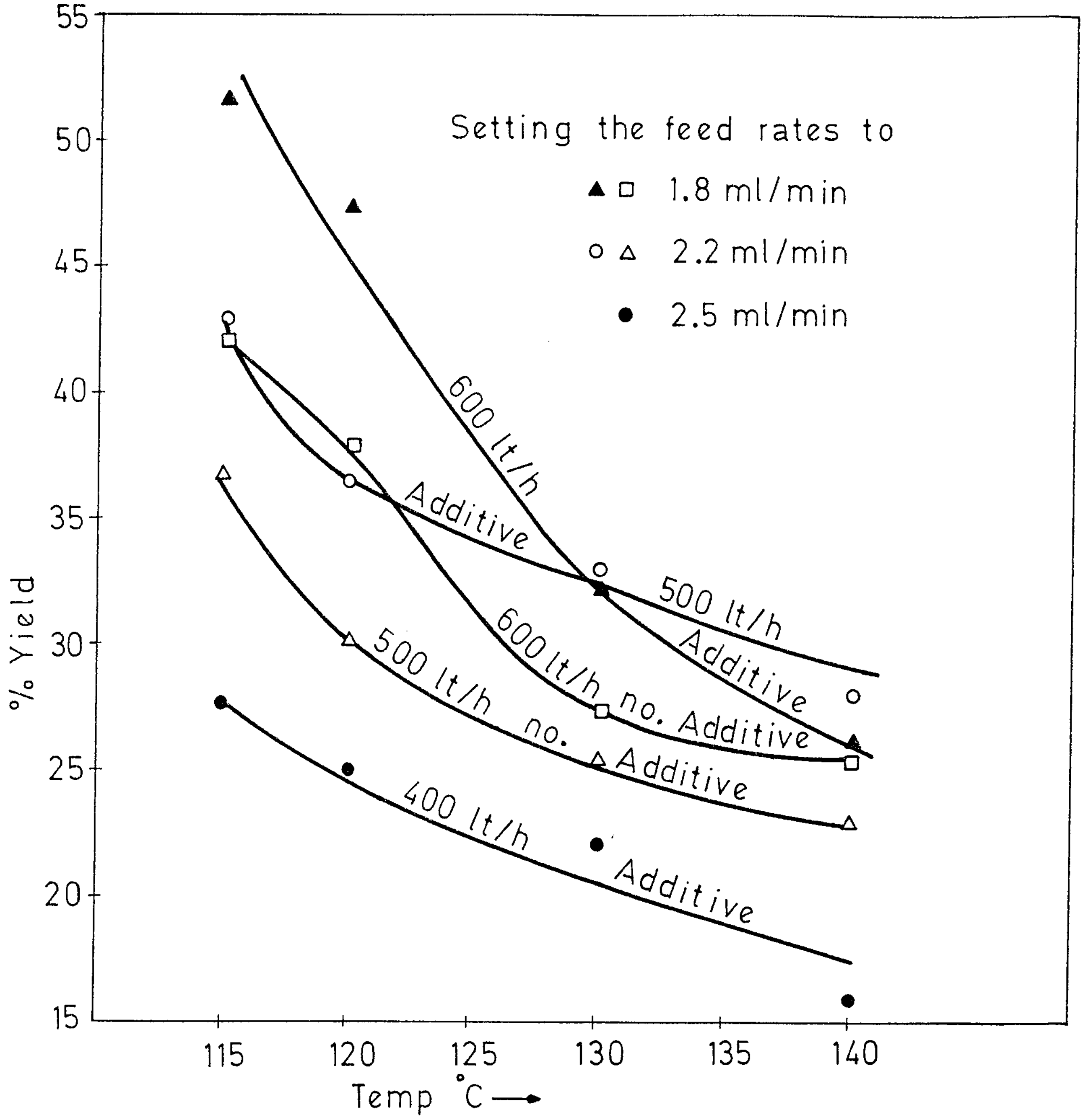


Figure 6.8 Yield of product related with air flow rate through nozzle and feed rate, Experimental conditions ; 24 m^3/h air flow rate through drying chamber, additives 1.5 % TS CMC + 2 % TS NaCl , no additive ; scraper speed 12 rpm tomato paste 15 Brix.

iii. Effect of additive composition

Concerning the effectiveness of the composition of the additive on the yield at constant drying temperature, speed of scraper and air flow rate through nozzle is shown in Fig. 6.9.

It was noticed that when NaCl was kept constant and C.M.C. was reduced from 1.5 % TS to 1 % TS the yield increased from 42.0 % to 70.25 %.Upon increasing the amount of salt from 1 % TS to 2 % TS and keeping C.M.C. constant as 1.5 % TS, the yield was observed to increase to 67.38 %. Furthermore when the amount of salt was increased from 2 % TS to 2.5 % TS, 3 % TS and 3.5 % TS gradually and the amount of CMC was kept constant, the yield was observed to reduce from 67.38 % to 46.61 %, 36.5 % and 40.90 % respectively.

Experiments were carried out with the addition of corn starch (CS) at variable total solid basis with constant mixture of 1 % TS NaCl, 1 % TS CMC under the same conditions as the previous work. The yield of runs are shown in Fig. 6.9. It was observed that on dry basis the addition of 0.25 percent CS, to the feed was not so effective on the yield and reduced the outcome from 70.25 % to 67.38 %. However, with it was raised to 0.5% a maximum in yield was observed at 71.12% successive increments of CS up to 1.5% TS indicated a gradual reduction in yield.

iv. Effect of temperature on maximum yield

In this section the effect of temperature on the maximum yield which was obtained from the previous run was investigated as shown in Fig. 6.10.

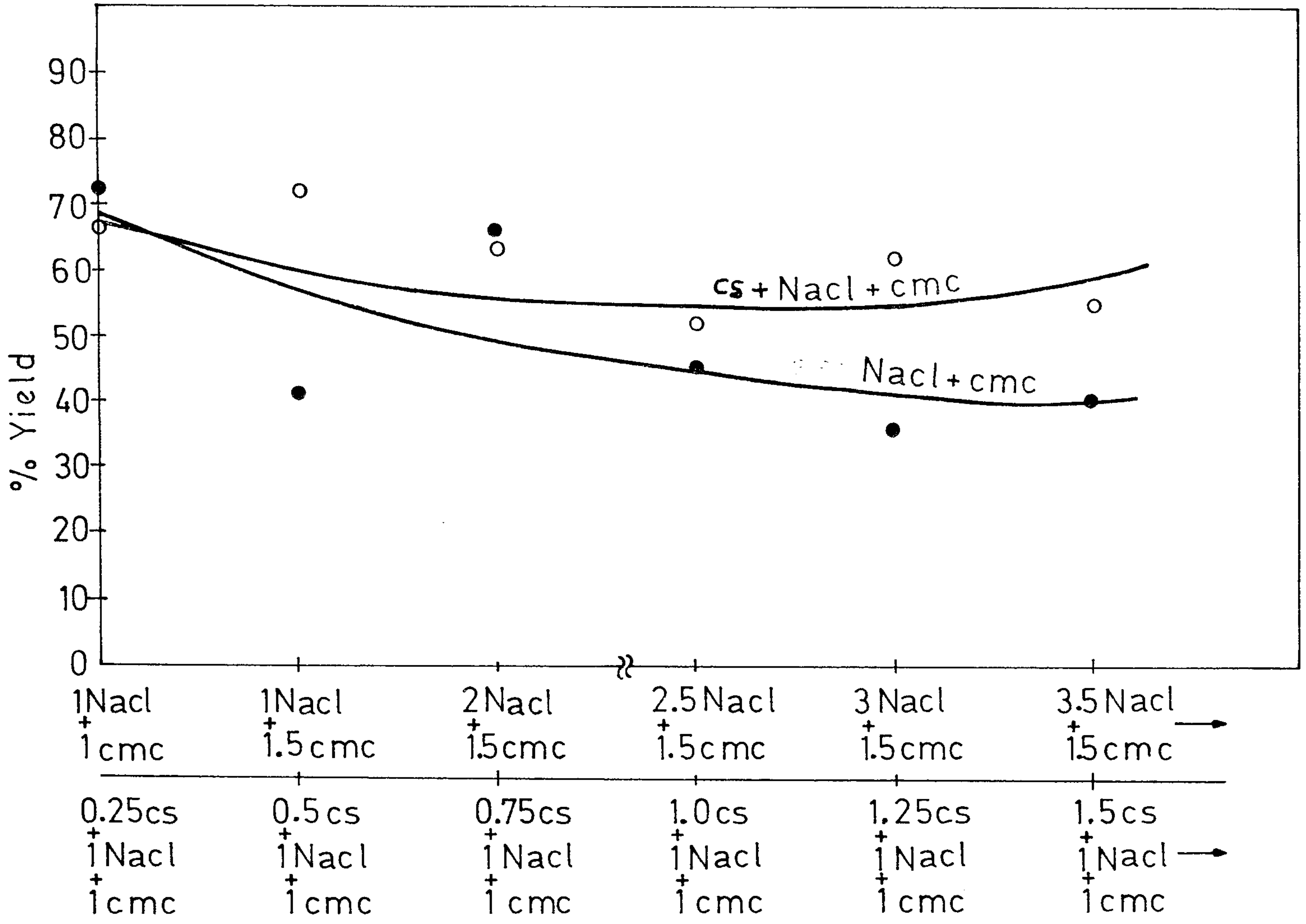


Figure 6.9 Yield related with additives, air flow rate through nozzle 700 lt/h and drying chamber 24 m^3/h, feed rate 1.8 ml/min, speed of scraper 12 rpm at 115^{0}C drying temperature.

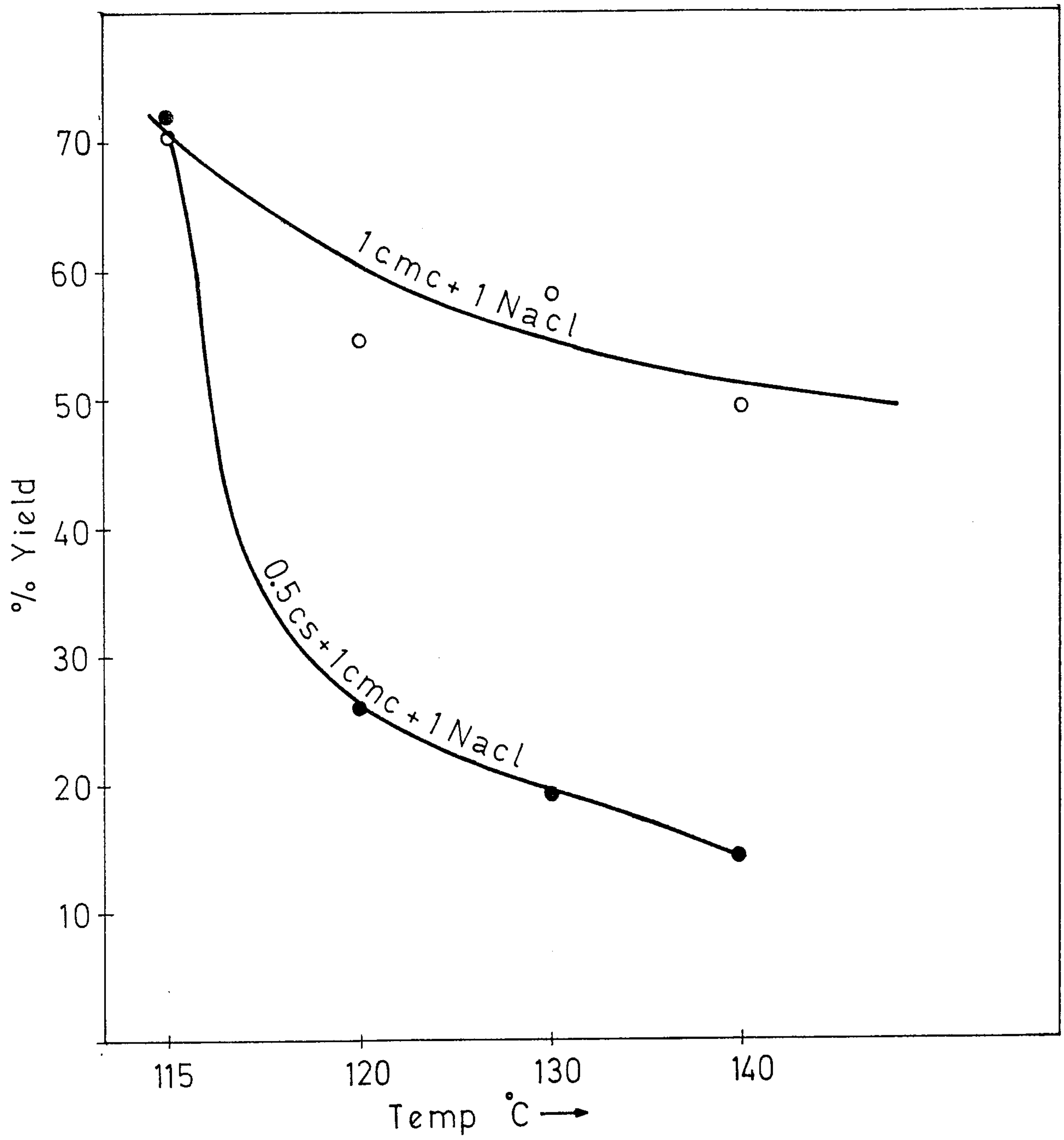


Figure 6.10 Yield related with temperature, Experimental conditions, Feed rate 1.8 ml/min , Air flow rate through nozzle 700 lt/h and Drying chamber 24 m^3/h speed of scraper 12 rpm.

As the temperature of inlet air was increased the yield was reduced for both cases of 1 % TS CMC, 1 % TS NaCl and 0.5 % TS CS, 1 % TS CMC, 1 % TS NaCl additive mixtures. The reduction in the yield was more apparent when corn starch was used as compared to NaCl + CMC only. For example, at 115°C the initial yield for both cases were observed to be 70.25 % and 71.25 % whereas at 140°C the yields were 14.5% and 49.2 % respectively.

v. Effect of scraper speed on yield

Finally the effectiveness of the scraper speed on yield was investigated. The additive mixture (0.5 % TS CS, 1 % TS NaCl, 1 % TS CMC), temperature (at 115°C), feed rate , air flow rate and air flow through the nozzle were kept constant as shown in Fig. 6.11. Generally as the speed of scraper was increased above 12 rpm, the yield decreased. At 18 rpm , 24 rpm, 30 rpm, and 36 rpm scraper speeds the yields were found out to be 64.75 %, 55.15 %, 51.48 % and 40.76 % respectively. When the speed of scraper was reduced to 11 rpm, 10 rpm, 9 rpm, 8 rpm, 7 rpm and 6 rpm the yields obtained were 69.28 %, 76.98 % 69.88 rpm, 65.11 %, 66.87 % and 66.87 % correspondingly as shown in Fig. 6.11. Furthermore at low speeds 6-8 rpm a significant contribution was not observed.

vi. Effect of direct cooling

Under the same conditions as above when the outlet temperature was reduced from 61°C to 55°C on the grounds that more cooling air was sent, the yield was observed to reduce from 71.12 % to 43.90 % run no 11-10 in Appendix B.

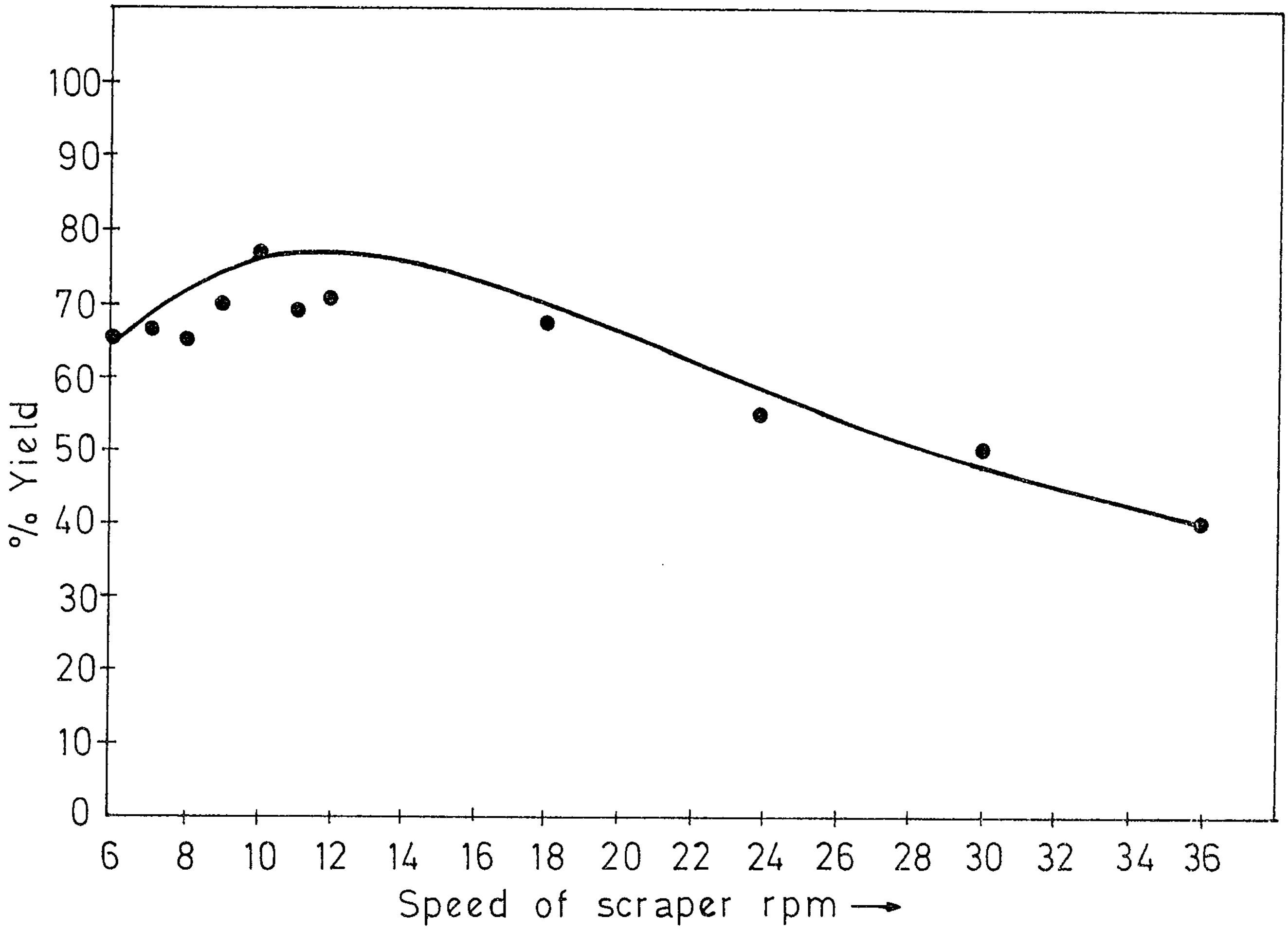


Figure 6.11 Yield related with speed of scraper, feed rate 1.8 ml/min Air flow rate 24 m^3/h and through nozzle 700 lt/h at 115°C.

6.5 Discussion

Serious drying problems are encountered during spray drying of tomato paste because of the thermoplastic and hygroscopic properties of the powder whose solids are predominantly low melting sugars. Lazar and Rumsey [78] . Many researchers have been investigating spray drying tomato paste and many patents in literature describe various types of cooling wall chamber for preventing wall deposition of tomato powder during spray drying, Lazar [31] , Karl et. al. [32] , Christensen [23][77] , Utag [33] , Pryzbla [29] , Masters [18] , Dr. Madis Lab. [84] and Swientek [83] . But it is still questionable whether such an equipment could perform well with thermoplastic and hygroscopic property of tomato powder to avoid the wall deposition, Goose [3] . Therefore it was tried to design a scraped type of drying chamber which can scrape dried tomato powder from the chamber wall in order to avoid wall deposition during spray drying. There is an obvious lack of information in the literature on the scraped type of drying chamber. However there have been big advances in the design of scraper type of drying chamber in order to overcome the difficulties mentioned for the spray drying chambers as given in chapter 2. section 2.8.

In accordance with the points mentioned above, a scraped surface drying chamber was designed to improve the yield on the combined efects of temperature, additive, speed of scraper in the drying chamber and air flow rate through the nozzle.

In the light of the evidence obtained from these results the following discussions can be made.

When the additives, feeding rate and air flow rate through nozzle were kept constant and the air inlet temperature was increased above 115^{o}C, the yield was observed to be decreasing as shown in Figs. 6.7, 6.8 and 6.10. This may be due to thermoplasticty of tomato powder which was effected by wall temperature, Lazar [31] , Christensen [23] , Masters [8]and Dr. Madis Lab. [84] . As the temperature increased the removal of moisture from the droplet became more difficult as explained in detail in Chapter 5.

When the feed was kept constant and amount of CMC as additive aid was increased from 0.5 % TS to 1.5 % TS at the same conditions of drying, the yield of product which was obtained up to 51.0 % at 115^{o}C was more promising as shown in Fig. 6.7. Salt and CMC were widely used as drying aids because of the ease of reconstitution in water. CMC prevented the wall deposition during spray drying which was recommended in range of 0.05-2.5 % TS by Krumel and Sarker [81] . The salt reacted with pectic acid which also caused stickiness of the powder during drying Perech [75] . Low concentration of 0.5 % TS CMC was not so effective to prevent the wall deposition as 1.5 % TS during spray drying tomato paste. The use of additives was more effective to prevent wall deposition during spray drying of tomato paste which is in agreement with other findings [31] [32] [8] [35] .

Moreover, when some runs were carried out with and without additives at constant speed of scraper at 12 rpm and air flow rate through nozzle 600 lt/h and 500 lt/h as shown in Fig. 6.8. it was observed that presence of additives was more promising on the yield than without additives although the overall yield was still not at an acceptable value. The yield of product was observed to reduce when the air inlet temperature was increased in accordance with the previous experimental runs. This fact is again a consequence of the conclusion achieved in Chapter 4.

As the air inlet temperature increased, the yield was reduced correspondingly. From this point, it can be inferred that the wall deposition at high temperatures may also be associated with the thermoplastic property of powder at high temperature of chamber wall Goose [3] , Lazar [31] , Rizvi and Benado [11] .

Furthermore as the air flow rate through the nozzle was reduced from 700 lt/h to 400 lt/h with the same amount of additives and feed rate as was used in the previous experiment, the yield was as well reduced even both at low air flow rate through the nozzle and at high temperatures above 115°C of the air inlet of the drying chamber Fig. 6.8. It is more likely that the deposition on the chamber wall is associated with non-uniform atomization, Spraco Lechler Comp. [19] and Christensen [23][77] .

Increasing the amount of air rate through nozzle from 600 lt/h to 700 lt/h may give more uniform atomization due to smaller droplets [19] [16] . Similarly, combined effect of the reduction of the feed rate and increasing the amount of air rate through nozzle also gives more uniform atomization and therefore the movement of moisture from sprayed droplet becomes more uniformly distributed in the drying chamber, Crawe [21] , Bruin and Luyben [79] and Christensen [77] . A combination of (1.0 % TS) NaCl and (1 % TS) CMC and 0.25 % CS was found to be most effective in reducing the thermoplastic and hygroscopic property of the material when scraper was used as indicated in Figs. 6.9. Meanwhile, it was further observed that, when CMC and NaCl in the mix was increased, the yield decreases at 115°C.

Most of the wall deposition were observed to be around the nozzle, that is, at the top of the drying chamber just below the nozzle. However, no wall depositions were seen on the other side of the drying chamber. The wall deposition on the top of the chamber might be due to the shape of the drying chamber which was cylindrical. Because of the stickiness of the tomato powder, the droplets coming out of the nozzle struck the chamber wall at a high speed before starting to dry and thus may have caused wall deposition which was very difficult to scrape from the surface of the drying chamber. Occasionally, uneven scraping occured due to the collection of wall deposition at the top of the chamber wall.

Furthermore at high temperatures, the operation of the scraper became difficult and even stopped because of the thermoplastic and stickiness properties of the powder Fig. 6.10. The same problem was reported during drum drying of the tomato paste, Heigh [28] , Lazar and Rumsey [78] . It is more likely that the major reason for this problem was the cylindrical shape of the drying chamber. It can be inferred that the said problem can be overcome by employing a drying chamber which should be conical in shape rather than cylindrical. As our system was based on Buchi type 190, it was not possible to have a further modification on the design. However, when the scraper type of drying chamber is compared with other spray dryers Lazar [31] , Utag [33] , Christensen [23] [77] , Masters [8] , Dr. Madis Lab. [84] , Karl et.al. [32] and Pryzbla [29] , an important advantage of our drying chamber exists. That is, because the dried particles were scraped from the surface of the drying chamber wall, the accumulation of particles sticking on each other and burning is avoided. As known, when particles are exposed to hot air for a long time, they are apt to lose their Vitamin C and colour as explained in Chapters 3 and 5. which is easily prevented by using a scraper in the drying chamber like the one being constructed for this work. Also, in cool wall techniques the humidity in the breaking and falling 2.5 cm layer was about 10-13 %. Thus, in addition to cool wall chamber, a fluidized bed and milling sections were used in order to reduce moisture from 10-12 % to 3-5 % for spray dryed tomato paste. However, these are not needed with our scraped type of chamber and thus spray drying of tomato paste seems to be more economical and less complex.

With our chamber the optimum results were obtained on the grounds when the spray drying temperature was 115°C and the outlet temperature was 61°C. Although the outlet temperature was in very good agreement with the recommendations [31] [32] [33] and[[23] , the air inlet temperature in our drying chamber was higher than the specially designed drying chamber of Birs tower and lower than that of "cool wall" chamber, The drying temperature of 115°C produced a 4 % moisture content powder enough to cause inactivation of microorganisms which cause the spoilage of tomato powder during storage, Nickerson and Sinskey [13], Brock [12] and Frazer and Westhoff [15].

Finally, when the speed of the scraper was changed, its effectiveness on the yield was investigated and it was observed that at a speed of scraper above 12 rpm the apparent yield was reduced. Optimum result was obtained when the speed of the scraper was lower than 12 rpm such as 10 rpm with additive of 0.5 % TS CS, 1 % TS CMC and 1 % TS NaCl, as shown in Fig. 6.11. It is believed that at higher speeds of the scraper smaller particles are obtained from the chamber wall which could not be held by the cyclone of the Buchi model-190. Even the exhauster fan was stuck from time to time at high speeds of the scraper above 12 rpm due to these uncaptured particles. On the other hand, at lower speeds of the scraper below 10 rpm relatively larger particles were scraped from the chamber wall which could easily stick on one another because of the increased scraping interval. The cooling air which was not sufficient to cool these particles caused them to stick on the surface of the cyclone. The same problem was observed during drum drying of tomato paste by Lazar and Rumsey [78] and Heigh [28] who found out that a thin layer was formed at high speed of drum dryer and that a thick layer was formed at low speed of drum dryer. Although the apparent yield at optimum conditions is about 80 %, it can be claimed that with an improved collection system this figure can be easily increased to above 90 %.

6.6 Conclusion

The spray drying of tomato paste is one of the most difficult processes due to the thermoplastic and sticky character of tomato powder as reported. The suggested scraped surface spray dryer design enables the use of smaller dimensions for spray drying of such materials with acceptable results.

It can be stated that very favorable results are obtained when a Buchi-190 model spray drier was modified to a scraped type of drying chamber at 115°C air inlet and 61°C air outlet temperatures with the additions of 1 % TS CMC, 1 % TS NaCl and % TS 0.5 CS which is compatible with those reported by various investigators.

Advantages of using scraper type of drying chamber is that the dried particles could be scraped down from the chamber wall without delay before they accumulate on one another and thus the burning on of the particles will be prevented. Furthermore, the presence of a fluidized bed in the drying chamber prevents the scraped, big particles from falling down to the bottom of the drying chamber where additional cooling takes place.

RECOMMENDATION

For future work it will be interesting to investigate the effect of air humiditiy on the drying rates of droplet and on the related diffusivity. Moreover a pilot scale scraped surface drying chamber which is conical in shape and will enable spray drying of the tomato paste at high concentrations is believed to be of practical importance, together with an improved particle collection system.

Finally, the storage stability of the tomato powder so obtained should be investigated taking into consideration the packaging conditions.

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LIST OF REFERENCES

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APPENDICES

APPENDIX A

TABLE Calibration data for air flowrate

rotameter scale	volumetric air rate (ml/s)
2	0.512
3	1.082
4	1.860
5	3.410
6	4.390
7	6.000
8	7.640
9	9.830
10	11.900

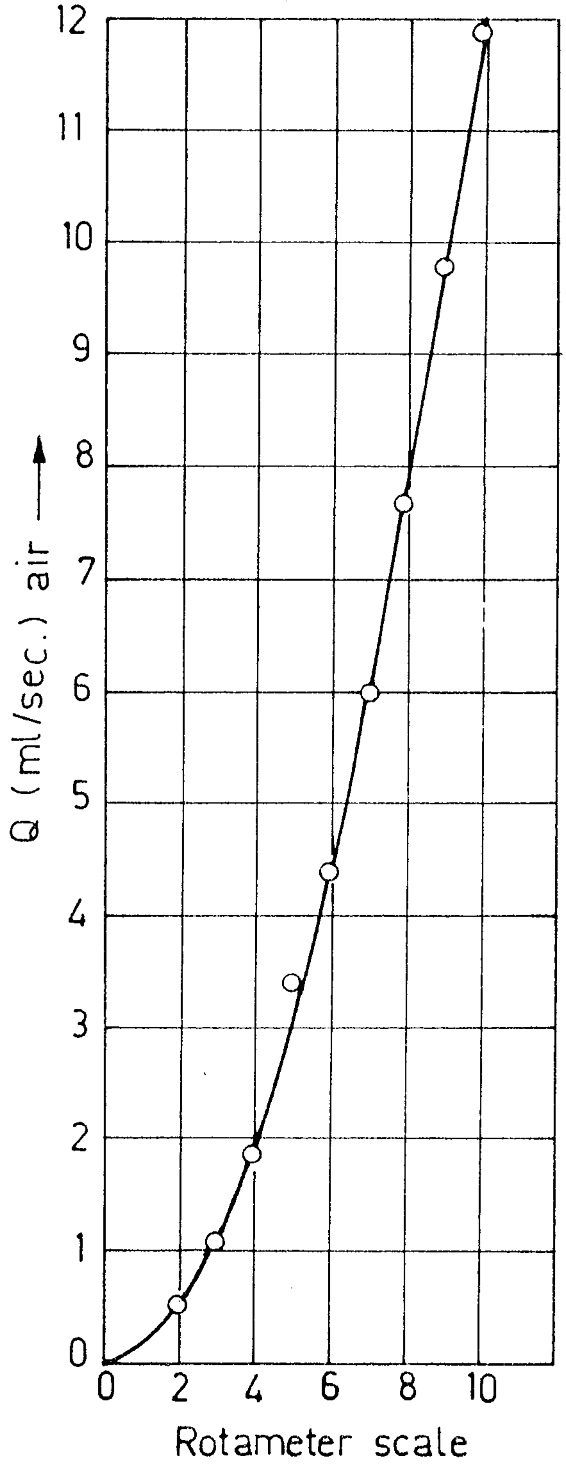

Figure : 4.1

Calibration curve for rotameter

Table.A.1.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 105°C and 60°C,
U_s:11.90 ml/s, H_s: 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta\theta}$	$\frac{\Delta X}{\Delta\theta . S}$
0.0	5.2	0.26	4.94	19.00	-	-
0.5	4.8	0.26	4.54	17.46	0.80	3.07
1.0	4.3	0.26	4.04	15.53	1.00	3.84
1.5	3.5	0.26	3.24	12.46	1.60	6.15
2.0	3.1	0.26	2.84	10.92	0.80	3.07
2.5	2.4	0.26	2.14	8.23	1.40	5.38
3.0	2.0	0.26	1.74	6.69	0.80	3.07
3.5	1.7	0.26	1.44	5.53	0.60	2.30
4.0	1.3	0.26	1.04	4.00	0.80	3.07
4.5	1.2	0.26	0.94	3.61	0.20	0.76
5.0	0.8	0.26	0.54	2.07	0.80	3.07
5.5	0.8	0.26	0.54	2.07	0.00	0.00
6.0	0.8	0.26	0.54	2.07	0.00	0.00
6.5	0.8	0.26	0.54	2.07	0.00	0.00
7.0	0.6	0.26	0.34	1.30	0.40	1.52
8.0	0.6	0.26	0.34	1.30	0.00	0.00
9.0	0.6	0.26	0.34	1.30	0.00	0.00
10.0	0.6	0.26	0.34	1.30	0.00	0.00

Table.A.2. The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 115°C and 70°C ,
U_s:11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta\theta}$	$\frac{\Delta X}{\Delta\theta . S}$
0.0	5.2	0.26	4.94	19.0	-	-
0.5	4.9	0.26	4.64	17.84	0.60	2.30
1.0	4.5	0.26	4.24	16.30	0.80	3.07
1.5	4.1	0.26	3.84	14.76	0.80	3.07
2.0	3.6	0.26	3.34	12.84	1.00	3.84
2.5	3.0	0.26	2.74	10.53	1.20	4.61
3.0	3.0	0.26	2.74	10.53	0.00	0.00
3.5	2.0	0.26	1.74	6.69	2.00	7.69
4.0	1.9	0.26	1.64	6.30	0.20	0.76
4.5	1.3	0.26	1.04	4.00	1.20	4.61
5.0	0.8	0.26	0.54	2.07	1.00	3.84
5.5	0.8	0.26	0.54	2.07	0.00	0.00
6.0	0.6	0.26	0.34	1.30	0.40	1.52
6.5	0.5	0.26	0.24	0.92	0.20	0.76
7.0	0.3	0.26	0.04	0.15	0.40	1.52
7.5	0.3	0.26	0.04	0.15	0.00	0.00
8.0	0.3	0.26	0.04	0.15	0.00	0.00

Table.A,3.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 125°C and 75°C,
U_S:11.90 ml/s , H_S : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.3	0.215	4.085	19.00	-	-
0.25	3.9	0.215	3.685	17.10	1.60	7.44
0.50	3.2	0.215	2.985	13.88	2.80	13.00
0.75	3.0	0.215	2.785	12.95	0.80	3.72
1.00	2.1	0.215	1.885	8.76	3.60	16.74
1.25	2.1	0.215	1.885	8.76	0.00	0.00
1.50	1.6	0.215	1.385	6.44	2.00	9.30
1.75	1.6	0.215	1.385	6.44	0.00	0.00
2.00	0.7	0.215	0.485	2.25	3.60	16.74
2.25	0.7	0.215	0.485	2.25	0.00	0.00
2.50	0.5	0.215	0.285	1.32	0.80	3.72
2.75	0.4	0.215	0.185	0.39	0.80	3.72
3.00	0.3	0.215	0.085	0.39	0.37	1.72
3.25	0.3	0.215	0.00	0.00	0.37	1.72

Table.A.4.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 135°C and 80°C ,
U_S:11.90 ml/s , H_S : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	2.6	0.13	2.47	19.00	-	-
0.25	2.3	0.13	2.17	16.69	1.20	9.23
0.50	2.0	0.13	1.87	14.38	1.20	9.23
0.75	1.5	0.13	1.37	15.38	2.00	15.38
1.00	1.2	0.13	1.07	8.23	1.20	9.23
1.25	0.9	0.13	0.77	5.92	1.20	9.23
1.50	0.5	0.13	0.37	2.84	1.60	12.30
1.75	0.5	0.13	0.37	2.84	0.00	0.00
2.00	0.3	0.13	0.17	1.30	0.80	6.15
2.25	0.2	0.13	0.07	0.53	0.40	3.07
2.50	0.1	0.13	0.00	0.00	0.28	2.15

Table.A.5.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 160^{o}C and 100^{o}C,
U_S : 11.90 ml/s , H_S : 20^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	3.5	0.175	3.325	19.00	-	-
0.25	3.4	0.175	3.225	18.42	0.40	2.28
0.50	3.2	0.175	3.025	17.28	0.80	4.56
0.75	2.7	0.175	2.525	14.42	2.00	11.42
1.00	2.2	0.175	2.025	11.57	2.00	11.42
1.25	1.8	0.175	1.625	9.28	1.60	9.14
1.50	1.3	0.175	1.125	6.42	2.00	11.42
1.75	1.3	0.175	1.125	6.42	0.00	0.00
2.00	0.9	0.175	0.725	4.14	1.60	9.14
2.25	0.4	0.175	0.225	1.28	2.00	11.42
2.50	0.3	0.175	0.125	0.71	0.40	2.28
2.75	0.3	0.175	0.125	0.71	0.00	0.00
3.00	0.3	0.175	0.125	0.71	0.00	0.00
3.50	0.3	0.175	0.125	0.71	0.00	0.00
4.00	0.3	0.175	0.125	0.71	0.00	0.00

Table.A.6. The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 105^{o}C and 60^{o}C,
U_S:11.90 ml/s , H_S : 20^{o}C

Q(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta Q}$	$\frac{\Delta X}{\Delta Q . S}$
0.00	5.1	0.51	4.59	9.00	-	-
0.25	4.9	0.51	4.39	8.60	0.80	1.56
0.50	4.8	0.51	4.29	8.41	0.40	0.78
0.75	4.7	0.51	4.19	8.21	0.40	0.78
1.00	4.6	0.51	4.09	8.01	0.40	0.78
1.25	4.6	0.51	4.09	8.01	0.00	0.00
1.50	4.6	0.51	4.09	8.01	0.00	0.00
1.75	4.6	0.51	4.09	8.01	0.00	0.00
2.00	4.6	0.51	4.09	8.01	0.00	0.00
2.25	4.5	0.51	3.99	7.82	0.40	0.78
2.50	4.4	0.51	3.89	7.62	0.40	0.78
3.00	4.3	0.51	3.79	7.43	0.20	0.39
3.50	4.3	0.51	3.79	7.43	0.00	0.00
4.00	4.2	0.51	3.69	7.23	0.20	0.39
4.50	3.8	0.51	3.29	6.45	0.80	1.56
5.00	3.6	0.51	3.09	6.05	0.40	0.78
5.50	3.6	0.51	3.09	6.05	0.00	0.00
6.00	3.2	0.51	2.69	5.27	1.00	1.96
6.50	3.2	0.51	2.69	5.27	0.00	0.00
7.00	3.1	0.51	2.59	5.27	0.20	0.39
7.50	2.9	0.51	2.39	4.68	0.40	0.78
8.00	2.5	0.51	1.99	3.90	0.80	1.56
8.50	2.0	0.51	1.49	2.92	1.00	1.96
9.00	2.0	0.51	1.49	2.92	0.00	0.00
10.00	2.0	0.51	1.49	2.92	0.00	0.00

Table.A.7.The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 115°C and 70°C,
U_S : 11.90 ml/s , H_S : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.0	0.4	3.6	9.00	-	-
0.25	3.7	0.4	3.3	8.25	1.20	3.00
0.50	3.1	0.4	2.7	6.75	2.40	6.00
0.75	2.8	0.4	2.4	6.00	1.20	3.00
1.00	2.5	0.4	2.1	5.25	1.20	3.00
1.25	2.5	0.4	2.1	5.25	0.00	0.00
1.50	2.2	0.4	1.8	4.50	1.20	3.00
1.75	2.2	0.4	1.8	4.50	0.00	0.00
2.00	1.8	0.4	1.4	3.50	1.60	4.00
2.50	1.5	0.4	1.1	2.75	0.60	1.50
3.00	1.4	0.4	1.0	2.50	0.30	0.50
3.50	0.9	0.4	0.5	1.25	1.00	2.50
4.00	0.9	0.4	0.5	1.25	0.00	0.00
4.50	0.7	0.4	0.3	0.75	0.40	1.00
5.00	0.6	0.4	0.2	0.50	0.20	0.50
5.50	0.5	0.4	0.1	0.25	0.20	0.50
6.00	0.4	0.4	0.1	0.25	0.00	0.00
6.50	0.4	0.4	0.1	0.25	0.00	0.00

Table.A.8.The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 125°C and 75°C ,
U_S : 11.90 ml/s , H_S: 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.6	0.46	4.14	9.00	-	-
0.50	3.7	0.46	3.24	7.04	1.80	3.91
1.00	2.1	0.46	1.64	3.56	1.20	2.60
1.50	2.1	0.46	1.64	3.56	0.00	0.00
2.00	1.5	0.46	1.04	2.26	1.20	2.60
2.50	1.2	0.46	0.74	1.60	0.60	1.30
3.00	1.1	0.46	0.64	1.39	0.20	0.43
3.50	0.8	0.46	0.34	0.73	0.60	1.30
4.00	0.8	0.46	0.34	0.73	0.00	0.00
4.50	0.7	0.46	0.24	0.52	0.20	0.43
5.00	0.6	0.46	0.14	0.30	0.20	0.43
5.25	0.5	0.46	0.04	0.08	0.40	0.86
5.50	0.5	0.46	0.04	0.08	0.00	0.00
6.00	0.5	0.46	0.04	0.08	0.00	0.00

Table.A.9 .The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 135°C and 80°C,
U_S: 11.90 ml/s , H_S : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.0	0.4	3.6	9.00	-	-
0.25	3.4	0.4	3.0	7.50	2.40	6.00
0.50	3.2	0.4	2.8	7.00	0.80	2.00
0.75	3.0	0.4	2.6	6.50	0.80	2.00
1.00	2.7	0.4	2.3	5.75	1.20	3.00
1.25	2.2	0.4	1.8	4.50	2.00	5.00
1.50	1.7	0.4	1.3	3.25	2.00	5.00
1.75	1.0	0.4	0.6	1.50	2.80	7.00
2.00	0.6	0.4	0.2	0.50	1.60	4.00
2.25	0.5	0.4	0.1	0.25	0.40	1.00
2.50	0.5	0.4	0.1	0.25	0.00	0.00
2.75	0.5	0.4	0.1	0.25	0.00	0.00
3.00	0.4	0.4	0.0	0.00	0.40	1.00

Table.A.10.The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 160°C and 100°C,
U_S : 11.90 ml/s , H_S: 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	3.3	0.33	2.97	9.00	-	-
0.25	3.0	0.33	2.67	8.09	1.20	3.63
0.50	2.6	0.33	2.27	6.87	1.60	4.84
0.75	2.1	0.33	1.77	5.36	2.80	8.48
1.00	1.4	0.33	1.07	3.24	2.80	8.48
1.25	0.7	0.33	0.37	1.12	2.80	8.48
1.50	0.5	0.33	0.17	0.51	0.80	2.42
1.75	0.4	0.33	0.07	0.21	0.40	1.21
2.00	0.33	0.33	0.00	0.00	0.28	0.84

Table.A.11.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 105^{o}C and 60^{o}C,
U_S:11.90 ml/s , H_S : 20^{o}C

Θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \Theta}$	$\frac{\Delta X}{\Delta \Theta . S}$
0.00	4.4	0.66	3.74	5.66	-	-
0.50	4.0	0.66	3.34	5.06	0.80	1.21
1.00	3.7	0.66	3.04	4.60	0.60	0.90
1.50	3.5	0.66	2.84	4.30	0.40	0.60
2.00	3.0	0.66	2.34	3.54	1.00	1.51
2.50	3.0	0.66	2.34	3.54	0.00	0.00
3.00	3.0	0.66	2.34	3.54	0.00	0.00
3.50	2.8	0.66	2.14	3.24	0.40	0.60
4.00	2.6	0.66	1.94	2.93	0.40	0.60
4.50	2.5	0.66	1.84	2.78	0.20	0.30
5.00	2.5	0.66	1.84	2.78	0.00	0.00
5.50	2.5	0.66	1.84	2.78	0.00	0.00
6.00	2.4	0.66	1.74	2.63	0.20	0.30
6.50	2.2	0.66	1.54	2.33	0.40	0.60
7.00	2.0	0.66	1.34	2.03	0.40	0.60
7.50	1.6	0.66	0.94	1.42	0.80	1.21
8.00	1.4	0.66	0.74	1.12	0.40	0.60
8.50	1.4	0.66	0.74	1.12	0.00	0.00
9.00	1.4	0.66	0.74	1.12	0.00	0.00
9.50	1.0	0.66	0.34	0.51	0.80	1.21
10.00	1.0	0.66	0.34	0.51	0.00	0.00
10.50	1.0	0.66	0.34	0.51	0.00	0.00
11.00	1.0	0.66	0.34	0.51	0.00	0.00

Table, A.12. The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 115°C and 70°C,
U_S : 11.90 ml/s , H_S : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.6	0.99	5.61	5.66	-	-
0.25	6.4	0.99	5.41	5.46	0.80	0.80
0.50	6.2	0.99	5.21	5.26	0.80	0.80
0.75	6.2	0.99	5.21	5.26	0.00	0.00
1.00	5.7	0.99	4.71	4.75	1.00	1.00
1.50	5.2	0.99	4.21	4.25	1.00	1.00
2.00	4.5	0.99	3.51	3.54	1.40	1.41
2.50	3.7	0.99	2.71	2.73	1.60	1.61
3.00	3.2	0.99	2.21	2.23	1.00	1.00
3.50	2.8	0.99	1.81	1.82	0.80	0.80
4.00	2.0	0.99	1.01	1.02	0.40	0.40
4.50	2.0	0.99	1.01	1.02	0.00	0.00
5.00	2.0	0.99	1.01	1.02	0.00	0.00
5.50	1.9	0.99	0.91	0.91	0.20	0.20
6.00	1.7	0.99	0.71	0.71	0.40	0.40
6.50	1.7	0.99	0.71	0.71	0.00	0.00
7.00	1.5	0.99	0.51	0.51	0.40	0.40
7.50	1.4	0.99	0.41	0.41	0.20	0.20
8.00	1.3	0.99	0.31	0.31	0.20	0.20
8.50	1.3	0.99	0.31	0.31	0.00	0.00
9.00	1.3	0.99	0.31	0.31	0.00	0.00

Table.A.13.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 125°C and 75°C,
U_s: 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.7	1.005	5.695	5.66	-	-
0.25	6.4	1.005	5.395	5.36	1.20	1.19
0.50	6.0	1.005	4.995	4.97	1.60	1.59
0.75	5.5	1.005	4.495	4.47	2.00	1.99
1.00	5.0	1.005	3.995	3.97	2.00	1.99
1.25	5.0	1.005	3.995	3.97	0.00	0.00
1.50	4.6	1.005	3.595	3.57	1.60	1.59
1.75	4.0	1.005	2.995	2.98	2.40	2.38
2.00	3.7	1.005	2.695	2.68	1.20	1.19
2.25	3.3	1.005	2.295	2.28	1.60	1.59
2.50	3.0	1.005	1.995	1.98	1.20	1.19
2.75	2.7	1.005	1.695	1.68	1.20	1.19
3.00	2.5	1.005	1.495	1.48	0.80	0.79
3.25	2.4	1.005	1.395	1.38	0.40	0.39
3.50	2.3	1.005	1.295	1.28	0.40	0.39
3.75	2.2	1.005	1.195	1.18	0.40	0.39
4.00	2.0	1.005	0.995	0.99	0.80	0.79
4.25	1.9	1.005	0.895	0.89	0.40	0.39
4.50	1.8	1.005	0.795	0.79	0.40	0.39
4.75	1.8	1.005	0.795	0.79	0.00	0.00
5.00	1.7	1.005	0.695	0.69	0.40	0.39
5.25	1.6	1.005	0.595	0.59	0.40	0.39
5.50	1.6	1.005	0.595	0.59	0.00	0.00
6.00	1.4	1.005	0.395	0.39	0.40	0.39
6.50	1.3	1.005	0.295	0.29	0.20	0.19
7.00	1.2	1.005	0.195	0.19	0.20	0.19
7.50	1.2	1.005	0.195	0.19	0.00	0.00
8.00	1.2	1.005	0.195	0.19	0.00	0.00

Table.A.14.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 135°C and 80°C,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	7.5	1.125	6.375	5.66	-	-
0.25	6.6	1.125	5.475	4.86	3.60	3.20
0.50	6.1	1.125	4.975	4.42	2.00	1.77
0.75	5.6	1.125	4.475	3.97	2.00	1.77
1.00	4.6	1.125	3.475	3.08	4.00	3.55
1.25	4.2	1.125	3.075	2.73	1.60	1.42
1.50	3.6	1.125	2.475	2.20	2.40	2.13
1.75	3.1	1.125	1.975	1.75	2.00	1.77
2.00	3.0	1.125	1.875	1.66	0.40	0.35
2.25	2.5	1.125	1.375	1.22	2.00	1.77
2.50	2.1	1.125	0.975	0.86	1.60	1.42
2.75	2.1	1.125	0.975	0.86	0.00	0.00
3.00	2.1	1.125	0.975	0.86	0.00	0.00
3.25	2.1	1.125	0.975	0.86	0.00	0.00
3.50	1.6	1.125	0.475	0.42	2.00	1.77
4.00	1.6	1.125	0.475	0.42	0.00	0.00
4.50	1.6	1.125	0.475	0.42	0.00	0.00
5.00	1.3	1.125	0.175	0.15	1.20	1.06
5.50	1.3	1.125	0.175	0.15	0.00	0.00
6.00	1.2	1.125	0.075	0.06	0.06	0.05
6.50	1.2	1.125	0.075	0.06	0.00	0.00
7.00	1.2	1.125	0.075	0.06	0.00	0.00

Table.A,15.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 160°C and 100°C,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	2.1	0.315	1.785	5.66	-	-
0.25	1.9	0.315	1.585	5.03	0.80	2.53
0.50	1.9	0.315	1.585	5.03	0.00	0.00
0.75	1.2	0.315	0.885	2.80	2.80	8.88
1.00	0.9	0.315	0.585	1.85	1.20	3.80
1.25	0.8	0.315	0.485	1.53	0.40	1.26
1.50	0.8	0.315	0.485	1.53	0.00	0.00
1.75	0.6	0.315	0.285	0.90	0.80	2.53
2.00	0.5	0.315	0.185	0.58	0.40	1.26
2.25	0.5	0.315	0.185	0.58	0.00	0.00
2.50	0.5	0.315	0.185	0.58	0.00	0.00
2.75	0.5	0.315	0.185	0.58	0.00	0.00
3.00	0.4	0.315	0.085	0.26	0.40	1.26
3.50	0.4	0.315	0.085	0.26	0.00	0.00
4.00	0.4	0.315	0.085	0.26	0.00	0.00

Table.A,16.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 105°C and 60°C,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.0	7.5	1.5	6.0	4.00	-	-
0.5	7.5	1.5	6.0	4.00	0.00	0.00
1.0	7.1	1.5	5.6	3.73	0.80	0.53
1.5	7.0	1.5	5.5	3.66	0.20	0.13
2.0	6.9	1.5	5.4	3.60	0.20	0.13
2.5	6.9	1.5	5.4	3.60	0.00	0.00
3.0	6.3	1.5	4.8	3.20	1.20	0.80
3.5	5.0	1.5	3.5	2.33	2.60	1.73
4.0	4.8	1.5	3.3	2.20	0.40	0.26
4.5	4.5	1.5	3.0	2.00	0.60	0.40
5.0	4.2	1.5	2.7	1.80	0.60	0.40
5.5	4.2	1.5	2.7	1.80	0.00	0.00
6.0	3.9	1.5	2.4	1.60	0.60	0.40
6.5	3.6	1.5	2.1	1.40	0.60	0.40
7.0	3.0	1.5	1.5	1.00	1.20	0.80
7.5	3.0	1.5	1.5	1.00	0.00	0.00
8.0	2.7	1.5	1.2	0.80	0.60	0.40
8.5	2.3	1.5	0.8	0.53	0.80	0.53
9.0	2.2	1.5	0.7	0.46	0.20	0.13
9.5	2.2	1.5	0.7	0.46	0.00	0.00
10.0	2.1	1.5	0.6	0.40	0.00	0.13
10.5	2.1	1.5	0.6	0.40	0.00	0.00
11.0	2.1	1.5	0.6	0.40	0.00	0.00

Table.A.17.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 115°C and 70°C ,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.7	0.94	3.76	4.00	-	-
0.25	4.2	0.94	3.26	3.46	2.00	2.12
0.50	3.6	0.94	2.66	2.82	2.40	2.55
0.75	3.4	0.94	2.46	2.61	0.80	0.85
1.00	3.2	0.94	2.26	2.40	0.80	0.80
1.50	2.9	0.94	1.96	2.08	0.60	0.63
2.00	2.7	0.94	1.76	1.87	0.40	0.42
2.50	2.3	0.94	1.36	1.44	0.80	0.85
3.00	1.7	0.94	0.76	0.80	1.20	1.27
3.50	1.5	0.94	0.56	0.59	0.40	0.42
4.00	1.5	0.94	0.56	0.59	0.00	0.00
4.50	1.4	0.94	0.46	0.48	0.20	0.21
5.00	1.4	0.94	0.46	0.48	0.00	0.00
5.50	1.4	0.94	0.46	0.48	0.00	0.00
6.00	1.3	0.94	0.36	0.38	0.20	0.21
6.50	1.3	0.94	0.36	0.38	0.00	0.00
7.00	1.0	0.94	0.06	0.06	0.60	0.63

Table.A.18.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 125°C and 75°C ,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	3.6	0.72	2.88	4.00	-	-
0.25	3.3	0.72	2.58	3.58	1.20	1.66
0.50	2.7	0.72	1.98	2.75	1.60	2.22
0.75	2.5	0.72	1.78	2.47	0.80	1.11
1.00	2.0	0.72	1.28	1.77	2.00	2.77
1.25	1.6	0.72	0.88	1.22	1.60	2.22
1.50	1.5	0.72	0.78	1.08	0.40	0.55
1.75	1.4	0.72	0.68	0.94	0.40	0.55
2.00	1.3	0.72	0.58	0.80	0.40	0.55
2.25	1.3	0.72	0.58	0.80	0.00	0.00
2.50	1.2	0.72	0.48	0.66	0.40	0.55
2.75	1.1	0.72	0.38	0.52	0.40	0.55
3.0	1.0	0.72	0.28	0.38	0.40	0.55
3.25	0.9	0.72	0.18	0.25	0.40	0.55
3.50	0.9	0.72	0.18	0.18	0.00	0.00
3.75	0.9	0.72	0.18	0.25	0.00	0.00

Table.A.19.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 135^{o} and 80^{o}C ,
U_s : 11.90 ml/s , H_s : 20^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.8	0.96	3.84	4.00	-	-
0.25	4.2	0.96	3.24	3.37	2.40	2.50
0.50	4.2	0.96	3.24	3.37	0.00	0.00
0.75	4.2	0.96	3.24	3.37	0.00	0.00
1.00	3.8	0.96	2.84	2.95	1.60	1.66
1.25	3.8	0.96	2.84	2.95	0.00	0.00
1.50	3.3	0.96	2.34	2.95	0.00	0.00
1.75	3.3	0.96	2.34	2.95	0.00	0.00
2.00	2.7	0.96	1.74	1.81	2.40	2.50
2.25	2.7	0.96	1.74	1.81	0.00	0.00
2.50	2.3	0.96	1.34	1.39	1.60	1.66
2.75	2.3	0.96	1.34	1.39	0.00	0.00
3.00	2.0	0.96	1.04	1.08	1.20	1.25
3.25	2.0	0.96	1.04	1.08	0.00	0.00
3.50	1.6	0.96	0.64	0.66	1.60	1.66
4.00	1.6	0.96	0.64	0.66	0.00	0.00
4.50	1.6	0.96	0.64	0.66	0.00	0.00
5.00	1.6	0.96	0.64	0.66	0.00	0.00

Table.A.20.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 160^{o}C and 100^{o}C,
U_s : 11.90 ml/s , H_s : 20^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	2.8	0.56	2.24	4.0	-	-
0.25	2.6	0.56	2.04	3.64	0.80	1.42
0.50	2.6	0.56	2.04	3.64	0.00	0.00
0.75	2.6	0.56	2.04	3.64	0.00	0.00
1.00	2.3	0.56	1.74	3.10	1.20	2.14
1.25	2.3	0.56	1.74	3.10	0.00	0.00
1.50	2.2	0.56	1.64	2.92	0.40	0.71
1.75	2.2	0.56	1.64	2.92	0.00	0.00
2.00	1.9	0.56	1.34	2.39	1.20	2.14
2.25	1.7	0.56	1.14	2.03	0.80	1.42
2.50	1.5	0.56	0.94	1.67	0.80	1.42
2.75	1.5	0.56	0.94	1.67	0.00	0.00
3.00	1.2	0.56	0.64	1.14	1.20	2.14
3.50	1.1	0.56	0.54	0.96	0.20	0.35
4.00	0.8	0.56	0.24	0.42	0.60	1.07
4.50	0.8	0.56	0.24	0.42	0.40	0.71

Table.A.21. The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 105° and 60°C,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	8.2	2.3	5.9	2.57	-	-
0.50	7.7	2.3	5.4	2.34	1.00	0.43
1.00	7.0	2.3	4.7	2.04	1.40	0.60
1.50	5.7	2.3	3.4	1.47	1.40	0.60
2.00	5.3	2.3	3.0	1.30	0.80	0.34
2.50	5.3	2.3	3.0	1.30	0.00	0.00
3.00	4.8	2.3	2.5	1.08	1.00	0.43
3.50	4.6	2.3	2.3	1.00	0.40	0.17
4.00	4.3	2.3	2.0	0.86	0.60	0.26
4.50	3.8	2.3	1.5	0.65	1.00	0.43
5.00	3.5	2.3	1.2	0.52	0.60	0.26
5.50	3.4	2.3	1.1	0.47	0.20	0.08
6.00	3.0	2.3	0.7	0.40	0.34	0.14
6.50	2.8	2.3	0.5	0.21	0.38	0.76
7.00	2.5	2.3	0.2	0.08	0.60	0.26
7.50	2.5	2.3	0.2	0.08	0.00	0.00
8.00	2.5	2.3	0.2	0.08	0.00	0.00

Table.A.22.The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 125°C and 75°C,
U_s : 11.90 ml/s , H_s : 20°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	5.3	1.484	3.816	2.57	-	-
0.25	4.8	1.484	3.316	2.23	2.00	1.34
0.50	4.3	1.484	2.816	1.89	2.00	1.34
0.75	4.0	1.484	2.516	1.69	1.20	0.80
1.00	3.6	1.484	2.116	1.42	1.60	1.07
1.25	3.4	1.484	1.916	1.29	0.80	0.53
1.50	3.2	1.484	1.716	1.15	0.80	0.53
1.75	3.0	1.484	1.516	1.02	0.80	0.53
2.00	2.8	1.484	1.316	0.88	0.80	0.53
2.25	2.8	1.484	1.316	0.88	0.00	0.00
2.50	2.7	1.484	1.216	0.81	0.40	0.26
2.75	2.7	1.484	1.216	0.81	0.00	0.00
3.00	2.6	1.484	1.116	0.75	0.40	0.26
3.50	2.5	1.484	1.016	0.68	0.20	0.13
4.00	2.3	1.484	0.816	0.54	0.40	0.26
4.50	2.3	1.484	0.816	0.54	0.00	0.00
5.00	2.2	1.484	0.716	0.48	0.20	0.13
5.50	2.1	1.484	0.616	0.41	0.20	0.13
6.00	1.9	1.484	0.416	0.28	0.40	0.26
6.50	1.8	1.484	0.316	0.21	0.20	0.13
7.00	1.8	1.484	0.316	0.21	0.00	0.00
7.50	1.8	1.484	0.316	0.21	0.00	0.00

Table.A.23.The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 135^{o}C and 80^{o}C,
U_S : 11.90 ml/s , H_S : 20^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	5.7	1.596	4.104	2.57	-	-
0.25	5.5	1.596	3.904	2.44	0.80	0.50
0.50	5.2	1.596	3.604	2.25	1.20	0.75
0.75	5.2	1.596	3.604	2.25	0.00	0.00
1.00	4.5	1.596	2.904	1.81	2.80	1.75
1.25	4.2	1.596	2.604	1.63	1.20	0.75
1.50	4.0	1.596	2.404	1.50	0.80	0.50
1.75	4.0	1.596	2.404	1.50	0.00	0.00
2.00	3.6	1.596	2.004	1.25	1.60	1.00
2.25	3.6	1.596	2.004	1.25	0.00	0.00
2.50	3.2	1.596	1.604	1.00	1.60	1.00
2.75	3.2	1.596	1.604	1.00	0.00	0.00
3.00	2.8	1.596	1.204	0.75	1.60	1.00
3.25	2.6	1.596	1.004	0.62	0.80	0.50
3.50	2.2	1.596	0.604	0.37	1.60	1.00
3.75	2.2	1.596	0.604	0.37	0.00	0.00
4.00	1.6	1.596	0.004	0.00	2.40	1.50

Table.A.24.The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 160^{o}C and 100^{o}C,
U_S : 11.90 ml/s , H_S : 20^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	8.8	2.464	6.336	2.57	-	-
0.25	7.5	2.464	5.036	2.04	5.20	2.11
0.50	7.1	2.464	4.636	1.88	1.60	0.64
0.75	6.9	2.464	4.636	1.80	0.00	0.00
1.00	5.9	2.464	3.436	1.39	4.00	1.62
1.25	5.9	2.464	3.436	1.39	0.00	0.00
1.50	5.5	2.464	3.036	1.23	1.60	0.64
1.75	4.7	2.464	2.236	0.90	3.20	1.28
2.00	4.7	2.464	2.236	0.90	0.00	0.00
2.25	4.7	2.464	2.236	0.90	0.00	0.00
2.50	4.5	2.464	2.036	0.82	0.80	0.32
2.75	4.5	2.464	2.036	0.82	0.00	0.00
3.00	4.2	2.464	1.736	0.70	1.20	0.48
3.50	3.8	2.464	1.336	0.54	0.80	0.32
4.00	3.7	2.464	1.236	0.50	0.20	0.08
4.50	3.4	2.464	0.936	0.37	0.60	0.24
5.00	3.3	2.464	0.836	0.33	0.20	0.08
5.50	3.2	2.464	0.736	0.29	0.20	0.08
6.00	3.2	2.464	0.736	0.29	0.00	0.00
6.50	3.2	2.464	0.736	0.29	0.00	0.00
7.50	3.2	2.464	0.736	0.29	0.00	0.00

Table.A25.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 105°C and 60°C,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	7.7	0.385	7.315	19.0	-	-
0.25	7.1	0.385	6.715	17.44	2.40	6.23
0.50	6.9	0.385	6.515	16.92	0.80	2.07
0.75	6.5	0.385	6.115	15.88	1.60	4.15
1.00	6.0	0.385	5.615	14.58	2.00	5.19
1.25	5.6	0.385	5.215	13.54	1.60	4.15
1.50	5.2	0.385	4.815	12.50	1.60	4.15
1.75	4.7	0.385	4.315	11.20	0.40	1.03
2.00	4.2	0.385	3.815	9.90	2.00	5.19
2.25	3.9	0.385	3.515	9.12	1.20	3.11
2.50	3.6	0.385	3.215	8.35	1.20	3.11
2.75	3.0	0.385	2.615	6.79	2.40	6.22
3.00	3.0	0.385	2.615	6.79	0.00	0.00
3.50	2.5	0.385	2.115	5.49	1.00	2.59
4.00	1.9	0.385	1.515	3.93	1.20	3.11
4.50	1.5	0.385	1.115	2.89	0.80	2.07
5.00	1.1	0.385	0.715	1.18	0.80	2.07
5.50	0.8	0.385	0.415	1.07	0.60	1.55
6.00	0.6	0.385	0.215	0.55	0.40	1.03
6.50	0.5	0.385	0.115	0.29	0.20	0.50
7.00	0.5	0.385	0.115	0.29	0.00	0.00
7.50	0.5	0.385	0.115	0.29	0.00	0.00

Table.A26.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 115°C and 70°C,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.2	0.31	5.89	19.0	-	-
0.25	5.9	0.31	5.59	18.03	1.6	5.16
0.50	5.4	0.31	5.09	16.41	2.0	6.45
0.75	5.2	0.31	4.89	15.77	0.80	2.58
1.00	4.8	0.31	4.49	14.48	1.6	5.16
1.25	3.6	0.31	3.29	10.6	4.8	15.48
1.50	3.2	0.31	2.89	9.32	1.6	5.16
1.75	3.0	0.31	2.69	8.67	0.80	2.58
2.00	2.9	0.31	2.59	8.35	0.40	1.29
2.25	2.3	0.31	1.99	6.41	2.4	7.74
2.50	2.3	0.31	1.99	6.41	0.0	0.00
2.75	2.0	0.31	1.69	5.41	1.20	3.87
3.00	1.5	0.31	1.19	3.83	2.0	6.45
3.25	1.4	0.31	1.09	3.51	0.40	1.29
3.50	1.0	0.31	0.69	2.22	1.60	5.16
3.75	0.7	0.31	0.39	1.25	1.20	3.87
4.00	0.6	0.31	0.29	0.93	0.40	1.29
4.25	0.6	0.31	0.29	0.93	0.00	0.00
4.50	0.5	0.31	0.19	0.61	0.40	1.29
4.75	0.5	0.31	0.19	0.61	0.00	0.00
5.00	0.5	0.31	0.19	0.61	0.00	0.00
5.25	0.5	0.31	0.19	0.61	0.00	0.00
5.50	0.4	0.31	0.09	0.29	0.40	1.29
6.00	0.4	0.31	0.09	0.29	0.00	0.00
6.50	0.4	0.31	0.09	0.29	0.00	0.00

Table.A.27.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 125^{o}C and 75^{o}C,
U_s : 11.90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	5.4	0.27	5.13	19.0	-	-
0.25	5.1	0.27	4.83	17.8	1.20	4.44
0.50	4.5	0.27	4.23	15.66	2.40	8.88
0.75	3.8	0.27	3.53	13.07	2.8	10.37
1.00	3.3	0.27	3.03	11.22	2.0	7.40
1.25	2.8	0.27	2.53	9.37	2.0	7.40
1.50	2.5	0.27	2.23	8.25	1.20	4.44
1.75	2.1	0.27	1.83	6.77	1.60	5.92
2.00	2.1	0.27	1.83	6.77	0.00	0.00
2.25	1.7	0.27	1.43	5.29	1.60	5.92
2.50	1.4	0.27	1.13	4.18	1.20	4.44
2.75	1.1	0.27	0.83	3.07	1.20	4.44
3.00	0.9	0.27	0.63	2.33	0.80	2.96
3.25	0.7	0.27	0.43	1.59	0.80	2.96
3.50	0.6	0.27	0.33	1.22	0.40	1.48
3.75	0.6	0.27	0.33	1.22	0.00	0.00
4.00	0.5	0.27	0.23	0.85	0.40	1.48
4.25	0.4	0.27	0.13	0.48	0.40	1.48
4.50	0.3	0.27	0.03	0.11	0.40	1.48
5.00	0.3	0.27	0.03	0.11	0.00	0.00
5.50	0.3	0.27	0.03	0.11	0.00	0.00
6.00	0.3	0.27	0.03	0.11	0.00	0.00

Table.A.28.The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 135^{o}C and 80^{o}C,
U_s : 11.90 ml/s , H_s : 30oC

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.6	0.23	4.37	19.0	-	-
0.25	3.5	0.23	3.27	14.2	3.6	15.60
0.50	3.0	0.23	2.77	12.0	2.0	8.69
0.75	3.0	0.23	2.77	12.0	0.0	0.00
1.00	2.7	0.23	2.47	10.7	1.2	5.21
1.25	2.4	0.23	2.17	9.43	1.2	5.21
1.50	1.4	0.23	1.17	5.0	4.0	17.39
1.75	1.4	0.23	1.17	5.0	0.0	0.00
2.00	0.8	0.23	0.57	2.47	2.4	10.43
2.25	0.8	0.23	0.57	2.47	0.0	0.00
2.50	0.5	0.23	0.27	1.17	1.2	5.21
2.75	0.3	0.23	0.07	0.30	0.80	3.47
3.00	0.23	0.23	0.00	0.00	0.28	1.20

Table.A.29 The drying of tomato paste droplet : 5 Brix
Air inlet and outlet : 160°C and 100°C,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.4	0.22	4.18	19.0	-	-
0.25	3.7	0.22	3.48	15.8	2.8	12.72
0.50	3.0	0.22	2.78	12.63	2.8	12.72
0.75	2.3	0.22	2.08	8.32	2.8	12.72
1.00	1.7	0.22	1.48	6.72	2.4	10.90
1.25	1.5	0.22	1.28	5.81	0.8	3.63
1.50	1.5	0.22	1.28	5.81	0.0	0.00
1.75	1.0	0.22	0.78	3.54	2.0	9.09
2.00	0.5	0.22	0.28	1.27	2.0	9.09
2.25	0.4	0.22	0.18	0.81	0.40	1.81
2.50	0.3	0.22	0.08	0.36	0.40	1.81
2.75	0.22	0.22	0.00	0.00	0.32	1.45

Table.A.30.The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 105°C and 60°C ,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	8.4	0.84	7.56	9.00	-	-
0.25	7.9	0.84	7.06	8.40	2.00	2.38
0.50	7.7	0.84	6.86	8.16	0.80	0.95
0.75	7.6	0.84	6.76	8.04	0.40	0.47
1.00	7.5	0.84	6.66	7.92	0.40	0.47
1.25	7.0	0.84	6.16	7.32	2.0	2.38
1.50	6.7	0.84	5.86	6.96	1.20	1.42
1.75	6.2	0.84	5.36	6.38	2.0	2.38
2.00	5.9	0.84	5.06	6.02	1.20	1.42
2.25	5.8	0.84	4.96	5.90	0.40	0.47
2.50	5.4	0.84	4.56	5.42	1.60	1.90
2.75	5.2	0.84	4.36	5.19	0.80	0.95
3.00	4.9	0.84	4.06	4.83	1.20	1.42
3.25	4.7	0.84	3.86	4.59	0.80	0.95
3.50	4.4	0.84	3.56	4.23	1.20	1.42
3.75	4.2	0.84	3.36	4.00	0.80	0.95
4.00	3.9	0.84	3.06	3.64	1.20	1.42
4.25	3.7	0.84	2.86	3.40	0.80	0.95
4.50	3.4	0.84	2.56	3.04	1.20	1.42
4.75	2.9	0.84	2.06	2.45	2.00	2.38
5.00	2.9	0.84	2.06	2.45	0.00	0.00
5.25	2.8	0.84	1.96	2.33	0.40	0.47
5.50	2.5	0.84	1.66	1.96	1.20	0.47
6.00	2.3	0.84	1.46	1.73	0.40	0.47
6.50	2.1	0.84	1.26	1.50	0.40	0.47
7.00	1.9	0.84	1.06	1.26	0.40	0.47
7.50	1.6	0.84	0.76	0.90	0.60	0.71
8.00	1.5	0.84	0.66	0.78	0.20	0.23
8.50	1.4	0.84	0.56	0.66	0.20	0.23
9.00	1.2	0.84	0.36	0.42	0.20	0.23
9.50	0.9	0.84	0.06	0.07	0.60	0.71
10.00	0.9	0.84	0.06	0.07	0.00	0.00
10.50	0.9	0.84	0.06	0.07	0.00	0.00

Table.A.31.The drying of tomato paste droplet: 10 Brix
Air inlet and outlet : 115^{o}C and 70^{o}C,
U_S : 11.90 ml/s , H_S : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.7	0.47	4.23	9.00	-	-
0.25	4.5	0.47	4.03	8.57	0.80	1.70
0.50	4.1	0.47	3.63	7.72	1.60	3.40
0.75	3.9	0.47	3.43	7.29	0.80	1.70
1.00	3.7	0.47	3.23	6.87	0.80	1.70
1.25	3.6	0.47	3.13	6.65	0.40	0.85
1.50	3.3	0.47	2.83	6.02	1.20	2.55
1.75	3.3	0.47	2.83	6.02	0.00	0.00
2.00	2.9	0.47	2.43	5.17	1.60	3.40
2.25	2.9	0.47	2.43	5.17	0.00	0.00
2.50	2.6	0.47	2.13	4.53	1.20	2.55
2.75	2.6	0.47	2.13	4.53	0.00	0.00
3.00	2.1	0.47	1.63	3.46	1.60	3.40
3.25	2.1	0.47	1.63	3.46	0.00	0.00
3.50	2.0	0.47	1.53	3.25	0.40	0.85
4.00	1.6	0.47	1.13	2.40	0.80	1.70
4.50	1.4	0.47	0.93	1.97	0.40	0.85
5.00	1.3	0.47	0.83	1.76	0.40	0.85
5.50	1.1	0.47	0.63	1.34	0.40	0.85
5.75	0.8	0.47	0.33	0.70	1.2	2.55
6.00	0.8	0.47	0.33	0.70	0.00	0.00
6.50	0.6	0.47	0.13	0.27	0.40	0.85
7.50	0.5	0.47	0.03	0.07	0.10	0.21
8.00	0.5	0.47	0.03	0.07	0.00	0.00
8.50	0.5	0.47	0.03	0.07	0.00	0.00

Table.A.32 The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 135°C and 80°C,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0 .00	5.1	0.51	4.59	9.0	-	-
0.25	4.7	0.51	4.19	8.21	1.60	3.13
0.50	4.5	0.51	3.99	7.82	0.80	1.56
0.75	4.3	0.51	3.79	7.43	0.80	1.56
1.00	3.9	0.51	3.39	6.64	1.60	3.13
1.25	3.5	0.51	2.99	5.86	1.60	3.13
1.50	3.2	0.51	2.69	5.27	1.20	2.35
1.75	2.7	0.51	2.19	4.29	2.00	3.92
2.00	2.3	0.51	1.79	3.50	0.80	1.56
2.25	1.9	0.51	1.39	2.72	1.60	3.13
2.50	1.3	0.51	0.79	1.54	2.40	4.70
2.75	1.3	0.51	0.79	1.54	0.00	0.00
3.00	1.2	0.51	0.69	1.35	0.40	0.78
3.25	1.0	0.51	0.49	0.96	0.80	1.56
3.50	0.9	0.51	0.39	0.76	0.40	0.78
3.75	0.8	0.51	0.29	0.56	0.40	0.78
4.00	0.6	0.51	0.09	0.17	0.80	0.56
4.50	0.5	0.51	0.00	0.00	0.18	0.35

Table.A.33.The drying of tomato paste droplet : 10 Brix
Air inlet and outlet : 160^{o}C and 100^{o}C,
U_s : 11.90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.6	0.46	4.14	9.00	-	-
0.25	4.2	0.46	3.74	8.13	1.60	3.47
0.50	3.4	0.46	2.94	6.43	3.20	6.95
0.75	3.0	0.46	2.54	5.56	1.60	3.47
1.00	2.6	0.46	2.14	4.65	1.60	3.47
1.25	2.0	0.46	1.54	3.34	2.40	5.21
1.50	1.8	0.46	1.34	2.91	0.80	1.73
1.75	1.7	0.46	1.24	2.69	0.40	0.86
2.00	1.6	0.46	1.14	2.47	0.40	0.86
2.25	1.1	0.46	0.64	1.39	2.00	4.34
2.50	0.9	0.46	0.44	0.95	0.80	1.73
2.75	0.8	0.46	0.34	0.73	0.20	0.43
3.00	0.6	0.46	0.14	0.30	0.40	0.43
3.25	0.4	0.46	0.00	0.00	0.00	0.00

Table.A.34.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 105^{o}C and 60^{o}C,
U_s : 11,90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	8.0	1.2	6.8	5.66	-	-
0.25	7.9	1.2	6.7	5.58	0.40	0.33
0.50	7.5	1.2	6.3	5.25	1.60	1.33
0.75	7.5	1.2	6.3	5.25	0.00	0.00
1.00	7.3	1.2	6.1	5.08	0.80	0.66
1.25	7.1	1.2	5.9	4.91	0.80	0.66
1.50	7.0	1.2	5.8	4.83	0.40	0.33
1.75	6.8	1.2	5.6	4.66	0.80	0.66
2.00	6.3	1.2	5.1	4.25	2.00	1.66
2.25	6.3	1.2	5.1	4.25	0.00	0.00
2.50	5.9	1.2	4.7	3.91	1.60	1.33
2.75	5.9	1.2	4.7	3.91	0.00	0.00
3.00	5.5	1.2	4.3	3.58	1.60	1.33
3.50	5.3	1.2	4.1	3.41	0.40	0.33
3.75	4.4	1.2	3.2	2.66	0.40	0.33
4.00	4.3	1.2	3.1	2.58	0.40	0.33
4.50	4.3	1.2	3.1	2.58	0.00	0.00
5.00	3.9	1.2	2.7	2.25	0.80	0.66
5.50	3.7	1.2	2.5	2.08	0.40	0.33
6.00	3.4	1.2	2.2	1.83	0.60	0.50
6.50	3.1	1.2	1.9	1.58	0.60	0.50
7.00	2.9	1.2	1.7	1.41	0.40	0.33
7.50	2.2	1.2	1.0	0.83	1.4	1.16
8.00	2.0	1.2	0.8	0.66	0.40	0.33
8.50	2.0	1.2	0.8	0.66	0.00	0.00
9.00	2.0	1.2	0.8	0.66	0.00	0.00
9.50	2.0	1.2	0.8	0.66	0.00	0.00

Table.A.35.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 115^oC and 70^oC ,
U_s : 11.90 ml/s , H_s : 30^oC

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta\theta . S}$
0.00	5.3	0.795	4.505	5.66	-	-
0.25	5.1	0.795	4.305	5.41	0.80	1.00
0.50	4.9	0.795	4.105	5.16	0.80	1.00
0.75	4.4	0.795	3.605	4.53	2.00	2.51
1.00	3.9	0.795	3.105	3.90	2.00	2.51
1.25	3.9	0.795	3.105	3.90	2.00	2.51
1.50	3.7	0.795	2.905	3.65	0.80	1.00
1.75	3.5	0.795	2.705	3.40	0.80	1.00
2.00	3.1	0.795	2.305	2.89	1.60	2.01
2.25	2.9	0.795	2.105	2.64	0.80	1.00
2.50	2.7	0.795	1.905	2.39	0.80	1.00
2.75	2.7	0.795	1.905	2.39	0.00	0.00
3.00	2.5	0.795	1.705	2.14	0.80	1.00
3.25	2.3	0.795	1.505	1.89	0.80	1.00
3.50	2.0	0.795	1.205	1.51	1.20	1.50
3.75	1.9	0.795	1.105	1.38	0.40	0.50
4.00	1.8	0.795	1.005	1.26	0.40	0.50
4.25	1.5	0.795	0.705	0.88	1.20	1.50
4.50	1.2	0.795	0.405	0.50	1.20	1.50
4.75	1.2	0.795	0.405	0.50	0.00	0.00
5.00	1.1	0.795	0.305	0.38	0.40	0.50
5.25	1.0	0.795	0.205	0.25	0.40	0.50
5.50	1.0	0.795	0.205	0.25	0.00	0.00
6.00	0.9	0.795	0.105	0.25	0.00	0.00
6.50	0.8	0.795	0.005	0.25	0.00	0.00

Table.A.36.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 125^{o}C and 75^{o}C ,
U_S : 11.90 ml/s , H_S : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.5	0.975	5.525	5.66	-	-
0.25	6.1	0.975	5.125	5.25	1.60	1.64
0.50	5.9	0.975	4.925	5.05	0.80	0.82
0.75	5.4	0.975	4.425	4.53	2.00	2.05
1.00	4.5	0.975	3.525	3.61	3.60	3.69
1.25	4.5	0.975	3.525	3.61	0.00	0.00
1.50	4.2	0.975	3.225	3.30	1.20	1.23
1.75	4.1	0.975	3.125	3.20	0.40	0.41
2.00	3.7	0.975	2.725	2.79	1.60	1.64
2.25	3.4	0.975	2.425	2.48	1.20	1.23
2.50	2.8	0.975	1.825	1.87	2.40	2.46
2.75	2.5	0.975	1.525	1.56	1.20	1.23
3.00	2.4	0.975	1.425	1.46	0.40	0.41
3.25	2.2	0.975	1.225	1.25	0.80	0.82
3.50	2.0	0.975	1.025	1.05	0.80	0.82
3.75	1.5	0.975	0.525	0.53	2.00	2.05
4.00	1.4	0.975	0.425	0.46	0.40	0.41
4.25	1.4	0.975	0.425	0.46	0.00	0.00
4.50	1.4	0.975	0.425	0.46	0.00	0.00
4.75	1.3	0.975	0.325	0.33	0.40	0.41
5.00	1.2	0.975	0.225	0.23	0.40	0.41
5.25	1.1	0.975	0.125	0.12	0.40	0.41
5.50	1.1	0.975	0.125	0.12	0.00	0.00
5.75	1.1	0.975	0.125	0.12	0.00	0.00
6.00	1.0	0.975	0.025	0.12	0.00	0.41

Table.A.37.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 135^{o}C and 80^{o}C ,
U_s : 11.90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	9.1	1.365	7.735	5.66	-	-
0.25	8.3	1.365	6.935	5.08	3.20	2.34
0.50	7.6	1.365	6.235	4.56	2.80	2.05
0.75	7.0	1.365	5.635	4.12	2.40	1.75
1.00	6.0	1.365	4.635	3.39	4.00	2.93
1.25	5.7	1.365	4.335	3.17	1.20	0.87
1.50	5.0	1.365	3.635	2.66	2.80	2.05
1.75	4.7	1.365	3.335	2.44	1.20	0.87
2.00	4.5	1.365	3.135	2.29	0.80	0.58
2.25	4.1	1.365	2.735	2.00	0.80	0.58
2.50	3.5	1.365	2.135	1.56	1.60	1.17
2.75	3.0	1.365	1.635	1.19	2.40	1.75
3.00	2.8	1.365	1.435	1.05	2.0	1.46
3.25	2.5	1.365	1.135	0.83	0.80	0.58
3.50	2.3	1.365	0.935	0.68	1.20	0.87
3.75	2.0	1.365	0.635	0.46	0.80	0.58
4.00	1.9	1.365	0.535	0.39	1.20	0.87
4.25	1.9	1.365	0.535	0.39	0.00	0.00
4.50	1.7	1.365	0.335	0.24	0.80	0.58
4.75	1.5	1.365	0.135	0.09	0.80	0.58
5.00	1.4	1.365	0.035	0.02	0.40	0.29
5.50	1.4	1.365	0.035	0.02	0.00	0.00

Table.A.38.The drying of tomato paste droplet : 15 Brix
Air inlet and outlet : 160°C and 100°C ,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	3.2	0.48	2.72	5.66	-	-
0.25	2.7	0.48	2.22	4.62	2.00	4.16
0.50	2.4	0.48	1.92	4.00	1.20	2.50
0.75	1.9	0.48	1.42	2.95	2.00	4.16
1.00	1.4	0.48	0.92	1.91	2.00	4.16
1.25	1.2	0.48	0.72	1.50	0.80	1.66
1.50	1.0	0.48	0.52	1.08	0.80	1.66
1.75	0.9	0.48	0.42	0.87	0.40	0.83
2.00	0.8	0.48	0.32	0.66	0.40	0.83
2.25	0.7	0.48	0.22	0.45	0.40	0.83
2.50	0.5	0.48	0.02	0.04	0.80	1.66
3.50	0.5	0.48	0.02	0.04	0.00	0.00

Table.A.39.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 105^{o}C and 60^{o}C ,
U_s : 11.90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	7.0	1.4	5.6	4.00	-	-
0.25	6.7	1.4	5.3	3.78	1.20	0.85
0.50	6.4	1.4	5.0	3.57	1.20	0.85
0.75	6.0	1.4	4.6	3.28	1.60	1.14
1.00	5.9	1.4	4.5	3.21	0.40	0.28
1.25	5.9	1.4	4.5	3.21	0.00	0.00
1.50	5.6	1.4	4.2	3.00	1.20	0.85
1.75	5.3	1.4	3.9	2.78	1.20	0.85
2.00	5.1	1.4	3.7	2.64	0.80	0.56
2.25	5.1	1.4	3.7	2.64	0.00	0.00
2.50	4.7	1.4	3.3	2.35	1.60	1.14
2.75	4.5	1.4	3.1	2.21	0.80	0.56
3.00	4.3	1.4	2.9	2.07	0.80	0.56
3.50	4.3	1.4	2.9	2.07	0.00	0.00
3.75	4.3	1.4	2.9	2.07	0.00	0.00
4.00	4.1	1.4	2.7	1.92	0.80	0.56
4.50	3.8	1.4	2.4	1.71	1.20	0.85
5.00	3.4	1.4	2.0	1.42	1.60	1.14
5.50	3.2	1.4	1.8	1.28	0.80	0.56
6.00	2.8	1.4	1.4	1.00	1.60	1.14
6.50	2.5	1.4	1.1	0.78	1.20	0.85
7.00	2.5	1.4	1.1	0.78	0.00	0.00
7.50	2.2	1.4	0.8	0.57	1.20	0.85
8.00	2.0	1.4	0.6	0.42	0.80	0.56
8.50	1.8	1.4	0.4	0.28	0.80	0.56
9.00	1.8	1.4	0.4	0.28	0.00	0.00
9.50	1.8	1.4	0.4	0.28	0.00	0.00
10.00	1.8	1.4	0.4	0.28	0.00	0.00

Table.A.40.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 115^oC and 70^oC ,
U_s : 11.90 ml/s , H_s : 30^oC

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.2	1.24	4.96	4.00	-	-
0.25	5.7	1.24	4.46	3.59	2.0	1.61
0.50	5.5	1.24	4.26	3.43	0.8	0.64
0.75	5.3	1.24	4.06	3.27	0.8	0.64
1.00	4.7	1.24	3.46	2.79	2.4	1.93
1.25	4.5	1.24	3.26	2.62	0.8	0.64
1.50	4.1	1.24	2.86	2.27	1.6	1.29
1.75	3.7	1.24	2.46	1.98	1.6	1.29
2.00	3.7	1.24	2.46	1.98	0.0	0.00
2.25	3.3	1.24	2.06	1.66	1.6	1.29
2.50	3.1	1.24	1.86	1.50	0.8	0.64
2.75	2.9	1.24	1.66	1.33	0.8	0.64
3.00	2.7	1.24	1.46	1.17	0.8	0.64
3.25	2.4	1.24	1.16	0.93	1.2	0.96
3.50	2.3	1.24	1.06	0.85	0.4	0.32
3.75	2.1	1.24	0.86	0.69	0.8	0.64
4.00	1.9	1.24	0.66	0.53	0.8	0.64
4.25	1.9	1.24	0.66	0.53	0.0	0.00
4.50	1.8	1.24	0.56	0.45	0.4	0.32
4.75	1.8	1.24	0.56	0.45	0.0	0.00
5.00	1.7	1.24	0.46	0.37	0.4	0.32
5.25	1.6	1.24	0.36	0.29	0.4	0.32
5.75	1.5	1.24	0.26	0.23	0.2	0.16
6.25	1.3	1.24	0.06	0.04	0.4	0.32
7.00	1.3	1.24	0.06	0.04	0.0	0.00
7.50	1.3	1.24	0.06	0.04	0.0	0.00

Table.A.41 .The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 125^{o}C and 75^{o}C,
U_s : 11.90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.6	0.92	3.68	4.00	-	-
0.25	4.3	0.92	3.38	3.67	1.20	1.30
0.50	3.8	0.92	2.88	3.13	2.00	2.17
0.75	3.7	0.92	2.78	3.02	0.40	0.43
1.00	3.2	0.92	2.28	2.47	2.00	2.17
1.25	2.9	0.92	1.98	2.15	1.20	1.30
1.50	2.6	0.92	1.68	1.82	1.20	1.30
1.75	2.4	0.92	1.48	1.60	0.80	0.86
2.00	2.3	0.92	1.38	1.50	0.40	0.43
2.25	2.3	0.92	1.38	1.50	0.00	0.00
2.50	2.0	0.92	1.08	1.17	1.20	1.30
2.75	2.0	0.92	1.08	1.17	0.00	0.00
3.00	1.8	0.92	0.88	0.95	0.80	0.86
3.25	1.8	0.92	0.88	0.95	0.00	0.00
3.50	1.7	0.92	0.78	0.84	0.40	0.43
3.75	1.6	0.92	0.68	0.73	0.40	0.43
4.00	1.5	0.92	0.58	0.63	0.40	0.43
4.25	1.3	0.92	0.38	0.41	0.80	0.86
4.50	1.3	0.92	0.38	0.41	0.00	0.00
4.75	1.2	0.92	0.28	0.30	0.40	0.43
5.00	1.0	0.92	0.08	0.08	0.80	0.86
5.50	1.0	0.92	0.08	0.08	0.00	0.00

Table.A.42.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : 135°C and 80°C ,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	5.7	1.14	4.56	4.0	-	-
0.25	5.2	1.14	4.06	3.56	2.00	1.75
0.50	5.0	1.14	3.86	3.38	0.80	0.70
0.75	4.6	1.14	3.46	3.03	1.60	1.40
1.00	4.1	1.14	2.96	2.59	2.00	1.75
1.25	3.9	1.14	2.76	2.42	0.80	0.70
1.50	3.6	1.14	2.46	2.15	1.20	1.05
1.75	3.0	1.14	1.86	1.63	2.40	2.10
2.00	2.8	1.14	1.66	1.45	0.80	0.70
2.25	2.5	1.14	1.36	1.19	1.20	1.05
2.50	2.3	1.14	1.16	1.01	0.80	0.70
2.75	2.2	1.14	1.06	0.92	0.40	0.35
3.00	1.9	1.14	0.76	0.66	1.20	1.05
3.25	1.9	1.14	0.76	0.66	0.00	0.00
3.50	1.8	1.14	0.66	0.57	0.40	0.35
3.75	1.7	1.14	0.56	0.49	0.40	0.35
4.00	1.6	1.14	0.46	0.40	0.40	0.35
4.25	1.4	1.14	0.26	0.22	0.80	0.70
4.50	1.4	1.14	0.26	0.22	0.00	0.00
4.75	1.3	1.14	0.16	0.14	0.40	0.35
5.00	1.1	1.14	0.00	0.00	0.00	0.00

Table.A.43.The drying of tomato paste droplet : 20 Brix
Air inlet and outlet : $160^{o}C$ and $100^{o}C$,
U_s : 11.90 ml/s , H_s : $30^{o}C$

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	4.4	0.88	3.52	4.0	-	-
0.25	3.6	0.88	2.72	3.09	3.20	3.65
0.50	2.7	0.88	1.82	2.06	3.60	4.09
0.75	2.3	0.88	1.42	1.61	1.60	1.81
1.00	1.9	0.88	1.02	1.16	1.60	1.81
1.25	1.4	0.88	0.52	0.59	2.00	2.27
1.50	1.0	0.88	0.12	0.13	1.60	1.81
1.75	1.0	0.88	0.12	0.13	0.48	0.54
2.00	1.0	0.88	0.12	0.13	0.00	0.00
2.50	1.0	0.88	0.12	0.13	0.00	0.00
3.00	1.0	0.88	0.12	0.13	0.00	0.00

Table.A.44. The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : $105^{o}C$ and $60^{o}C$,
U_s : 11.90 ml/s , H_s : $30^{o}C$

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	12.0	3.36	8.64	2.57	-	-
0.25	11.8	3.36	8.44	2.51	0.80	0.23
0.50	11.6	3.36	8.24	2.45	0.80	0.23
0.75	11.4	3.36	8.04	2.39	0.80	0.23
1.00	11.2	3.36	7.84	2.33	0.80	0.23
1.25	11.0	3.36	7.64	2.27	0.80	0.23
1.50	10.8	3.36	7.44	2.21	0.80	0.23
1.75	10.6	3.36	7.24	2.15	0.80	0.23
2.00	10.4	3.36	7.04	2.09	0.80	0.23
2.25	10.2	3.36	6.84	2.03	0.80	0.23
2.50	9.9	3.36	6.74	2.03	0.40	0.11
2.75	9.9	3.36	6.74	2.03	0.00	0.0
3.00	9.7	3.36	6.54	1.94	0.80	0.23
3.50	9.4	3.36	6.24	1.85	0.60	0.17
4.00	8.9	3.36	5.74	1.70	1.00	0.29
4.50	8.9	3.36	5.74	1.70	0.00	0.00
5.00	8.9	3.36	5.74	1.70	0.00	0.00
5.50	8.9	3.36	5.74	1.70	0.00	0.00
6.00	7.9	3.36	4.74	1.41	2.00	0.59
6.50	7.9	3.36	4.74	1.41	0.00	0.00
7.00	7.8	3.36	4.64	1.41	0.20	0.05
7.50	7.8	3.36	4.64	1.41	0.00	0.00
8.00	7.8	3.36	4.64	1.41	0.00	0.00
9.00	7.8	3.36	4.64	1.41	0.00	0.00
10.00	7.8	3.36	4.64	1.41	0.00	0.00
11.00	7.8	3.36	4.64	1.41	0.00	0.00

Table.A.45. The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 115°C and 70°C ,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.2	1.736	4.464	2.57	-	-
0.25	5.7	1.736	3.964	2.28	2.00	1.15
0.50	5.5	1.736	3.764	2.16	0.80	0.46
0.75	5.5	1.736	3.764	2.16	0.00	0.00
1.00	5.4	1.736	3.664	2.11	0.40	0.23
1.25	5.4	1.736	3.664	2.11	0.00	0.00
1.50	5.3	1.736	3.564	2.05	0.40	0.23
1.75	5.1	1.736	3.364	1.93	0.80	0.46
2.00	4.7	1.736	2.964	1.70	1.60	0.92
2.25	4.6	1.736	2.864	1.64	0.40	0.23
2.50	4.5	1.736	2.764	1.59	0.40	0.23
2.75	4.3	1.736	2.564	1.47	0.80	0.46
3.00	4.3	1.736	2.564	1.47	0.00	0.00
3.25	4.1	1.736	2.364	1.36	0.40	0.23
3.50	4.0	1.736	2.264	1.30	0.40	0.23
3.75	4.0	1.736	2.264	1.30	0.00	0.00
4.00	3.8	1.736	2.064	1.18	0.80	0.46
4.25	3.8	1.736	2.064	1.18	0.00	0.00
4.50	3.7	1.736	1.964	1.13	0.40	0.23
4.75	3.6	1.736	1.864	1.07	0.40	0.23
5.00	3.6	1.736	1.864	1.07	0.00	0.00
5.50	3.5	1.736	1.764	1.01	0.40	0.23
5.75	3.3	1.736	1.564	0.90	0.80	0.46
6.00	3.3	1.736	1.564	0.90	0.00	0.00
6.25	3.0	1.736	1.264	0.72	1.20	0.69
6.50	2.8	1.736	1.064	0.61	0.80	0.46
6.75	2.7	1.736	0.964	0.55	0.80	0.46
7.00	2.7	1.736	0.964	0.55	0.00	0.00
7.50	2.6	1.736	0.864	0.49	0.20	0.11
8.00	2.5	1.736	0.764	0.44	0.20	0.11
8.50	2.4	1.736	0.664	0.38	0.20	0.11
9.00	2.3	1.736	0.564	0.32	0.20	0.11
9.50	2.1	1.736	0.364	0.20	0.40	0.23
10.00	2.0	1.736	0.264	0.15	0.20	0.11
10.50	2.0	1.736	0.264	0.15	0.00	0.00
11.00	2.0	1.736	0.264	0.15	0.00	0.00
11.50	2.0	1.736	0.264	0.15	0.00	0.00

Table . A.46. The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 125°C and 75°C,
U_s : 11.90 ml/s , H_s : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	7.4	2.07	5.33	2.57	-	-
0.25	7.0	2.07	4.93	2.38	1.60	0.77
0.50	6.6	2.07	4.53	2.18	1.60	0.77
0.75	6.5	2.07	4.43	2.14	0.40	0.19
1.00	6.4	2.07	4.33	2.09	0.40	0.19
1.25	6.2	2.07	4.13	1.99	0.80	0.38
1.50	5.3	2.07	3.23	1.56	3.60	1.73
1.75	5.3	2.07	3.23	1.56	0.00	0.00
2.00	5.2	2.07	3.13	1.51	0.40	0.19
2.25	5.0	2.07	2.93	1.41	0.80	0.38
2.50	4.8	2.07	2.73	1.31	0.80	0.38
2.75	4.6	2.07	2.53	1.22	0.80	0.38
3.00	4.4	2.07	2.33	1.12	0.80	0.38
3.25	4.0	2.07	1.93	0.93	1.60	0.77
3.50	3.8	2.07	1.73	0.83	0.80	0.38
3.75	3.7	2.07	1.63	0.78	0.40	0.19
4.00	3.6	2.07	1.53	0.73	0.40	0.19
4.25	3.6	2.07	1.53	0.73	0.00	0.00
4.50	3.4	2.07	1.33	0.64	0.80	0.38
5.00	3.4	2.07	1.33	0.64	0.00	0.00
5.25	3.3	2.07	1.23	0.59	0.40	0.19
5.50	3.1	2.07	1.03	0.49	0.80	0.38
5.75	3.0	2.07	0.93	0.44	0.40	0.19
6.00	3.0	2.07	0.93	0.44	0.00	0.00
6.50	2.6	2.07	0.53	0.25	0.80	0.38
7.00	2.2	2.07	0.21	0.10	0.64	0.35
8.00	2.1	2.07	0.07	0.02	0.07	0.07
8.50	2.1	2.07	0.07	0.02	0.00	0.07
9.00	2.1	2.07	0.07	0.02	0.00	0.07

Table.A.47. The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 135^{o}C and 80^{o}C,
U_s : 11.90 ml/s , H_s : 30^{o}C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	9.6	2.688	6.912	2.57	-	-
0.25	8.5	2.688	5.812	2.16	4.40	1.63
0.50	8.1	2.688	5.412	2.01	1.60	0.59
0.75	7.9	2.688	5.212	1.93	0.80	0.29
1.00	7.2	2.688	4.512	1.67	3.50	1.30
1.25	7.0	2.688	4.312	1.60	0.80	0.29
1.50	6.5	2.688	3.812	1.41	2.00	0.74
1.75	6.0	2.688	3.312	1.23	2.00	0.74
2.00	5.8	2.688	3.112	1.15	0.80	0.29
2.25	5.5	2.688	2.812	1.04	1.20	0.44
2.50	5.3	2.688	2.612	0.97	0.80	0.29
2.75	5.0	2.688	2.312	0.86	1.20	0.44
3.00	4.5	2.688	1.812	0.67	2.00	0.74
3.25	4.3	2.688	1.612	0.59	0.80	0.29
3.50	4.3	2.688	1.612	0.59	0.00	0.00
3.75	3.8	2.688	1.112	0.41	2.00	0.74
4.00	3.6	2.688	0.912	0.33	0.80	0.29
4.25	3.3	2.688	0.612	0.22	1.20	0.44
4.50	3.0	2.688	0.312	0.11	1.20	0.44
4.75	3.0	2.688	0.312	0.11	0.00	0.00
5.00	2.9	2.688	0.212	0.07	0.80	0.29
5.50	2.8	2.688	0.112	0.04	0.40	0.07
6.00	2.7	2.688	0.012	0.01	0.40	0.07
6.50	2.7	2.688	0.012	0.01	0.00	0.00

Table . A.48. The drying of tomato paste droplet : 28 Brix
Air inlet and outlet : 160°C and 100°C,
U_S : 11.90 ml/s , H_S : 30°C

θ(min)	W(mg)	S(mg)	X(mg)	y = X/S	$\frac{\Delta X}{\Delta \theta}$	$\frac{\Delta X}{\Delta \theta . S}$
0.00	6.5	1.82	4.68	2.57	-	-
0.25	6.0	1.82	4.18	2.29	2.00	1.09
0.50	5.5	1.82	3.68	2.02	2.00	1.09
0.75	5.2	1.82	3.38	1.85	1.20	0.65
1.00	4.7	1.82	2.88	1.58	2.00	1.09
1.25	4.3	1.82	2.48	1.36	1.60	0.87
1.50	4.1	1.82	2.28	1.25	0.80	0.43
1.75	3.9	1.82	2.08	1.14	0.80	0.43
2.00	3.8	1.82	1.98	1.08	0.40	0.21
2.25	3.8	1.82	1.98	1.08	0.00	0.00
2.50	3.7	1.82	1.88	1.03	0.40	0.21
2.75	3.3	1.82	1.48	0.81	1.60	0.87
3.00	3.2	1.82	1.38	0.72	0.40	0.21
3.25	3.1	1.82	1.28	0.70	0.40	0.21
3.75	2.9	1.82	1.08	0.59	0.80	0.43
4.25	2.8	1.82	0.98	0.53	0.40	0.21
4.75	2.7	1.82	0.88	0.48	0.40	0.21
5.25	2.6	1.82	0.78	0.42	0.40	0.21
5.50	2.6	1.82	0.78	0.42	0.40	0.21
6.00	2.6	1.82	0.78	0.42	0.00	0.00
6.50	2.6	1.82	0.78	0.42	0.00	0.00
7.00	2.6	1.82	0.78	0.42	0.00	0.00
7.50	2.6	1.82	0.78	0.42	0.00	0.00
8.00	2.6	1.82	0.78	0.42	0.00	0.00

Table.A 49 The drying of tomato paste droplet : 5 Brix
U_s : 11.9 ml/s , H_s : 20°C

t = 105-60°C		t = 115-70°C		t = 125-75°C		t = 135-80°C		t = 160-100°C	
Θ(min)	m*	Θ(min)	m*	Θ(min)	m*	Θ(min)	m*	Θ(min)	m*
0.00	1.000	0.00	1.000	0.00	1.000	0.00	1.000	0.00	1.000
0.50	0.913	0.50	0.938	0.25	0.900	0.25	0.878	0.25	0.968
1.00	0.804	1.00	0.857	0.50	0.731	0.50	0.809	0.50	0.906
1.50	0.636	1.50	0.775	0.75	0.682	0.75	0.757	0.75	0.750
2.00	0.543	2.00	0.673	1.00	0.461	1.00	0.433	1.00	0.594
2.50	0.391	2.50	0.551	1.25	0.461	1.25	0.312	1.25	0.468
3.00	0.304	3.00	0.551	1.50	0.339	1.50	0.149	1.50	0.312
3.50	0.239	3.50	0.347	1.75	0.339	1.75	0.068	1.75	0.312
4.00	0.152	4.00	0.326	2.00	0.118	2.00	0.027	2.00	0.187
4.50	0.130	4.50	0.206	2.25	0.118			2.25	0.031
5.00	0.043	5.00	0.102	2.50	0.069				
5.50	0.043	5.50	0.102	2.75	0.020				
6.00	0.043	6.00	0.061	3.00	0.020				
6.50	0.043	6.50	0.041						

Table . A 50 The drying of tomato paste droplet : 10 Brix
U_s : 11.90 ml/s , H_s : 20°C

t = 105-60°C		t = 115-70°C		t = 125-75°C		t = 135-80°		t = 160-100°C	
Θ(min)	m^*	Θ(min)	m^*	Θ(min)	m^*	Θ(min)	m^*	Θ(min)	m^*
0.00	1.000	0.00	1.000	0.00	1.000	0.00	1.000	0.00	1.000
0.25	0.934	0.25	0.914	0.50	0.780	0.25	0.833	0.25	0.899
0.50	0.903	0.50	0.743	1.00	0.390	0.50	0.778	0.50	0.763
0.75	0.870	0.75	0.657	1.50	0.390	0.75	0.722	0.75	0.596
1.00	0.837	1.00	0.571	2.00	0.244	1.00	0.639	1.00	0.393
1.25	0.837	1.25	0.571	2.50	0.170	1.25	0.500	1.25	0.124
1.50	0.837	1.50	0.486	3.00	0.147	1.50	0.361	1.50	0.057
1.75	0.837	1.75	0.486	3.50	0.072	1.75	0.167	1.75	0.023
2.00	0.837	2.00	0.371	4.00	0.072	2.00	0.056		
2.25	0.806	2.50	0.286	4.50	0.049	2.25	0.028		
2.50	0.773	3.00	0.257	5.00	0.024	2.50	0.028		
3.00	0.742	3.50	0.114			2.75	0.028		
3.50	0.742	4.00	0.114						
4.00	0.709	4.50	0.057						
4.50	0.580	5.00	0.028						
5.00	0.515								
5.50	0.515								
6.00	0.386								
6.50	0.386								
7.00	0.386								
7.50	0.289								
8.00	0.161								

Table ,A 51 The drying of tomato paste droplet : 15 Brix
U_s : 11.90 ml/s , H_s : 20°C

t = 105-60°C		t = 115-70°C		t = 125-75°C		t = 135-80°C		t = 160-100°C	
Θ(min)	m*	Θ(min)	m*	Θ(min)	m*	Θ(min)	m*	Θ(min)	m*
0.50	0.883	0.25	0.964	0.25	0.945	0.25	0.857	0.25	0.883
1.00	0.794	0.50	0.928	0.50	0.874	0.50	0.778	0.50	0.883
1.50	0.736	0.75	0.928	0.75	0.782	0.75	0.698	0.75	0.470
2.00	0.588	1.00	0.836	1.00	0.691	1.00	0.539	1.00	0.287
2.50	0.588	1.50	0.746	1.25	0.691	1.25	0.477	1.25	0.235
3.00	0.588	2.00	0.618	1.50	0.618	1.50	0.382	1.50	0.235
3.50	0.530	2.50	0.472	1.75	0.510	1.75	0.302	1.75	0.118
4.00	0.470	3.00	0.382	2.00	0.455	2.00	0.286	2.00	0.059
4.50	0.441	3.50	0.308	2.25	0.382	2.25	0.207	2.25	0.059
5.00	0.441	4.00	0.164	2.50	0.327	2.50	0.143	2.50	0.059
5.50	0.441	4.50	0.164	2.75	0.272	2.75	0.143	2.75	0.059
6.00	0.412	5.00	0.164	3.00	0.236	3.00	0.143		
6.50	0.353	5.50	0.144	3.25	0.217	3.25	0.143		
7.00	0.295	6.00	0.108	3.50	0.199	3.50	0.064		
7.50	0.177	6.50	0.108	3.75	0.181	4.00	0.064		
8.00	0.118	7.00	0.072	4.00	0.146	4.50	0.064		
8.50	0.118	7.50	0.054	4.25	0.128	5.00	0.064		
9.00	0.118	8.00	0.036	4.50	0.110	5.50	0.016		
		8.50	0.018	4.75	0.110				
				5.00	0.091				
				5.25	0.073				
				5.50	0.073				
				6.00	0.036				
				6.50	0.018				

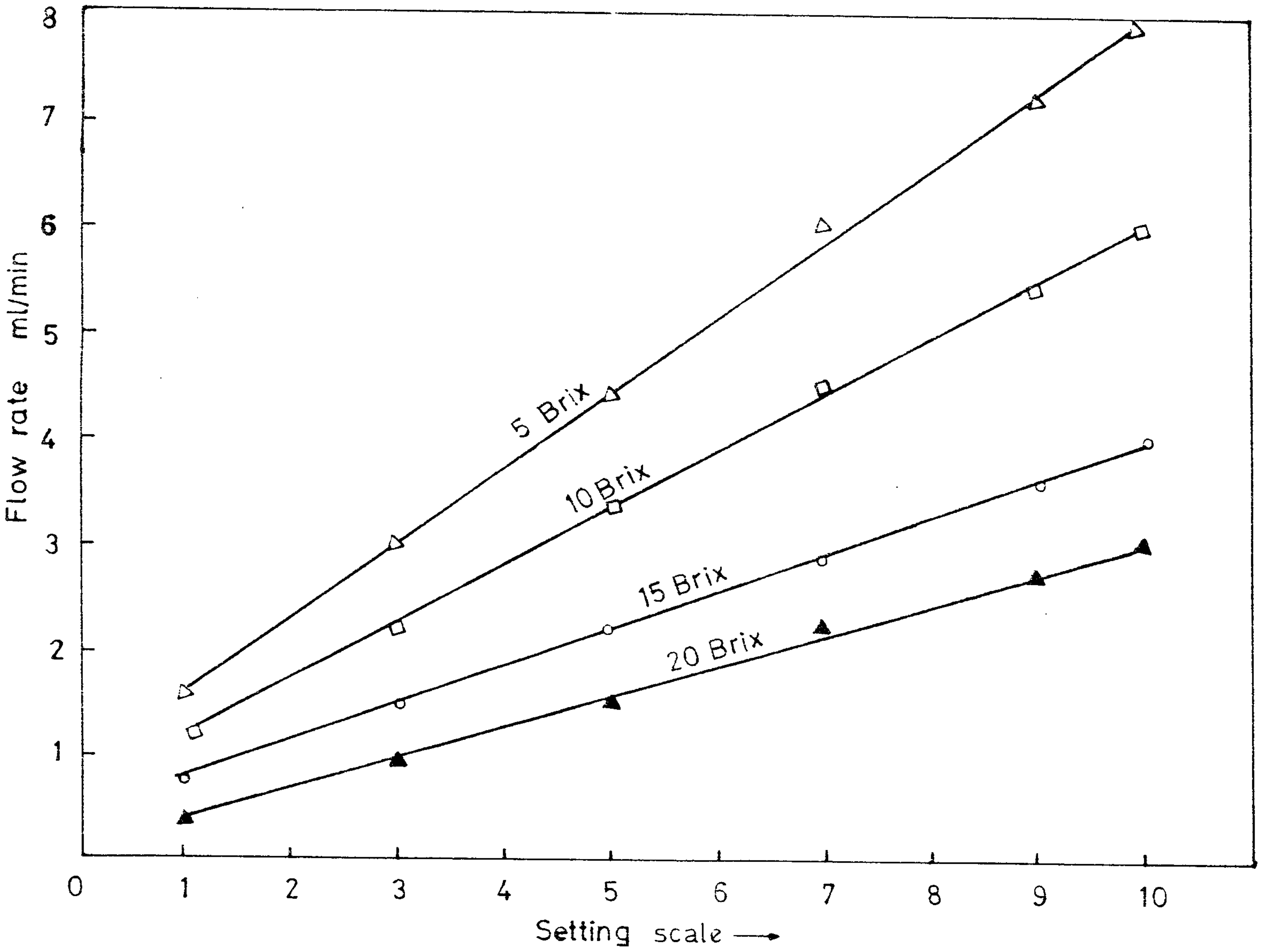

Figure 5.2 a Feed rate of tomato paste for different concentrations

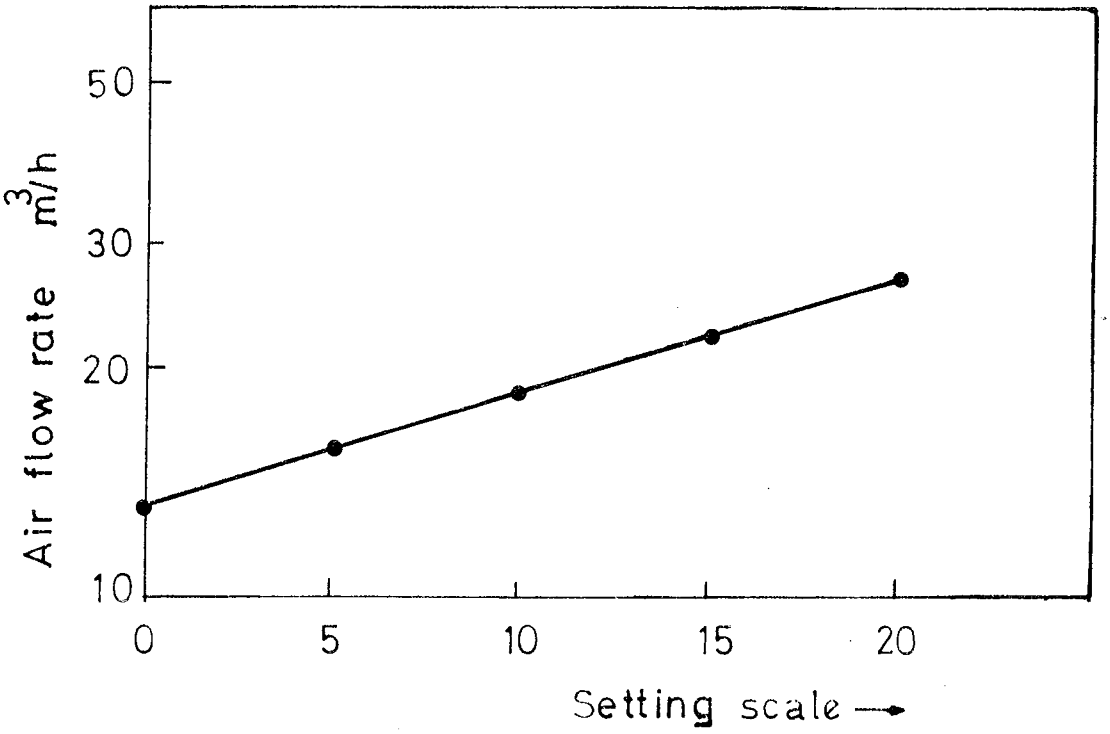

Figure 5.2b Air flow rate in the drying chamber

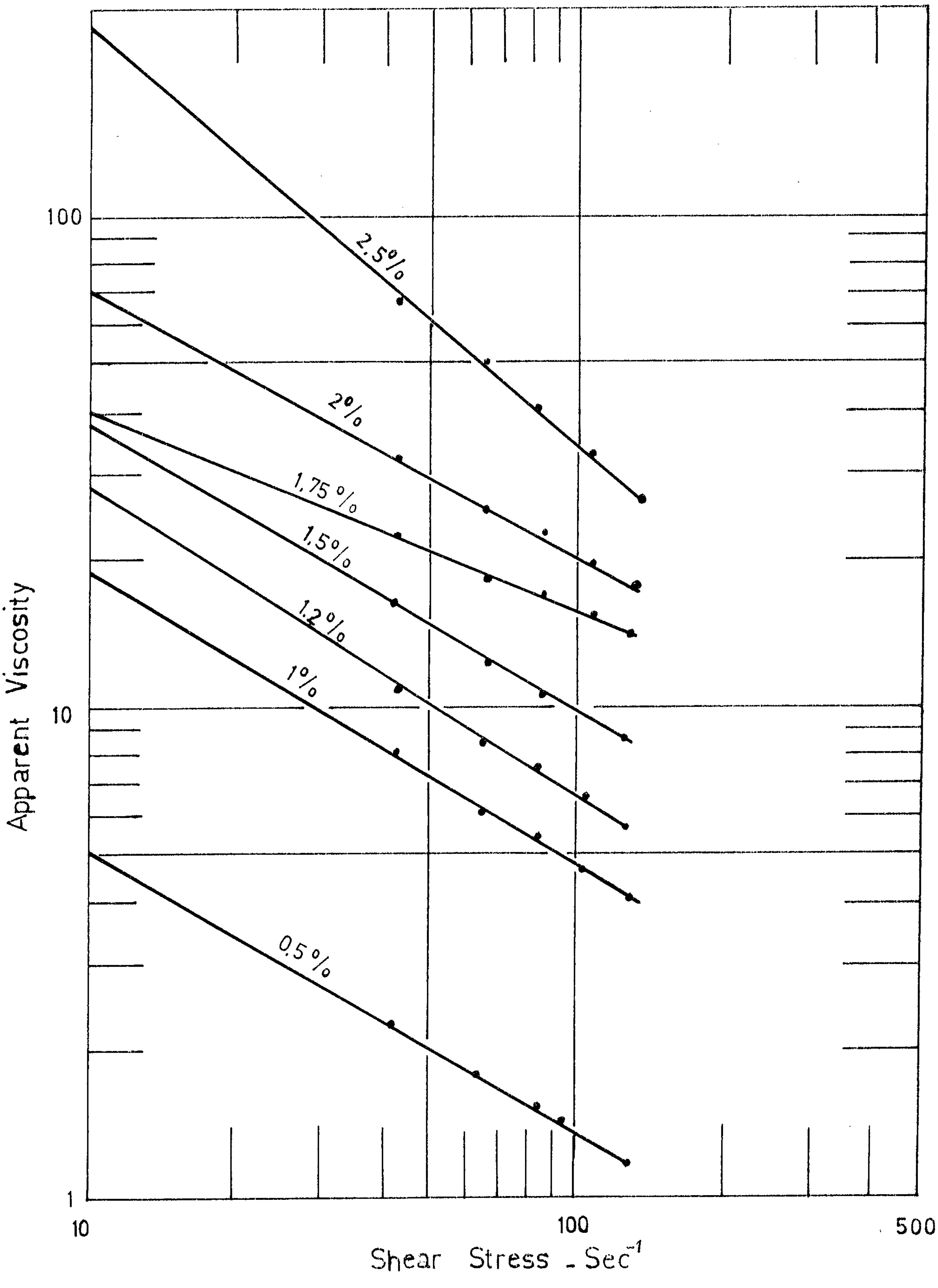

Figure 5.3 Viscosity of CMC for different dilutions.

Table. B.1 Spray drying of tomato paste

Air flow rate: 24 m^3/h Feed rate: 6 scale Air flow rate through nozzle : 700 lt/h

Run No	Brix	Θ_1 (°C)	Θ_2 (°C)	P(g)	D(g)	Y(%)	ρ (kg/m^3 x10^3)	M(%)
1.1	5	125	82	-	11.8	0	-	13.8
1.2	5	130	84	-	8.6	0	-	12.5
1.3	5	135	86	-	11.5	0	-	12.0
1.4	5	140	89	-	10.7	0	-	11.8
1.5	5	150	99	-	12.1	0	-	10.7
1.6	5	160	112	-	10.5	0	-	10.0
1.7	5	170	114	-	9.8	0	-	9.5
1.8	10	125	92	2.5	11.3	18.1	0.44	10.2
1.9	10	130	92	3.0	9.7	30.9	0.45	8.7
1.10	10	135	94	3.9	9.6	28.8	0.43	7.5
1.11	10	140	94	3.5	10.6	24.8	0.43	6.3
1.12	10	150	105	2.5	13.3	15.8	0.46	5.9
1.13	10	160	112	1.1	12.3	8.2	0.43	3.5
1.14	10	170	114	0.8	14.3	5.6	0.44	2.5

Table. B.2 Spray drying of tomato paste

Air flow rate: $24 m^3/h$ Feed rate: 6 scale Air flow rate through nozzle : 700 lt/h

Run No	Brix	Θ_1 (^oC)	Θ_2 (^oC)	P(g)	D(g)	Y(%)	ρ(kg/m^3) $x10^3$	M(%)
1.15	15	130	86	8.0	19.2	20.3	0.45	7.9
1.16	15	135	90	8.2	17.5	31.9	0.44	6.5
1.17	15	140	95	4.0	23.9	14.3	0.43	5.5
1.18	15	150	100	3.2	21.2	13.0	0.41	4.2
1.19	15	160	112	2.1	21.9	8.7	0.42	3.1
1.20	15	170	113	1.5	26.5	5.5	0.43	1.4
1.21	20	125	86	2.4	16.0	13.0	0.44	8.9
1.22	20	130	86	3.5	19.8	15.0	0.43	7.3
1.23	20	135	90	6.1	17.9	23.0	0.44	5.7
1.24	20	140	95	4.2	17.0	18.8	0.45	4.5
1.25	20	150	100	3.1	22.3	12.2	0.44	2.9
1.26	20	160	112	2.2	23.1	8.6	0.43	1.8
1.27	20	170	113	1.7	27.2	6.2	0.42	1.1

Table. B.3 Spray drying of tomato paste

Air flow rate : $24 m^3/h$ Feed rate : 4 scale

Air flow rate through nozzle : 700 lt/h

Run No	Brix	Θ_1(^oC)	Θ_2(^oC)	P(g)	D(g)	Y(%)
1.28	5	125	83	-	15.8	-
1.29	5	130	86	-	14.6	-
1.30	5	135	89	-	14.7	-
1.31	5	140	95	1.2	13.2	8.3
1.32	5	150	98	1.5	12.8	10.4
1.33	10	125	84	2.9	12.1	19.3
1.34	10	130	87	3.1	11.8	20.8
1.35	10	135	91	3.8	11.7	24.5
1.36	10	140	96	3.7	11.3	24.6
1.37	10	150	102	1.9	13.2	12.5
1.38	15	125	85	4.0	11.7	25.4
1.39	15	130	88	4.5	11.5	28.1
1.40	15	135	92	4.5	10.8	28.4
1.41	15	140	97	4.0	10.7	27.2
1.42	15	150	105	2.5	12.7	16.4
1.43	20	125	86	2.3	13.2	14.8
1.44	20	130	88	2.2	12.8	14.6
1.45	20	135	92	2.8	13.1	17.6
1.46	20	140	98	1.9	13.5	12.3
1.47	20	150	108	1.3	13.9	8.5

Table. B.4. Spray drying tomato paste

Air flow rate : $24m^3/h$ Feed rate : 8 scale

Air flow rate through nozzle : 700 lt/h

Run No.	Brix	$\Theta_1(^oC)$	$\Theta_2(^oC)$	P(g)	D(g)	Y(%)
1.48	5	125	80	-	15.6	-
1.49	5	130	82	-	15.1	-
1.50	5	135	84	-	15.2	-
1.51	5	140	86	-	15.7	-
1.52	5	150	95	-	15.6	-
1.53	10	125	81	1.1	14.0	7.2
1.54	10	130	84	2.2	13.5	14.0
1.55	10	135	85	3.1	12.5	19.8
1.56	10	140	90	2.9	12.7	18.5
1.57	10	150	96	1.7	14.1	10.7
1.58	15	125	90	2.5	13.2	6.3
1.59	15	130	92	3.2	12.0	21.0
1.60	15	135	93	3.5	12.5	21.8
1.61	15	140	95	2.4	13.3	15.2
1.62	15	150	98	1.8	12.9	12.2
1.63	20	125	85	1.6	13.5	11.1
1.64	20	130	87	2.3	12.7	15.3
1.65	20	135	91	2.7	13.1	17.0
1.66	20	140	96	2.1	12.8	14.0
1.67	20	150	99	1.9	12.3	13.3

Table B.5 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min (6 scale)

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	An. lt/h
1.68	135	90	8.1	17.4	31.7	700
1.69	135	90	6.5	17.5	27.0	800
1.70	135	90	7.1	17.3	29.0	600
1.71	135	90	5.1	17.7	22.3	500
1.72	135	90	4.6	17.3	21.0	400
1.73	135	90	-	22.8	0	200
1.74	140	95	4.2	17.0	19.8	700
1.75	140	95	3.5	18.1	16.3	800
1.76	140	95	3.2	17.1	15.7	600
1.77	140	95	3.1	17.6	14.9	500
1.78	140	95	2.1	19.1	9.9	400
1.79	140	95	0.5	20.4	2.3	200

Table B.6 Spray drying tomato paste : 15 Brix

Air flow rate through nozzle : 700 lt/h

Feed rate : 2.5 ml/min (6 scale)

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Afr. m^3/h
1.80	135	90	6.2	17.6	26.0	28
1.81	135	90	8.2	17.8	31.9	24
1.82	135	90	5.7	18.5	23.5	20
1.83	135	90	4.5	19.2	18.9	16
1.84	135	90	4.1	20.4	13.19	12
1.85	140	95	3.0	20.1	12.9	28
1.86	140	95	4.0	20.8	16.1	24
1.87	140	95	3.7	21.1	14.9	20
1.88	140	95	2.1	22.5	8.5	16
1.89	140	95	1.8	23.1	7.2	12

Table B.7 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min (6 scale)

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Ad. T.S. %	An. lt/h
2.1	135	90	3.0	18.2	14.0	2.5 NaCl	500
2.2	135	90	6.8	14.3	32.2	5 NaCl	500
2.3	135	90	6.5	18.9	25.5	10 NaCl	500
2.4	135	90	7.0	17.8	28.1	15 NaCl	500
2.5	135	90	7.2	19.8	26.6	20 NaCl	500
2.6	135	90	6.7	19.0	26.0	25 NaCl	500
2.7	135	90	6.3	18.9	25.0	30 NaCl	500
2.8	135	90	4.8	17.3	21.7	5 NaCl	700
2.8	140	95	1.9	17.9	9.5	5 NaCl	700
2.9	150	105	1.5	18.7	7.4	5 NaCl	700
2.10	140	95	3.5	15.0	18.9	5 NaCl	500
2.11	150	95	3.0	17.3	14.7	5 NaCl	500
2.12	135	90	3.1	17.0	15.4	0.5 CMC	500
2.13	135	90	4.1	18.9	17.8	1.0 CMC	500
2.14	135	90	3.5	16.5	17.5	1.5 CMC	500
2.15	135	90	3.6	16.3	18.0	2.0 CMC	500
2.16	135	90	3.5	16.8	17.2	2.5 CMC	500
2.17	135	90	4.2	15.9	20.8	2 CMC	700
2.18	140	95	4.7	15.6	23.1	2 CMC	700
2.19	150	105	4.8	15.8	23.3	2 CMC	700
2.20	135	90	2.8	16.9	14.2	0.5 MgS	500
2.21	135	90	2.9	16.5	14.9	1 MgS	500
2.22	135	90	4.2	17.6	19.2	1.5 MgS	500

Cont.

Table B.7 (cont.)

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Ad. T.S.%	An. lt/h
2.23	135	90	3.3	17.8	15.6	2 MgS	500
2.24	135	90	4.1	16.9	19.5	1.5 MgS	700
2.25	140	95	3.3	17.9	15.5	1.5 MgS	700
2.26	150	105	2.8	17.3	13.9	1.5 MgS	700

Table B.8 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2,5 ml/min(6 scale)

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Ad. T.S. %	An. lt/h
2.27	135	90	5.0	18,3	21,4	1,5 CMC 5 NaCl	700
2.28	135	90	4.0	19,7	16,8	1,5 MgS 5 NaCl	700
2.29	135	90	4.1	20.1	16,9	2 CMC 5 NaCl	700
2.30	135	90	3.2	21,1	13,1	2 MgS 5 NaCl	700
2.31	135	90	4.5	17.2	20,2	2.0 CMC 1,5 NaCl	700
2.32	135	90	3.4	18,6	15.4	2 MgS 1,5 NaCl	700
2.33	135	90	7,1	13.0	35,3	2.5 CMC 1,5 NaCl	700
2.34	135	90	3.4	19,2	15,0	2.5 MgS 1,5 NaCl	700
2.35	140	95	5.3	14.6	26.6	2,5 CMC 1,5 NaCl	700
2.36	150	105	2.9	18,2	13.7	2,5 CMC 1,5 NaCl	700
2.37	140	95	4.1	18,7	17.9	1.5 CMC 5 NaCl	700
2.38	150	105	3.2	19,1	14,3	1.5 CMC 5 NaCl	700
2.39	140	95	2.9	19.3	13,0	2 MgS 5 NaCl	700
2.40	150	105	2.1	19,1	9,9	2 MgS 5 NaCl	700
2.41	140	95	3.7	18.1	16.9	2 CMC 1,5 NaCl	700
2.42	150	105	3,5	19.5	15.2	2 CMC 1.5 NaCl	700
2.43	140	95	2,7	19.6	12,7	2 MgS 1.5 NaCl	700
2.44	150	105	1,5	20.2	6,9	2 MgS 1,5 NaCl	700
2.45	135	90	5.2	17.1	23.3	2.5 CMC 1,5 NaCl	500
2.46	140	95	4.4	18.8	18.96	2.5 CMC 1.5 NaCl	500
2.47	150	105	2.5	19.2	11.52	2.5 CMC 1.5 NaCl	500
2.48	140	95	4.1	15,3	21,1	1,5 MgS	500
2.49	150	105	2.2	18.2	10,7	1,5 MgS	500

Table B.9 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min (6 scale)

With inderct cooling system.

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Ad. T.S. %	An. lt/h
3.1	135	90	5.1	17.9	22.1	2 CMC,5 NaCl	700
3.2	140	95	6.1	18.2	25.1	2 CMC,5 NaCl	700
3.3	150	105	3.5	19.3	15.3	2 CMC,5 NaCl	700
3.4	135	90	7.8	13.2	37.1	2.5 CMC,1.5 NaCl	700
3.5	140	95	7.9	14.5	35.2	2.5 CMC,1.5 NaCl	700
3.6	150	105	4.5	18.1	19.9	2.5 CMC,1.5 NaCl	700
3.7	135	90	6.7	15.3	30.4	2 CMC, 1.5 NaCl	700
3.8	140	95	6.5	14.1	31.55	2 CMC, 1.5 NaCl	700
3.9	150	105	3.8	17.3	18.0	2 CMC, 1.5 NaCl	700
3.10	135	90	4.9	16.6	22.7	No	700
3.11	140	95	5.1	16.8	23.2	No	700
3.12	150	105	3.2	19.1	14.3	No	700

Table B.10 Spray drying tomato paste : 15.0 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min (6 scale)
Air bleed into drying chamber through 12 mm Ø glass pipe

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	γ(%)	Ad. T.S.%	An. lt/h	Po mm
4.1	140	80	9.0	13.4	40.0	2 CMC 5 NaCl	500	30
4.2	140	81	10.4	11.7	47.0	2 CMC 5 NaCl	700	30
4.3	150	82	7.0	15.4	31.2	2 CMC 5 NaCl	700	30
4.4	150	86	4.1	20.2	16.8	2 CMC 5 NaCl	500	30
4.5	150	84	6.2	18.0	25.6	2 CMC 5 NaCl	700	90
4.6	150	82	8.2	15.9	34.0	1.5 CMC 2 NaCl	700	90
4.7	150	82	3.2	18.0	15.0	1.5 MgS	700	90
4.8	140	79	6.2	18.4	25.2	2 CMC 5 NaCl	700	32
4.9	140	73	8.5	14.0	37.7	2 CMC 5 NaCl	700	24
4.10	140	80	10.2	13.8	42.5	2 CMC 5 NaCl	700	20
4.11	140	80	6.5	14.2	31.4	No	700	20
4.12	140	82	10.3	13.4	43.4	2 CMC 5 NaCl	700	18
4.13	140	84	9.8	12.6	43.7	2 CMC 5 NaCl	700	14
4.14	140	84	9.7	12.4	43.8	2 CMC 5 NaCl	700	70

Table B.11 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min(6 scale)
Air blleding into drying chamber through different diameter of glass pipes.

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Ad. T.S.%	An.	da. Ø mm	Po. mm
5.1	140	82	6.1	18.3	25.0	2 CMC 5 NaCl	700	8	30
5.2	140	83	6.5	14.6	30.8	1.5 CMC 2 NaCl	700	8	30
5.3	140	87	7.3	17.5	29.4	1.5 CMC 2 NaCl	700	8	90
5.4	140	53	6.9	17.2	28.6	2 CMC 5 NaCl	700	20	10
5.5	140	52	4.6	18.4	20.0	1.5 CMC 1.5 NaCl	700	20	30
5.6	140	52	10.5	14.5	42.0	2 CMC 5 NaCl	700	20	10
5.7	145	78	8.3	15.4	35.0	2 CMC 5 NaCl	700	12	30
5.8	138	76	7.5	15.4	32.0	2 CMC 5 NaCl	700	12	30
5.9	140	79	6.0	19.0	24.0	2 CMC 5 NaCl	500	12	30
5.10	140	79	9.2	11.3	44.0	2 CMC 5 NaCl	700	12	30
5.11	140	79	11.0	12.8	46.2	1.5 CMC 2 NaCl	700	12	30
5.12	142	80	8.0	15.0	34.0	1.5 CMC 2 NaCl	700	12	30
5.13	143	81	8.3	15.0	35.6	1.5 CMC 2 NaCl	700	12	30
5.14	143	81	8.8	14.0	38.5	1.5 CMC 2 NaCl	700	12	30

Table B.12 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min(6 scale)
Air bleeding into drying chamber through different diameter of glass pipes.

Run No	Θ_1(°C)	Θ_2(°C)	P(g)	D(g)	Y(%)	Ad. T.S.%	An. lt/h	da. Ø mm	Po. mm
6.1	143	83	8.0	16.8	32.2	1.5 NaCl 2 CMC	700	12	60
6.2	143	83	10.1	15.5	39.4	1.5 NaCl 2 CMC	700	12	70
6.3	143	83	10.8	13.7	44.1	1.5 NaCl 2 CMC	700	12	90
6.4	143	83	9.7	15.0	39.3	1.5 NaCl 2 CMC	700	12	100
6.5	145	85	8.8	15.0	37.0	1.5 NaCl 2 CMC	700	12	60
6.7	145	85	7.0	17.3	28.8	1.5 NaCl 2 CMC	700	12	30
6.8	145	85	10.4	12.5	45.4	1.5 NaCl 2 CMC	700	12	90
6.9	145	85	9.2	14.3	39.1	1.5 NaCl 2 CMC	700	12	100
6.10	142	80	8.3	16.6	33.3	1.5 NaCl 2 CMC	700	12	30
6.11	142	80	4.5	18.0	20.0	1.5 NaCl 2 CMC	500	12	30
6.12	145	95	4.8	19.2	20.0	1.5 NaCl 2 CMC	700	20	30
6.13	142	82	7.7	14.3	35.0	1.5 NaCl 2 CMC	700	12	60
6.14	142	82	8.9	13.0	40.8	1.5 NaCl 2 CMC	700	12	90
6.15	142	82	9.4	14.6	39.1	1.5 NaCl 2 CMC	700	12	100

Table B.13 Spray drying tomato paste : 15 Brix

Air flow rate : 24 m^3/h Feed rate : 2.5 ml/min(6 scale)

Air flow through nozzle : 700 lt/h

Air bleeding into drying chamber through different diameter of glass pipes at fixed position of 30 mm inside the drying chamber

Run No	$\Theta_1 (^{o}C)$	$\Theta_2 (^{o}C)$	P(g)	D(g)	Y(%)	Ad. T.S. %	da Ø mm
7.1	143	76	7.5	15.3	32.8	1.5 CMC 2 NaCl	15
7.2	143	72	6.1	18.8	24.1	1.5 CMC 2 NaCl	16
7.3	140	74	8.8	13.9	38.7	1.5 CMC 2 NaCl	14
7.4	143	78	8.1	14.3	36.1	1.5 CMC 2 NaCl	13
7.5	141	92	9.2	15.3	37.5	1.5 CMC 2 NaCl	10
7.6	141	69	8.7	12.4	41.0	1.5 CMC 2 NaCl	16
7.7	143	92	8.1	16.8	32.0	1.5 CMC 2 NaCl	10
7.8	140	72	8.2	15.0	35.0	1.5 CMC 2 NaCl	16
7.9	140	78	8.0	14.0	33.3	1.5 CMC 2 NaCl	13
7.10	140	72	8.9	13.9	39.0	1.5 CMC 2 NaCl	16
7.11	140	76	10.5	12.8	45.0	1.5 CMC 2 NaCl	15
7.12	142	79	7.9	15.1	34.3	1.5 CMC 2 NaCl	13
7.13	142	69	8.4	15.3	37.0	1.5 CMC 2 NaCl	16
7.14	143	69	9.1	14.2	39.0	1.5 CMC 2 NaCl	16
7.15	145	72	6.7	18.1	27.0	1.5 CMC 2 NaCl	15

Table B 14 Estimation the Colours of Different Experimental Runs by Lovibond Tintometer

Run No	% Dilution	Name of dilution	Colours		
			Red	Yellow	Blue
-	5	Tomato paste	27.3	12.0	2.3
1.8	5	Powder	27.0	14.0	2.1
1.9	5	Powder	27.0	12.0	2.3
1.10	5	Powder	27.0	14.0	2.3
1.11	5	Powder	27.3	12.0	2.3
1.12	5	Powder	22.2	15.4	1.3
1.13	5	Powder	15.2	15.4	1.3
1.14	5	Powder	12.2	14.4	2.3
5.11	5	Powder	27.0	14.0	2.1
7.11	5	Powder	26.2	14.3	1.1
7.14	5	Powder	26.2	14.3	1.1
8.13	5	Powder	22.2	13.2	2.1
8.1	5	Powder	19.5	15.0	2.0
1.19	5	Powder	16.4	15.0	1.0
1.20	5	Powder	12.2	15.2	1.3

Table B 15 Colours of Tomato Paste and Powder, Transformation in CIE Standard Illuminant

Run No.	x'	y'	z'	Symbols on the graph
Tomato paste	0.536	0.396	0.066	A
1.8	0.520	0.415	0.064	B_1
1.9	0.520	0.429	0.047	C
1.10	0.520	0.429	0.047	D
1.11	0.501	0.426	0.072	E_1
1.12	0.469	0.454	0.076	F
1.13	0.454	0.484	0.060	G
1.14	0.408	0.513	0.078	H
5.11	0.519	0.416	0.064	K
7.14	0.534	0.398	0.067	L
7.11	0.519	0.416	0.065	M_1
8.13	0.536	0.391	0.066	N_1
8.1	0.490	0.452	0.057	O
1.19	0.439	0.489	0.070	P_1
1.20	0.405	0.490	0.104	R_1

For a particular colorimeter, the transformation equations were ;

$R = 0.744$xunit of Red $+$ 0.151xunit of Yellow $+$ 0.150xunit of Blue

$Y_e = 0.388$xunit of Red $+$ 0.721xunit of Yellow $+$ 0.046xunit of Blue

$B =$ 0.075xunit of Yellow $+$ 0.825xunit of Blue

$$x' = \frac{R}{R+Y_e+B}, \quad y' = \frac{Y_e}{R+Y_e+B}, \quad z' = \frac{B}{R+Y_e+B}$$

Table B.16 Spray drying tomato paste : 15 Brix
Air flow rate : 24 m^3/h N : 12 rpm

Run No	Θ_1 (°C)	Θ_2 (°C)	F (ml/min)	P(g)	D (g)	Y (%)	Ad % T.S.	An lt/h
8.1	150	103	2.5	3.0	14.6	17.0	2 NaCl 0.5 CMC	700
8.2	140	95	2.5	3.1	11.7	20.0	2 NaCl 0.5 CMC	700
8.3	135	93	2.5	5.1	18.2	21.5	2 NaCl 0.5 CMC	700
8.4	125	90	2.5	3.5	9.8	26.3	2 NaCl 0.5 CMC	700
8.5	120	85	2.5	4.5	10.1	28.8	2 NaCl 0.5 CMC	700
8.6	117	72	2.5	6.2	13.9	30.8	2 NaCl 0.5 CMC	700
8.7	115	71	2.5	5.1	7.2	40.9	2 NaCl 0.5 CMC	700
8.8	112	69	2.5	3.0	6.2	32.6	2 NaCl 0.5 CMC	700
8.9	140	77	2.5	4.0	17.7	18.4	2 NaCl 1.5 CMC	700
8.10	120	65	2.5	2.5	7.5	25.0	2 NaCl 1.5 CMC	700
8.11	125	69	2.5	4.1	9.1	30.7	2 NaCl 1.5 CMC	700
8.12	130	72	2.5	5.2	8.7	37.4	2 NaCl 1.5 CMC	700
8.13	115	61	2.5	4.9	4.11	51.7	2 NaCl 1.5 CMC	700
8.14	140	77	2.5	2.5	2.90	16.0	2 NaCl 1.5 CMC	400
8.15	130	72	2.5	5.3	18.1	22.6	2 NaCl 1.5 CMC	400
8.16	120	65	2.5	2.5	7.5	25.0	2 NaCl 1.5 CMC	400
8.17	115	61	2.5	4.1	10.7	27.7	2 NaCl 1.5 CMC	400

Table B.17 Spray drying tomato paste : 15 Brix
Air flow rate : 24 m^3/h

Run No	Θ_1 (^oC)	Θ_2 (^oC)	F(ml/min)	P(g)	D(g)	Y(%)	Ad. %T.S.	An. lt/h	N rpm
9.1	115	63	2.2	8.2	14.3	36.80	-	500	12
9.2	115	64	2.2	5.5	7.2	43.30	2 NaCl 1.5 CMC	500	12
9.3	120	72	2.2	4.6	8.0	36.50	2 NaCl 1.5 CMC	500	12
9.4	120	72	2.2	6.2	14.1	30.00	-	500	12
9.5	130	75	2.2	7.1	14.0	33.30	2 NaCl 1.5 CMC	500	12
9.6	130	75	2.2	5.2	15.0	25.70	-	500	12
9.7	140	79	2.2	5.7	14.2	28.64	2 NaCl 1.5 CMC	500	12
9.8	140	79	2.2	4.3	14.5	23.90	-	500	12
9.9	115	61	1.8	4.7	4.2	51.60	2 NaCl 1.5 CMC	600	12
9.10	115	61	1.8	3.8	5.2	42.22	-	600	12
9.11	120	72	1.8	6.1	6.76	47.43	2 NaCl 1.5 CMC	600	12
9.12	120	72	1.8	4.6	7.3	38.65	-	600	12
9.13	130	75	1.8	3.4	7.1	32.38	2 NaCl 1.5 CMC	600	12
9.14	130	75	1.8	2.9	7.8	27.10	-	600	12
9.15	140	79	1.8	2.7	7.4	26.73	2 NaCl 1.5 CMC	600	12
9.16	140	79	1.8	3.1	8.8	26.05	-	600	12

Table B.18 Spray drying tomato paste : 15 Brix
Air flow rate : 24 m^3/min Feed rate : 1.8 ml/min
Air on the nozzle : 700 lt/h ,Scraper : 12 rev/min

Run No	Θ_1 (^oC)	Θ_2 (^oC)	P(g)	D(g)	Y (%)	Ad. % T.S.
10.1	115	61	8.10	3.92	67.38	2 NaCl, 1.5 CMC
10.2	115	61	6.20	7.23	46.16	2.5 NaCl, 1.5 CMC
10.3	115	61	6.70	10.04	37.76	3 NaCl, 1.5 CMC
10.4	115	61	5.60	8.05	41.02	2 NaCl, 1.5 CMC
10.5	115	61	6.40	2.71	70.25	1 NaCl, 1 CMC
10.6	115	61	4.80	6.93	40.92	3.5 NaCl, 1.5 CMC
10.7	115	61	7.90	6.69	54.14	1 CS, 1 NaCl, 1 CMC
10.8	120	68	8.30	7.60	52.20	1 NaCl, 1 CMC
10.9	130	75	6.70	4.83	58.05	1 NaCl, 1 CMC
10.10	140	80	5.10	5.29	49.08	2 NaCl, 1 CMC
10.11	115	61	5.80	3.66	61.31	1.25 CS, 1 NaCl, 1 CMC
10.12	115	61	8.40	6.83	55.15	1.5 CS, 1 NaCl, 1 CMC
10.13	115	61	5.20	2.83	64.75	0.75 CS, 1 NaCl, 1 CMC
10.14	115	61	6.70	2.72	71.12	0.5 CS, 1 NaCl, 1 CMC
10.15	115	61	5.80	2.70	68.23	0.25 CS, 1 NaCl, 1 CMC

Table B.19 Spray drying tomato paste : 15 Brix
Air flow rate : 24 m^3/min Feed rate : 1.8 ml/min
Air on the nozzle : 700 lt/h

Run No	Θ_1 (°C)	Θ_2 (°C)	P(g)	D(g)	Y(%)	N(rpm)	Ad. % T.S.
11.1	115	61	5.20	2.83	64.75	18	0.5 CS, 1 CMC, 1 NaCl
11.2	115	61	8.40	6.83	55.15	24	0.5 CS, 1 CMC, 1 NaCl
11.3	115	61	8.30	7.82	51.48	30	0.5 CS, 1 CMC, 1 NaCl
11.4	115	61	4.70	6.83	40.76	36	0.5 CS, 1 CMC, 1 NaCl
11.4	115	61	7.21	3.78	65.54	6	0.5 CS, 1 CMC, 1 NaCl
11.5	115	61	5.35	3.01	66.87	7	0.5 CS, 1 CMC, 1 NaCl
11.6	115	61	5.60	3.00	65.11	8	0.5 CS, 1 CMC, 1 NaCl
11.7	115	61	6.22	2.68	69.88	9	0.5 CS, 1 CMC, 1 NaCl
11.8	115	61	5.72	1.71	76.98	10	0.5 CS, 1 CMC, 1 NaCl
11.9	115	61	6.45	2.86	69.28	11	0.5 CS, 1 CMC, 1 NaCl
11.10	115	55	4.50	5.75	43.90	12	0.5 CS, 1 CMC, 1 NaCl
11.12	120	61	2.62	8.75	23.04	12	0.5 CS, 1 CMC, 1 NaCl
11.13	130	61	2.11	8.82	19.30	12	0.5 CS, 1 CMC, 1 NaCl
11.14	140	61	1.95	13.45	12.26	12	0.5 CS, 1 CMC, 1 NaCl

Table B20. Ascorbic Acid Loss in the Tomato Powder for 15 % wt Feeding Concentrate Concentration

t	mg/100 g powder	% loss	Heat Exposed Particles in Cyclone min
Tomato paste	234.60	-	-
115 - 61	210.81	10.14	45
120 - 68	208.32	11.02	45
125 - 86	201.64	14.04	45
135 - 90	194.23	17.20	45
140 - 95	192.22	18.06	45
150 -105	185.95	20.73	45
160 -112	175.74	25.08	45
170 -113	163.12	30.46	45

VITA

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