DEVELOPMENT AND EVALUATION OF AIR RECIRCULATION SYSTEM FOR CONVECTIVE TRAY DRYER

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BY
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This is to certify that Mr. ***BABASO SHANKAR PATIL*** had successfully completed the comprehensive examination held on 14 /06/2005 as required under the regulation for the degree of **Master of Engineering.**

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This is to certify that this entitled **"Development and Evaluation of Air Recirculation System for Convective Tray Dryer"** submitted for the degree of **Master of Engineering** in the subject of **Agricultural Engineering** (Processing and Food Engineering) embodies bonafide research work carried out by Mr. ***BABASO SHANKAR PATIL*** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation has been fully acknowledged. The draft of the thesis was also approved by the advisory committee on dated / / .

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This is to certify that this entitled **"Development and Evaluation of Air Recirculation System for Convective Tray Dryer"** submitted by ***Mr. BABASO SHANKAR PATIL*** to the Maharana Pratap University of Agriculture and Technology, Udaipur in partial fulfillment of the requirements for the Degree of Master of Engineering (Processing and Food Engineering) after recommendation by the external examiner was refined by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We, therefore, recommend that the thesis be approved.

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This is to certify that **Mr. Babaso Shankar Patil** student of **Master of Engineering**, Department of Processing and Food Engineering, College of Technology and Engineering has made all the corrections/modifications in the thesis entitled **"Development and Evaluation of Air Recirculation System for Convective Tray Dryer"** which were suggested by the external examiner and the advisory committee in the oral examination held on / / /2005. The final copies of the thesis duly bound and corrected were submitted on / /2004, are enclosed here with for approval.

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ABSTRACT

In India mechanical drying is one of the important unit operation of post harvest technology of cereals, pulses, oilseeds, fruits and vegetables. There are many types of dryers in use for dehydration of foods. A majority of industrial dryers use steam, diesel, LPG, kerosene, electricity for heating. The financial value of energy varies enormously with its grading and electrical energy has highest energy grading of all. It is therefore imperative that electricity should be utilized efficiently and the areas of where the energy is wastefully used are to be identified and corrective measures are searched for adoption. Hence research has been carried out to achieve cost-effectiveness of drying process to conserve energy and to study product quality by recycling of exhaust air.

Dryer under study is classified as the air convection batch type tray dryer. Principal components of recirculatory system consists of exit air diversion tee, flow control gate, air recirculation duct and air mixing chamber. Tomatoes were used for testing of recirculatory type convective tray dryer. Tomatoes pretreated with freezing mixture of crushed ice and salt in the ratio 10:1 for 5 min followed by that dipping in 2 percent sodium chloride at 60^0C for 5 min was cut into 1 cm thick slice and subsequently dried in the recirculatory dryer. Drying experiment was carried out at $70/60^0$C (70^0C for first one hour and 60^0C thereafter) and $70/65^0$C under three recirculation rates (50, 75 and 90%). One experiment was carried out without any recirculation of exhaust air for comparative study. The moisture loss data was used to determine drying characteristics such as drying rate, diffusivity. Dryer performance was measured with respect to heat utilization factor (H.U.F.), thermal heat efficiency (T.H.E).

The initial moisture content of tomato slices was 93 - 94 per cent which reduced to 6 to 6.5 percent on dry basis and it took 8 - 11 h under different drying air conditions. Dehydration of tomato slices took place in falling rate of drying period only. Diffusivity values for tomato dehydration process was observed to be vary between 4.55×10^{-10} to 6.43×10^{-10} m^2/s. Tomato colour index (T.C.I.) of tomato powder varied in between 18.63 - 27.02. Highest retention of ascorbic acid was 10.67 mg/100g of sample dried at drying air temperature $70/60^0$C under 50% recirculation. Rehydration ratio was maximum for test carried under 75% recirculation rate. Maximum saving of energy with recirculation of exhaust air as compared to drying without any recirculation was 43 % when dried at $70/60^0$C and 90% recirculation. Thermal efficiency and heat utilization factor of the dryer increased with recirculation rate.

CHAPTER I

INTRODUCTION

1.1 IMPORTANCE

Drying is one of the cost-effective means of preservation of grains and food of all varieties. This technique has been practised since time immemorial, as it is first step in reducing quantitative and qualitative losses of grains after harvest. Drying serves purpose of preserving perishable commodities against deterioration or spoilage under the intended condition of storage and eventual use. Drying process reduces the cost and difficulty in packaging, handling and transportation of material by reducing bulk. The purpose of quality convenience may also be solved *e.g.* potato granules and flakes.

Water is an important contributor to the organoleptic quality of foods. A loss of water from high moisture content foods or gain in water by low moisture content foods can lead to reduction in organoleptic quality and the acceptability of said foods (Brennan *et al*., 1990). Thus, removing moisture from foods or making it less available can lead to an extension of the shelf life of foodstuffs. Generally the term drying refers to the removal of relatively small amount of moisture from solid or nearly solid material by evaporation (Chakraverty, 2000). Prescott and Sweet had defined dehydration when applied to foods as the process of removal of surplus water without destruction of cellular tissues, or impairment of energy values (Loesecke, 1999). Among the various methods of processing fruits and vegetables, dehydration is the most economical because dehydrated products require less expensive packaging, transportation and less energy during storage (Saxena, 2000). Also they are highly stable against deteriorative microbial, chemical and enzymatic reactions. Drying is the universal method of conditioning food grains by removing its moisture to defined level. In general, during drying process the moisture content of product is removed to its equilibrium level with normal atmospheric air in order to preserve quality and nutritive value for food and feed and its viability for seed.

1.2 SCOPE

In India mechanical drying is one of the important unit operations of post harvest technology of cereals, pulses, oilseeds, fruits and vegetables. India ranks first in the world with an annual output of 32 million MT. India is the second largest producer of vegetables in the world and accounts for about 15% of the world production of vegetables. The current production level is over 71 million MT (Annonymous, 2005). It has been observed that major chunks go to market for consuming as fresh and fraction of the produce goes to processor. It is reported that inspite of such large production, 1 to 1.5 % of the total fruits and vegetable are processed in India (Vhora, 2002). Post harvest losses of food grains and fruits and vegetables in India are reported to be 10 and 20 to 30 % respectively (Loesecke, 1999). Most of the fruits and vegetables can be preserved by reducing water activity by drying. Dried fruits are good source of energy because they contain concentrated fruit sugars. Many dried fruits are rich in riboflavin and iron. Dried fruits are good for children's lunches after school snacks, or parties. Dried fruits can also be used in cookie or granola recipes or with break fast cereals (Sharma, 2002). Also there has been awareness amongst the consumers in India about the processed food. The products such as ready to eat (RTE) snack food, breakfast cereals, extruded snack foods and textural vegetables, protein food has shown tremendous growth during the last few years. Thus in our country preservation of foods with modern drying technology will be of great significance.

There are many types of dryers in use for dehydration of foods. The particular type selected being governed by the nature of commodity to be dried. There are several conventional designs that have been used in practice over number of years either in food dehydration or in chemical industry. Small dryers at cottage industry level for cash crops like chillies, coconut, cardamom and other spices and fruits and vegetables *etc.* are commonly used. There may be about 2500-3000 of such dryers in operation (Shukla and Singh, 2003). Small Capacity dryers would also be needed for agro-processing industries in rural sectors. Hence importance of drying and dryers has been increased.

1.3 PROBLEM AND JUSTIFICATION

Drying is most important operation used in the food industry, as it is common to all sectors of food processing. Various studies revealed that as far as thermal energy consumption in industries is concerned drying consumes significantly large amount of energy which is next only to distillation process (Jain, 2002). Olabode *et al.* (1977) noted that drying requires the highest energy input among all operations examined in processing of potatoes (Walker and Wilhelm, 1995). Although dehydrators reduce the total cost of complete drying system for large scale production fruit growers with small production may find that dehydrator is not economical for drying portions of their crops because of high operating costs (Walker and Wilhelm, 1995). Thermal drying is an area, which requires concentrated efforts to develop better quality, energy efficient and economical drying system.

Considering economical factors, best drying method is one, which is least expensive, and provides required quality and characteristics in the products. A majority of industrial dryers use either steam, diesel, LPG, kerosene or electricity for heating. The financial value of energy varies enormously with its grading and electrical energy has highest energy grading of all (Rai, 2003). As energy becomes more scarce and costly, effective management of energy consumption is required. As energy cost increases it pose more of fiscal burden for every foodservice administrator whether operating commercial or non-profit facility. Thus fuel and power are major considerations in minimizing operational cost of dryer. Hence, we must conserve energy by all possible means to reduce manufacturing cost and stay complete vis-a vis our commercial rivals.

Energy conservation means reduction in energy consumption without making any sacrifice of quantity and quality of production. It insists for use of efficient processes thus decreasing cost of production to some extent. It is therefore imperative that electricity should be utilized efficiently and the areas of where the energy is wastefully used are to be identified and corrective measures are searched for adoption. Thus to achieve cost-effectiveness of drying process efforts were made to conserve energy by recycling of exhaust air.

Recirculating some of heated air through the dehydrator allows for significant energy savings thus reducing the operating energy costs (Walker and Wilhelm, 1995). Partial recirculation of exhaust air does have other beneficial implications. A factor often greatly affecting the drying rate is the shrinkage of the solid as moisture is removed. Rigid solids do not shrink appreciably but colloidal and fibrous material such as vegetables and other foodstuffs do under go shrinkage. The most serious is that these may develop hard layer on the surface, which is impervious to the flow of liquid or vapour or moisture and slows the drying rate. In many foodstuffs if drying occurs at too high temperature a layer of closely packed shrunken cells, which are sealed together forms at surface. This presents a barrier to moisture migration and is known as case hardening. Another effect of shrinkage is cause the material to wrap and changes its structure. To decrease the effect of shrinkage it is desirable to dry with moist air. Thus the effect of shrinkage on warping or hardening at the surface are greatly reduced (Geankoplis, 2005). The main advantages associated with recirculating some of the heated air in dehydrators are saving heat and fuel, adding moisture to the air, lowering drying costs and increasing quality (Walker and Wilhelm, 1995).

1.4 OBJECTIVES

Keeping above points in view this project was undertaken with following objectives.

1) To develop air recirculation system for existing tray dryer
2) Technoeconomic evaluation of modified tray dryer.

CHAPTER II
REVIEW OF LITERATURE

2.1 Drying of High Moisture Content Agricultural Produce

Vegetables and fruits are highly perishable, seasonal and available at particular area bringing complexity in their post harvest processing. Glut in the market leads to sharp fall in market prices, enormous deterioration in quality as well as quantity of vegetables. Dehydration of fruit and vegetables is one of the oldest forms of food preservation techniques known to man and consists primarily of establishments engaged in sun drying or artificially dehydrating fruits and vegetables. Although food preservation is the primary reason for dehydration, dehydration of fruits and vegetables also lowers the cost of packaging, storing, and transportation by reducing both the weight and volume of the final product. Given the improvement in the quality of dehydrated foods, along with the increased focus on instant and convenience foods, the potential of dehydrated fruits and vegetables is greater than ever.

Dried or dehydrated fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method used, which depends on the type of food and the type of characteristics of the final product. In general, dried or dehydrated fruits and vegetables undergo the following process steps: Predrying treatments such as size selection, peeling, and color preservation; drying or dehydration, using natural or artificial methods; and post-dehydration treatments, such as sweating, inspection, and packaging.

Table 2.1 Estimated number and size of dryers need in India based on number of plants and its full capacity utilization by the first decade of 21st century

Commodity Process	No. of Dryers	Capacity range, T/day
Fruits and vegetable processing plants	200	1-2
Food processing plants	150	1-2
Spices processing plants	100	1-2
Seed processing plants	100	1-5
Oil Seed processing plants	500	1-5
Coffee and tea	50	0.5-1
Rural agro processing	2000	0.5-1
Biscuits and bakery industries	50	1-5

Source: Shukla and Singh, 2003

2.1.1 Predrying Treatments

Predrying treatments prepare the raw product for drying or dehydration and include raw product preparation and color preservation. Raw product preparation includes selection and sorting, washing, peeling (some fruits and vegetables), cutting into the appropriate form, and blanching (for some fruits and most vegetables). Fruits and vegetables are selected; sorted according to size, maturity, and soundness; and then washed to remove dust, dirt, insect matter, mold spores, plant parts, and other material that might contaminate or affect the color, aroma, or flavor of the fruit or vegetable. Peeling or removal of any undesirable parts follows washing. The raw product can be peeled by hand (generally not used in the United States due to high labor costs), with alkali solution, with dry caustic and mild abrasion, with steam pressure, with high-pressure washers, or with flame peelers. For fruits, only apples, pears, bananas, and pineapples are usually peeled before dehydration. Vegetables normally peeled include beets, carrots, parsnips, potatoes, onions, and garlic. Prunes and grapes are dipped in an alkali solution to remove the natural waxy surface coating which enhances the drying process. Next, the product is cut into the appropriate shape or form (i. e., halves, wedges, slices, cubes, nuggets, etc.), although some items, such as cherries and corn, may by-pass this operation. Some fruits and vegetables are blanched by immersion in hot water (95 to 100^0C) or exposure to steam.

The final step in the predehydration treatment is color preservation, also known as sulfuring. The majority of fruits are treated with sulfur dioxide (SO_2) for its antioxidant and preservative effects. The presence of SO_2 is very effective in retarding the browning of fruits, which occurs when the enzymes are not inactivated by the sufficiently high heat normally used in drying. In addition to preventing browning, SO_2 treatment reduces the destruction of carotene and ascorbic acid, which are the important nutrients for fruits. Sulfuring dried fruits must be closely controlled so that enough sulfur is present to maintain the physical and nutritional properties of the product throughout its expected shelf life, but not so large that it adversely affects flavor. Some fruits, such as apples, are treated with solutions of sulfite (sodium sulfite and sodium bi-sulfite in approximately equal proportions) before dehydration. Sulfite solutions are less suitable for fruits than burning sulfur (SO_2 gas), because the solution penetrates the fruit poorly and can leach natural sugar, flavor, and other components from the fruit.

Though for dried fruits SO_2 gas is used commonly to prevent browning, this treatment is not practical for vegetables (Many and Shadaksharaswamy, 2001). Instead, most vegetables (potatoes, cabbage, and carrots) are treated with sulfite solutions to retard enzymatic browning. In addition to colour preservation, the presence of a small amount of sulfite in blanched, cut vegetables improves storage stability and makes it possible to increase the drying temperature during dehydration, thus decreasing drying time and increasing the drier capacity without exceeding the tolerance for heat damage.

2.1.2 Drying and Dehydration

Drying and dehydration is the removal of the majority of water contained in the fruit or vegetable and is the primary stage in the production of dehydrated fruits and vegetables. Several drying methods are commercially available and the selection of the optimal method is determined by quality requirements, raw material characteristics, and economic factors. There are three types of drying processes: sun and solar drying; atmospheric dehydration including stationary or batch processes (kiln, tower, and cabinet driers) and continuous processes (tunnel, continuous belt, belt-trough, fluidized-bed, foam-mat, spray, drum, and microwave-heated driers); and subatmospheric dehydration (vacuum shelf, vacuum belt, vacuum drum, and freeze driers).

Atmospheric forced-air driers artificially dry fruits and vegetables by passing heated air with controlled relative humidity over the food to be dried or by passing the food to be dried through the heated air, and is the most widely used method of fruit and vegetable dehydration. Various devices are used to control air circulation and recirculation. Stationary or batch processes include kiln, tower (or stack), and cabinet driers. Continuous processes are used mainly for vegetable dehydration and include tunnel, continuous belt, belt-trough, fluidized-bed, foam-mat, spray, drum, and microwave-heated driers. Tunnel driers are the most flexible, efficient, and widely used dehydration system available commercially.

Sub-atmospheric (or vacuum) dehydration occurs at low air pressures and includes vacuum shelf, vacuum drum, vacuum belt, and freeze driers. The main purpose of vacuum drying is to enable the removal of moisture at less than the boiling point under ambient conditions. Because of the high installation and operating costs of vacuum driers, this process is used for drying raw material that may deteriorate as a result of oxidation or may be modified chemically as a result of exposure to air at elevated temperatures. There are two categories of vacuum driers. In the first category, moisture in the food is evaporated from the liquid to the vapor stage, and includes vacuum shelf, vacuum drum, and vacuum belt driers. In the second category of vacuum driers, the moisture of the food is removed from the product by sublimation, which is converting ice directly into water vapor. The advantages of freeze drying are high flavor retention, maximum retention of nutritional value minimal damage to the product texture and structure, little change in product shape and color, and a finished product with an open structure that allows fast and complete rehydration. Disadvantages include high capital investment, high processing costs, and the need for special packing to avoid oxidation and moisture gain in the finished product.

2.1.3 Post Dehydration Treatments

Treatments of the dehydrated product vary according to the type of fruit or vegetable and the intended use of the product. These treatments may include sweating, screening, inspection, instantization treatments, and packaging. Sweating involves holding the dehydrated product in bins or boxes to equalize the moisture content. Screening removes dehydrated pieces of unwanted size, usually called "fines". The dried product is inspected to remove foreign materials, discolored pieces, or other imperfections such as skin, carpel, or stem particles. Instantization treatments are used to improve the rehydration rate of the low-moisture product. Packaging is common to most all dehydrated products and has a great deal of influence on the shelf life of the dried product. Packaging of dehydrated fruits and vegetables must protect the product against moisture, light, air, dust, microflora, foreign odor, insects and rodents; provide strength and stability to maintain original product size, shape, and appearance throughout storage, handling, and marketing; and consist of materials that are approved for contact with food. Cost is also an important factor in packaging. Package types include cans, plastic bags, drums, bins, and cartons, and depend on the end-use of the product.

Air emissions may arise from a variety of sources in the dehydration of fruits and vegetables. Particulate matter (PM) emissions may result mainly from solids handling, solids size reduction, and drying. Some of the particles are dusts, but other are produced by condensation of vapors and may be in the low-micrometer or submicrometer particle-size range.

Following are some reviews concerning to dehydration of highly perishable Agricultural produce which were sighted while undergoing project work.

Mandhyan *et al.* (1987) dehydrated winter vegetables like peas, spinach, carrot and cabbage in the sun and in the solar cabinet dryer and drying constants were calculated. It was observed that the rate of moisture depletion in the vegetables was high in the beginning and declined later. The moisture depletion with time indicated a straight line Function. Reduction in the drying time was observed to be 15 to 20 per cent when solar cabinet dryer was used in place of direct sun-drying.

Karathanos and Belessiotis (1999) applied a thin-layer model, such as the Page equation, to air drying data of high sugar-containing agricultural plant products such as currants, sultanas, figs and plums. A good linear relationship was found and two parameters of the Page equation were evaluated. The drying kinetics was evaluated for fresh material as well as for dried fruits. The Page equation was successful for the modeling of drying fresh fruits; it failed to predict the drying behavior when the drying was continued for moisture contents below 15% (d.b.), which was required water content to attain shelf stability of dried fruits. This was attributed to the Page equation being accurate only in cases where weight reduction was mainly due to water evaporation. Deviation from the Page equation occurs where there is a further reduction in weight due to the decomposition of sugars at relatively high drying temperatures and moisture contents lower than that typical of dried fruits (below 15% d.b.).

Pandey *et al.* (2000) studied hot-air drying characteristics of osmosed button mushroom (*Agaricus bisporus*) slices. During air drying at 40^0C temperature and 1.6 sample to solution ratio, the moisture content and moisture ratio decreased with time of drying. The changes in

DM/Mo and MR were higher during initial drying time. Osmosed mushroom took eight to twelve hours drying time to reach its EMC depending on drying air temperature. One variable and two variable power law models, exponential and Page's models very well fitted the experimental data of air drying. However Page's model and exponential model gave better results as compared to power law models. Also the predicted values of Page's model were very much close to observed values. Temperature dependence of drying rate constant followed the Arrehenious type of relationship.

Tan *et al.* (2001) studied thin-layer drying characteristics of sweet potato chips and pressed grates. Drying conditions were: temperatures of 33°C, 51^0C and 70°C; airflow rates of 0.084 and 0.345 $m^3/(s.m^2)$ and absolute humidity of 1.003 x 10^{-2} kg H_2O/ kg dry air. The drying rates of pressed grates were higher than those of chips. The modified Page equation describes thin-layer drying of chips and pressed grates. The drying time required for chips to reach the moisture ratio of 0.5 varied between 2.4 and 6.2 times that of pressed grates.

Mwithiga and Jindal (2003) dried Parchment coffee (Arabica) from an initial moisture content of about 90% to 10% (db) in a recirculating rotary convection type heating unit at controlled plenum temperatures of 100, 120 and 140^0C or controlled product temperatures of 50, 60, and 70^0C. The temperature of the plenum and moving beans could be maintained at specified levels with small variations during coffee drying experiments. The colour and specific gravity of coffee beans exhibited minimum changes as a result of drying operations. The susceptibility of coffee beans to breakage decreased with lowering of moisture and attained minimum values in the moisture content range of 20 to 30% db. The breakage susceptibility increased sharply with further reduction in moisture content. A drying model, which considered product temperature-time history alone under different operating conditions, estimated the change in moisture content adequately.

Lahsasni *et al.* (2003) conducted thin-layer solar drying experiments for the pear. The experimental drying curves obtained showed only falling rate period. The results verified, with good reproducibility, that the drying air temperature was the main factor in controlling the drying rate. The expression of the drying rate equation was determined empirically from the characteristic drying curve. Eight different drying models were compared according to their correlation coefficient (r) to estimate solar drying curves. The Page model could satisfactorily describe the solar drying curves of pear with correlation coefficient of 0.9995.

Veli *et al.* (2004) studied influence of airflow velocity (0.64, 1.00, 1.50, 2.00, 2.50 and 2.75 $m\ s^{-1}$) on the kinetics of convection drying of *Jonagold* apple, heat transfer and average effective diffusion coefficients. Drying was conducted in convection dryer at drying temperature of 60°C using cuboid-shaped (20 × 20 × 5 mm) apple samples. Temperature changes of dried samples, as well as relative humidity and temperature of drying air were measured during drying process. Dehydration ratio was used as a parameter for the dried sample quality. Kinetic equations were estimated by using an exponential mathematical model. The results of calculations corresponded well with experimental data. Two well-defined falling rate periods and a very short constant rate period at lower air velocities were observed. With an increase of the airflow velocity, an increase in heat transfer coefficient and effective diffusion coefficient was found.

Charles *et al.* (2005) studied the drying behavior of tomato slices at 45, 60 and 75 °C drying air temperature. Three falling rate periods were observed with diffusion coefficients in the range 3.72–12.27 × 10^{-9} $m^2\ s^{-1}$. The water vapour sorption isotherm of dehydrated tomato slices in the water activity (a_w) range of 0.08–0.85 was also determined at three temperature levels, i.e., 25, 30 and 40 °C. Five sorption models were fitted with the adsorption data generated from the gravimetric method. GAB and Oswin models described the adsorption characteristics of dehydrated tomato at 25 °C better than other models with GAB model being the best applicable model. The isosteric heat of adsorption decreased with increasing moisture.

2.2 Energy Requirement in Drying of Agricultural Produce

Total energy required to produce finished food servings has become increasingly important in recent years as the limited nature of fossil fuel resources has come more fully into focus.

Olabode *et al.* (1977) studied total energy to produce food servings as function of processing and marketing modes. Major food processing and marketing modes were examined in terms of there relative energy intensiveness in order to quantify the differences which existed among them. Detailed energy accounting was executed from point of harvest to point of consumption, using available industry data, direct experimentation, and theoretical engineering analysis for ten potato product models: Fresh, flake dried, microwave dried, granulated, spray dried, freeze dried, canned, retort pouched, refrigerated and frozen. Total energy for a finished 4 – oz serving of mashed potatoes was found to range from a low about 2057.25 kJ for a fresh to a high of 7332.25 kJ for frozen, with dehydrated models ranging form 2321 kJ for flaked to 6182.3 kJ for freeze dried. The broad differences between modes suggested a need for inclusion of energy accounting in decision making for food product development, processing, marketing and preparation.

Poole and Thygson (1980) described an energy audit of typical industrial convective type dryer determining the fixed and variable energy quantities that characterized the drying process. Because of its relatively high magnitude, the sensible heat load of the exhaust air was identified as that variable energy quantity most amenable to manipulation in such a way as to affect overall energy consumption of dryer. The implication of energy consumption principles to dryer performance was analyzed in the context of case study. Since variation in the exhaust rate frequently led to reduction in both energy consumption and production it was suggested that a cost/ benefit analysis be made to determine the optimal exhaust rate for specific drying system.

Ashworth and Caster (1980) studied the significance of operating conditions (dryer inlet dry bulb temperature, wet bulb temperature and outlet potential of the air stream) upon the energy efficiency of convective dryer. To promote the efficiency it was necessary to control the wet bulb temperature as high as practically possible. That was when moisture carrying capacity of the air stream was highest. Such conditions could be achieved by high inlet dry bulb temperature in a straight through flow dryer or by medium dry bulb temperature when operating the dryer with exhaust recycle.

Traub (2003) reported that in a drying system, the bulk of the energy was used in the form of heat. During drying, heat was intentionally lost through the stack referred to as stack or exhaust losses. This was a necessary requirement for the process to work. These losses could be minimized by optimizing the process performance and using this air directly in a recirculation system.

2.3 Energy Saving Recirculatory Dehydration System

One of the important parameter in dehydration technology is energy requirement for drying of agricultural produce. The feasibility of saving energy by recirculation of exhaust air in drying process was studied by several researchers.

Lasseran (1979) studied energy saving through heat recovery systems. A review of methods of reducing the energy requirement for drying, e.g. by direct heating using sulphur free fuels such as methane or liquid petroleum gas; the dry aeration system which was clamed to save above 20 percent of energy and increased dryer capacity by at least 40 percent compared with conventional drying; recirculation of exhaust air (about 70°C) from the air heater (110°C) and using it for drying; two stage drying in which oil burner and heat exchanger replaced by a gas burner for direct heating the exhaust air from the lower part of the drier being reheated by a gas burner to about 150°C and passed through the wetter grain in upper part, leaving 100°C. In heat recovery system described part of exhaust air from the recirculating continuous drier (130°C), which had a temperature of 73°C and humidity of 0.25-0.27 kg/kg was passed to a counter flow air or water heat exchanger, in which most of the sensible and latent heat was extracted, heating the water to 60°C. This was then used to warm the incoming air in a second drier via a heat exchanger. The heat consumption of such drier system was 2700 KJ/kg, compared with 2850 KJ/kg for dry aeration method. One modified drier was subdivided into sections, each with its own blower and shutters for regulating the mix of hot air from central source and natural air, so that the air flow and temperature could be controlled according to the condition of produce.

Harner *et al.*, (1982) described the method of improving peanut curing efficiency with air recirculation. The different batches of peanuts were cured with supplemental heat using recirculated air and solar energy. Exhaust air from conventional peanut curing trailers was mixed with ambient air and reused. The LPG savings were 8.29-12.00 L/h in 1980 and 5.03-12.26 L/h in 1981.

Walker and Wilhelm (1995) tested feasibility of saving energy by recirculating drying air in batch dehydrators. Peaches and apples received treatments of four constant recircutaon rates (0, 25. 50, and 75%). The total energy use for drying was reduced by 53% when drying peaches and 46% when drying apples with 75% recirculated air. Total drying times were almost the same for all recirculation rates. The results also suggested that even higher fixed recirculation rates could further optimize the drying system for greater energy savings.

Karathanos and Belessiotis (1997) performed drying experiments for various products, such as Sultana grapes, currants, figs, plums and apricots and the drying rates were found for both solar and industrial drying operations. Air and product temperatures were measured for the whole industrial drying process. It was proved that most materials were dried in the falling rate period, while currants, plums, apricots and figs exhibited two drying rate periods, first slowly decreasing (almost constant) and second fast decreasing (falling) drying rate period. Based on the findings of preliminary runs, the drying cycle of this fully automated industrial dryer was designed to give maximum quality of dried products with reasonable energy costs. A high air velocity and medium temperature were utilized in the beginning of the process; while during the second falling rate period, a medium air velocity, high air temperature and partial recirculation of the air stream were used. The industrial drying operation resulted in a product of superior quality.

Schoenau *et al.* (1999) in their experimental evaluation presented the energy conservation potential by recirculating exhaust air in commercial heated-air batch hay dryer . The design of the exhaust recirculation unit was such that only about 30% of the total exhaust air was recirculated through the heater inlet. Experimental tests were conducted on the dryer with and without exhaust air recirculation. Maximum energy savings of 27% and 17% were achieved with exhaust air recirculation during fall and summer dryer operation, respectively.

Pelegrina *et al.* (1999) developed model which was applied to simulate the effect of the air recirculation rate on the unit performance, in particular the time taken and the heat requirements to attain given final solid water content. The simulation assumed that part of the exhaust air was made to recycle and mix with the fresh air supply in controlled proportions, such that the conditions of the gas mixture blown to the drier could be set and the influence of the amount of air recycled on the drier performance was calculated. It was shown that there was, for given working conditions, an optimal mixing proportion which makes the energy delivered a minimum was due to the influence of the recycle if the drying time was the independent variable.

Iguaz *et al.* (2001) developed model for simulating the effect of air recycling on the performance and energy consumption of a concurrent rotary dryer for vegetable wholesale by-products. Simulating results indicated that air recycling provided energy savings of 21–38.5% and increased thermal efficiency in a range of 28–63% for the airflow rates studied. It was found that, for high recirculation ratios, higher retention times were required to obtain the same final product moisture content, resulting in a decreased dryer work capacity. Optimum recirculation ratios were determined for different performance conditions.

Bains *et al.* (2003) studied behavior of apple puree drying in a forced-air circulation cabinet drier with a cross-flow arrangement using a 3 × 2 factorial design of experiments involving air temperature (70°C and 94°C), flow rate (2·0 and 4·1 m/s) and relative humidity (5 and 15%) as main factors. The results showed that all three factors influenced rate of drying with the higher temperature-higher air velocity-lower relative humidity condition yielding the fastest drying rate, but also adversely affecting the product quality. A two-stage drying operation involving a high temperature, low humidity and high flow rate combination in the first stage followed by a lower temperature finish drying was found to give a better product.

Jain *et al*. (2003a) studied dehydration characteristics of spinach in air recirculatory tray dryer with different degrees of air recirculation. It was found that spinach did not have any constant rate of drying period and two clear cut falling rates were observed. It was also observed that with decrease in 5°C drying air temperature, electrical energy requirement reduced by 25% without significantly affecting total drying time. Whereas, for every 10% increase in recirculation of air, the electrical energy requirement decreased by 10 -15 %. The dehydrated spinach could be stored safely for six months in the polythene bags.

2.4 Performance Evaluation of Dryer

In order to evaluate performance it is necessary to know the outline procedure for testing of dryer at steady and quasi-steady state and to show how data be analyzed and transformed into various measures of performance.

Sergio *et al.* (1988) reported the means of improving the thermal efficiency of wheat drying in fluidized beds. One of the means consisted of the use of high air temperatures in the first zone of the drier. However, it was found that the high air velocities used for fluidization led to high temperature low-humidity of the exhaust air, thus making it suitable for recirculation. To quantify this effect, an algorithm was developed which allowed calculation of the recirculated fraction of the outlet air and the temperature of this fraction. The efficiency calculated for the new conditions showed a marked increase, reaching a value of about 53% (in drying with no air -recirculation, it was 28%).

An extension of the algorithm also made possible calculation of the heat supplied by air used to cool the grain, when it was added to the stream of recirculated air from the previous drying stage. Under such circumstances the efficiency was about 62%, which was comparable to that exhibited by cross-flow driers and some types of mixed-flow driers.

Singh (1994) developed a small capacity dryer for vegetable cauliflower, cabbage and onion. The drying time was in the range of 11–14 h and overall energy efficiency was 28.21–30.83% with 55–65°C temperature.

Arinze *et al.* (1995) reported the experimental data obtained from tests conducted on a newly developed heated-air batch hay drier. The computer simulated and measured temperature data at various locations for the drier agreed reasonably well. The simulation programme was subsequently used to optimize the drying system for minimum total drying costs within set bounds of drying time and overdrying for various initial moisture contents of hay, airflow rate, drying air temperature, hay stack height and batch size. The simulated results presented as an aid in the management and operation of the drier and as a guide in the design of similar new batch hay driers.

Das *et al.* (2001) reported that fruits and vegetables are highly perishable and deterioration in quality and quantity occurred due to poor storage and processing facilities at the production site in developing countries like India. Dehydration of vegetables using a recirculatory dryer was possible but limited, in practice. The recirculatory dryers so far developed have a drawback of non-uniform drying along the length of the trays. Hence an effort was made to solve this problem. A recirculatory cabinet dryer of capacity 5 kg/batch using a central air distribution system was developed. The dryer was tested for blanched potato chips. At a constant air flow rate of 1.5 m^3/min and 65°C temperature, it took about 3 h time to reduce the moisture content from

856.94% to 9.98% (dry basis). The heat utilization factor (HUF) and thermal heat efficiency (THE) of the developed dryer were found to be 18.94% and 22.16%, respectively.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with description of procedure adopted for carrying out investigation of re-circulatory type dryer. The later section of the chapter describes the methodology to evaluate the re-circulatory system and drying characteristics of tomato slices.

3.1 Details of Dryer Used for Test

Dryer under study was classified as the air convection batch type tray dryer. Its appropriate application was in laboratory for experimentation of theory and practices of drying. It was used as single unit. The material was heated principally by convection from the surrounding air, the temperature of which could be closely controlled to assure that material was never exposed above the specified temperature. The cross flow air circulation system was used where hot drying air passes across and upward through a screen base and then through open spaces or voids in the product bed.

The technical specifications of dryer is presented in Appendix C. The dryer comprised of drying chamber, heating unit and blower unit described as under.

3.1.1 Drying chamber

Dryer under study was made up of rectangular box, the right half of which is insulated box with single door opening at front. Stainless steel trays having rectangular holes are placed in the drying chamber.

The slices of 250 g tomatoes were uniformly spread in each tray with drying area of 318cm^2. Thus uniform spreading density of 7.84 kg/m^2 was observed. The hot air transfers heat to wet product for drying and simultaneously absorbs moisture from it. The moisture laden exit air escapes through central opening provided on top of drying chamber.

3.1.2 Heating unit

Left half of dryer was closed rectangular box which encompassed the heater and blower. There were two heaters each one could be operated separately as per requirement. The temperature of heated air was regulated by heater supply through thermostat operated controller.

3.1.3 Blower unit

It was positioned in lower left half (below heater unit) of rectangular box. The regulator was provided to adjust the speed of blower. Desired air flow rate could be obtained by regulating speed of blower. The air sucked by blower was carried towards drying chamber by passing it over the heaters.

3.2 Modification of Existing Dryer

Considering economical factors best drying was one which was least expensive and provided required quality and characteristics in the products. Recirculating some of heated air through the dehydrator allowed for significant energy savings thus reducing the operating energy costs. The recirculation system used for present dryer consisted of following different components.

3.2.1 Exit air diversion tee and flow control gates

Function of exit air diversion tee was to collect exit air of dryer and recirculate required quantity into the air recirculation duct and remaining to atmosphere with least pressure drop. The exit air diversion tee was made up of polyvinyl chloride (purchased from market). It was fitted with the flange fixed on exit of drying chamber, such that there was no leakage of air through joints.

The function of flow control gate was to divert desired quantity of exit air into air recirculation duct. The gates were made up of M.S. sheet (20 gauge) in circular cross section that fits on the exit air diversion tee. The size of gate was determined according to the calibration of dryer for required recirculation ratio. Calibration of dryer for definite recirculation rate is described in later part of the chapter.

3.2.2 Air recirculation duct

The fundamental requirement of design of duct system was to minimize the pressure and temperature loss per unit length of duct. Losses of pressure in ducts supplying air were due to friction, restriction to air flow, change in direction and enlargement or contraction of the cross sectional area of the duct. The total pressure at any point in a duct system was the sum of the static pressure and velocity pressure. Total pressure decreased continuously in the direction of flow. Static pressure and velocity pressures were mutually interchangeable and either might increased or decreased at points in the duct were cross sectional area became smaller or larger or where branch ducts were connected. In this dryer blower fan discharge, directly into the plenum and static pressure in the plenum was the static pressure at the fan so there was no loss of pressure from fan to plenum duct system. Also air from plenum enters after passing through perforated metal sheet into the drying chamber. As metal sheet having open area more than 10 % of total surface area of sheet pressure drop across it was negligible (Booker *et al.*, 1974) pressure loss inside the drying chamber was variable quantity as it depends upon rate of air flow, the surface and shape characteristics of the product, the number, size and configuration of voids, the variability of product particle size and product loading (Brooker *et al.*, 1974). The losses in total pressure in recirculating duct system were calculated as friction losses or dynamic losses that caused by surface friction. Dynamic losses were energy losses that occur because of change in cross sectional area of duct or because the direction change of flow. The dryer exit was of circular cross section with area of cross section 1734 mm^2 and 1934 mm^2 was that of recirculation duct. The dryer under study was a compact unit. The recirculatory system of dryer was straight duct system. The recirculatory system of dryer was straight duct system except slight smooth curve of recirculation duct. So there was negligible pressure loss due to fitting. The recirculatory duct was a circular hose pipe made up of polyvinyl chloride (PVC) of one meter length. Also no end contraction or expansion was used throughout the length of pipe. So total pressure losses through duct were minimized to great extent and need not to be considered separately.

3.2.3 Air inlet section

The main function of air inlet section was to prevent escape of recirculated air and achieve complete mixing of recirculated and fresh air. Keeping these objectives in mind the inlet air section was made up as rectangular chamber to fit the blower section of dryer. One end of chamber served as restricted inlet for fresh air along the longitudinal axis of chamber and circular hole on other end served as inlet for dryer blower. The entry of recirculation duct was made from top at an angle of 60^0 to top plane surface, so that air while traveling up to blower inlet mix thoroughly with ambient air without escaping from the chamber.

3.3 Laboratory Setup for Testing of Recirculatory Type Dryer

The laboratory test set up consisted of different accessories, equipments and instruments for evaluating the performance of recirculatory type dryer. In order to measure the exhaust air temperature, a scientific mercury thermometer was used and for measurement of temperature inlet air of dryer, a multi-span digital thermometer was used. Multi-span digital thermometer was calibrated with the help of mercury thermometer at ice point and boiling temperature of water. Digital thermo-hygrometer was used to measure the relative humidity of exhaust and ambient air. The list of the instruments are enumerated in Appendix K. The performance of the dryer was evaluated by determining various efficiencies and power requirement of the dryer.

3.3.1 Instrumentation and data acquisition

The temperature of drying chamber could be preset by adjusting the knob of thermostat cum controller provided on control panel of dryer. Multi-span digital thermometer which was calibrated with the help of mercury thermometer at 0^{0}C and 100^{0}C was used for measuring temperature of mixed air. Mercury thermometer was used for measuring temperature of exhaust air which was fitted at the end of diversion tee. Relative humidity of ambient and exhaust air was measured with the help of digital thermo-hygrometer. The measurement of data was done twice during each half an hour and averaged for that interval. The data acquired from experiment were used to find additional properties of air from psychrometric chart. Single phase energy meter were used to measure the energy supplied to the blower and heaters. Energy readings were periodically taken directly from the dial on meter. Schematic view of the recirculation system was shown in figure 3.1. Plate 3.1 and 3.2 were showing the experimental set up of tray dryer without any recirculation and with recirculation assembly respectively. All the instruments used for experiment are listed in the Appendix K.

3.3.2 Calibration of dryer for recirculation ratio

Dryer was made ready for experiment with all attachments of instruments as mentioned earlier. The dryer was calibrated for desired recirculation rate before testing. Calibration of dryer was done with empty trays in place. The blower speed was adjusted to required airflow rate. This was performed by measuring velocity of air accurately with the help of anemometer. The heaters were put on followed by setting of regulator to desired temperature; the dryer was operated as such for approximately half an hour to establish thermal equilibrium without any recirculation of dryer exhaust air. After establishment of desired temperature, recirculation duct was opened to air mixing chamber and by fitting circular gates over air escaping end of diversion tee, required air was diverted into air mixing chamber. Exact matching of desired recirculation ratio was monitored by temperature of mixed air measured at blower inlet. Monitoring temperature of mixed air was determined as described in Appendix D. Gates of different size were tested to attain the desired temperature match. Thus, size of flow control gate was determined by trial and error method.

The monitoring temperature was measured with $\pm 2^0$C accuracy with the help of multispan digital thermometer having $\pm$ 2^0C accuracy. Monitoring temperature of mixed air was calculated by using formula given by Verma and Jain (2005). The temperature of mixed air was calculated for each recirculation rate and calibration of dryer was made accordingly.

3.4 Experimental Test Procedure

Tomatoes were used for testing of recirculatory type convective tray dryer. The good quality, firm and ripen tomatoes of hybrid variety Pusa Rubi were procured from local market. Tomatoes were sorted and trimmed to remove stalks, blemished portion etc. they were washed under tap water to remove dust, dirt, surface adhering to surface and wiped to remove surface moisture. Tomatoes were then subsequently processed.

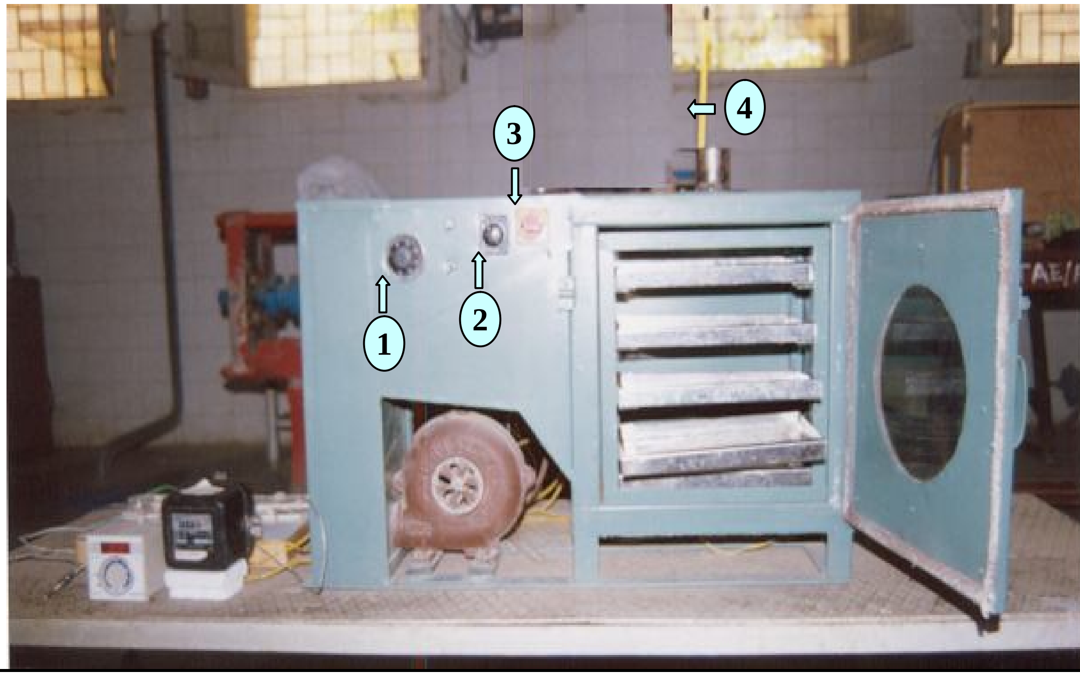

Plate 3.1 Experimental set up of tray dryer without any recirculation of exhaust air

1. Temperature regulator **2. Blower Regulator**

3. Dryer On/Off switch **4. Scientific mercury thermometer**

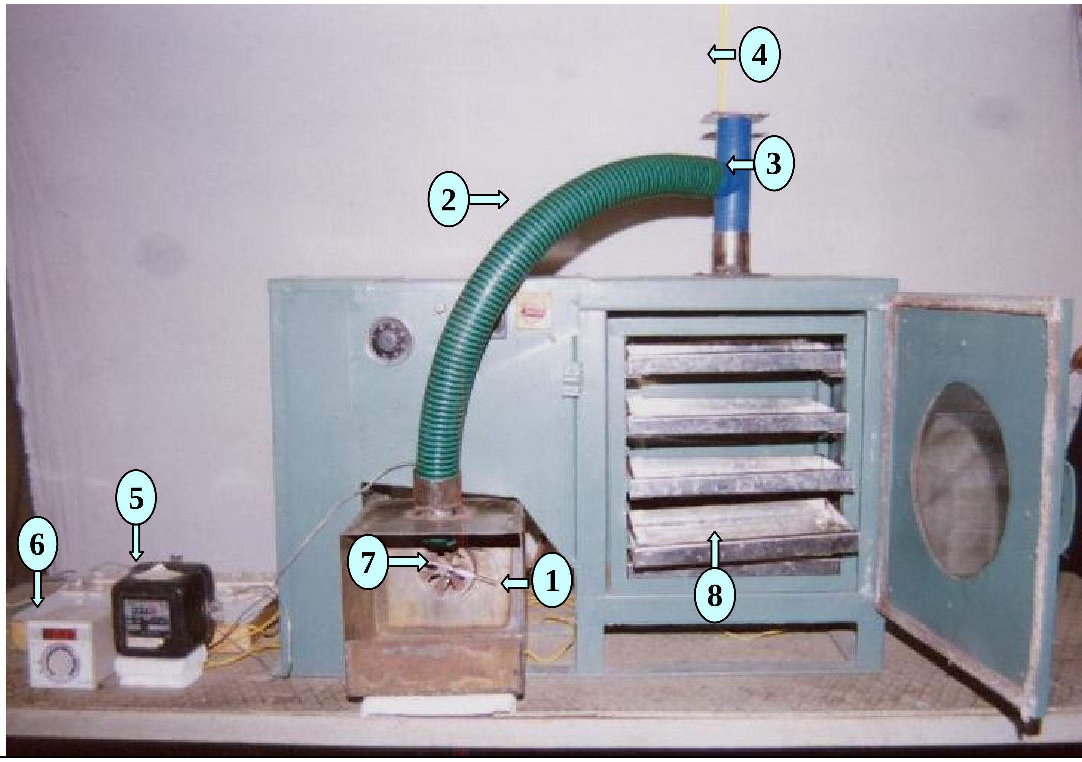

Plate 3.2 Experimental set up of tray dryer with attachments of recirculatory system.
1. Air mixing chamber 2. Air recirculation duct
3. Exit air diversion Tee 4. Scientific mercury thermometer
5. Energy meter 6. Multispan digital thermometer
7. Dryer blower 8. Trays

3.4.1 Average weight

Ten Tomatoes selected at random were weighed individually using an electronic balance having least count 0.l g. The average weight was calculated and the number of tomatoes per kg was also determined.

3.4.2 Moisture content

The initial moisture content of raw tomatoes was determined by oven drying method. The thermostatic temperature controller of oven was set at 100 ($\pm$1)^0 C. The oven was preheated for 30 min (Saxena, 2000).

The fresh tomato slices were put in thoroughly washed dried and pre-weighed moisture boxes. The initial weight of each sample was recorded. The moisture boxes were put in the oven. They were weighed at 30 min. interval for first two hours, followed by that of 1h for next 4 h and thereafter for each 2h interval until constant weight readings were observed. The weight of bone dry matter in the sample was determined as follows.

Weight of moisture box = W_1 (g)

Weight of moisture box + fresh sample = W_2 (g)

Weight of moisture box + oven dried sample = W_3 (g)

Weight of moisture evaporated, $W_w = W_2 - W_3$

Weight of bone dry matter (BDM), $W_d = W_3 - W_1$

The moisture contents of sample on wet basis (w.b.) and dry basis (d.b.) were computed as follows.

$$\text{Percent moisture content (w.b.)} = \frac{W_w}{W_w + W_d} \times 100$$

$$\text{Percent moisture content (d.b.)} = \frac{W_w}{W_d} \times 100$$

The final moisture content of dried tomato slices were determined by Sartorius Moisture analyzer. Pictorial view of the moisture analyzer is given in plate 3.4 and specifications of instrument are given in appendix H.

3.4.3 Selection of recirculation ratio

The objective of research work was to evaluate the energy savings resulting from re-circulating fixed percentage of drying air in batch dehydrators. Investigation made by Walker and Wilhelm (1995) and Jain *et al*. (2003) on recirculatory type dryer revealed that increased recirculation rates resulted in lower energy use for batch drying. Energy use steadily decreased with increased recirculation rate. It was also reported that for every 10% increase in recirculation of air the electrical energy requirement decreased by 10 – 15 %.

Hence, dehydration of tomatoes were carried out keeping of 50%, 75% and 90% recirculation rates at different drying air temperatures. One experiment without any recirculation was carried out for each temperature set for comparative study and designated as 0% recirculation rate.

3.4.4 Selection of drying air temperatures

Recirculation of exhaust air of dryer increases humidity of drying air. It was reported that when humidity of air increases the rate of drying decreases slightly (Geankoplis, 2005). Decreased drying rate increases drying time. It was reported that the energy consumption of the dryer was directly proportional to drying time (Saxena, 2000). Jain (2002) had reported that when humidity of the air increased drying rate decreased slightly however this effect was smaller in comparison to the effect of raised Temperature.

Based on the research work done on dehydration of tomato by Chhta (1988), Gupta and Nath (1982), in order to study the effect of temperature and recirculation rate on dehydration of tomato slices, it was decided to keep temperature at 70^{0}C for first one hour and 60^{0}C thereafter during first experimental set and 65^{0}C during next experimental set for remaining period of dehydration experiment.

3.4.5 Selection of pretreatment

Effect of pretreatment for different dehydrated products had been studied by many researchers. Also Saxena (2000) had reported that pretreatments of tomato had no effect upon moisture content of sample and dry matter recovery but the pretreated samples dried faster than untreated samples. It was also reported that treatment of freezing mixture of ice salt followed by dipping in hot solution of sodium chloride reduced drying time.

Hence, treatment of freezing mixture of crushed ice and salt in the ratio 10:1 for 5 min followed by that dipping in 2 percent sodium chloride at 60^{0}C for 5 min to facilitate peeling was selected.

3.4.6 Selection of tomato slice thickness

It was more drudgery to prepare 0.5 cm thick tomato slice and comparatively more loss of juice was observed in those samples. It was difficult to handle them during drying process. Also Saxena (2000) reported that under constant drying conditions1.5 cm thick slices required more time to dry as compared to 1.0 cm thick slices. About 22 percent drying time could be saved due to smaller thickness of 1.0 cm than 1.5 cm under similar drying condition. Therefore 1.0 cm was selected as thickness of tomato slices for drying in further experimental studies.

3.5 Computation of Drying Characteristics

3.5.1 Total drying time

The total time required for drying of sample was determined by cumulating various drying time intervals. The time required for drying of sample under different recirculation ratios (T_r) compared with that of sample dried under no recirculation (T_o). Increment in drying time was calculated as follows.

Total drying time required without recirculation = To (h)

Drying time required under particular recirculation ratio = T_r (h)

Difference in drying time due to recirculation, $\Delta T = (T_r - T_0)$

Percent increment in drying time $= \frac{\Delta T}{T_0} \times 100$

3.5.2 Bone dry matter

The initial moisture content of various samples was determined by oven drying method, as described earlier, the percentage and weight of bone dry matter in sample was calculated as follows.

$$\text{BDM}(\%) = 100.0 - \text{IMC } (\%\text{w.b.})$$

$$\text{Weight of BDM} = (\text{Initial weight of sample}) \times \frac{\%\text{BDM}}{100}$$

3.5.3 Drying rate and moisture content

The moisture loss data recorded during drying experiments were analyzed to determine the moisture lost by sample in particular time interval. The drying rate was calculated by mass balance equation as kg of moisture lost per kg of bone dry matter per hour.

3.5.4 Dehydration ratio and dry matter recovery

They were calculated as follows.

$$\text{Dehydration Ratio} = \frac{\text{weight of fresh sample}}{\text{weight of dried sample}}$$

$$\text{Dry Matter recovery } (\%) = \frac{\text{weight of dried sample}}{\text{weight of fresh sample}} \times 100$$

3.5.5 Diffusivity

In drying diffusivity is used to indicate the flow of moisture out of material. In falling rate period of drying moisture transfer is mainly by molecular diffusion. Diffusivity is mainly influenced by shrinkage, case hardening during drying, moisture content and temperature of material. The falling rate period of the biological material is best described by Ficks diffusion model as,

$$\frac{\partial M}{\partial t} = D\frac{\partial^2 M}{\partial X^2}$$

Where,

D= Diffusion coefficient, m^2/s

M= Moisture content, %

X = Distance from centre line

X is the distance from the center line and t is the time elapse during the drying. Assuming uniform initial moisture content distribution and negligible external resistance the solution of above mentioned equation as prepared by Crank for plane sheet of half thickness L (Bala , 1997).

$$\frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\exp[-(2n-1)^2\pi^2\frac{Dt}{L^2}]$$

Simplifying this by considering only first term of the series, the equation reduced to

$$MR = \frac{M - M_e}{M_0 - M} = \frac{8}{\pi^2}\exp[-\pi^2\frac{Dt}{L^2}]$$

Where,

MR = Moisture ratio, dimensionless

M_e = Equilibrium moisture content, g .H_2O / g. BDM

M_0 = Initial moisture content, g .H_2O / g. BDM

M = Moisture content at time (t), g .H_2O / g. BDM

L = Half thickness of slab, m

t = Time, s

D =Diffusivity coefficient, m^2/s

Rearranging above mentioned equation

$$\ln(MR) = \ln(\frac{8}{\pi^2}) - (\pi^2\frac{Dt}{L^2})$$

or

$$\ln(MR) = -0.2090 - [\pi^2\frac{Dt}{L^2}]$$

If ln (MR) versus time graph is plotted then it will result in straight line and slope of the line can be used to predict diffusivity.

3.6 Performance Evaluation of Re-circulatory System

The performance evaluation of the recirculatory tray drier was assessed using the heat utilization factor (H.U.F) and thermal heat efficiency (T.H.E.) (Das *et al.*, 2001). HUF is the ratio of heat utilized to heat supplied and THE is heat utilized to total heat available. The data acquired from experiment was used for determining the parameters like heat utilization factor (H.U.F.) and thermal efficiency of dryer.

$$\text{H.U.F.} = \frac{T_4 - T_2}{T_4 - T_3}$$

$$\text{Thermal efficiency,\%} = \frac{(\text{Amount of water vapour removed}) \times (\text{latent heat of evaporation, kJ/kg})}{\text{Heat value of fuel, kJ}} \times 100$$

Where,

T_2, T_3, T_4 = exit, inlet and heated air temperature respectively, ^{0}C

3.6.1 Economic evaluation of the dryer

For the success and commercialization of new technology and to know viability of the technology, an attempt was made to determine the economics of the recirculatory dryer. Based on the studies of Shekhawat and Laxman (1994) on agro-industrial solar dryer, economic evaluation of the dryer was been made as described below.

Economics of the dryer was worked out by different methods namely annualized cost method and energy savings for each method. For each method drying cost per unit weight of material was calculated as described below.

I. Annualized cost method

Annualized cost (AC) = Annual capital recovery (ACR) + Annual operation maintenance and repair (AOMR) + Annual fuel cost (AFC)

ACR= CRF x IC

$$\text{Capital recovery factor (CRF)} = \frac{r}{1-(1+r)^{-n}}$$

Where,

r = discount rate (in fraction)

n = operating life (years)

IC = Capital investment

AOMR= F x IC = Depreciation rate.

F = Fraction of investment cost which could be taken for maintenance yearly

AFC= (Specific fuel consumption) x (Rating) x (Number of working hours per year) x (Cost of fuel)

II. Yearly energy savings.

Yearly energy savings = (Energy consumed if drying is done by existing dryer) - (Energy consumption in modified recirculatory dryer)

Assumptions for economic evaluation:

Economic analysis has been carried out with the following assumption

1. The operating life of the system has been assumed to be 15 years considering that utilization of the dryer is throughout the year. This is assumed that sufficient quantity of tomatoes shall be available for drying throughout the year.
2. Considering the soft loans are available for small scale industrial processing operations a discount rate of 15 percent has been considered to compute capital recovery factor.
3. It has been observed from experiments that one kg of tomatoes takes 10 to 11 hours under efficient condition for removing initial moisture content of about 94% (w.b.) to safe moisture of 2% (w.b.). Therefore considering 365 days operation one can dry maximum

$$= \frac{365x11x1}{11} = 365kg$$

4. The labor for loading, unloading and material handling is considered to available free of cost.

3.7 Qualitative Evaluation of Dried Tomato Slices

3.7.1 Reconstitutional qualities

The rehydration tests were conducted to evaluate reconstitutional qualities of dehydrated samples. Pre-weighed samples were soaked in ample quantity of hot (50^{0}C) water for 30 minutes so as to make them soft and unshriveled. This preliminary first soaking was known as rehydration. After preliminary test cold water soaking was preferred for forthcoming rehydration tests. The time of second soaking was determined to be 90 minutes (Saxena, 2000). The samples drained with the help of tissue paper and stabilized at room temperature and reweighed.

The rehydration characteristics were determined as under:

(a) Rehydration ratio (RR) $= \frac{C}{D}$

(b) Coefficient of rehydration (CR) $= \frac{C(100 - A)}{(D - BD/100) \times 100}$

(c) Moisture content in rehydrated sample (%w.b.) $= \frac{C - (D - BD/100)}{C} \times 100$

Where,

A = Moisture content of samples before dehydration, (%w.b.)

B = Moisture content of dehydrated sample (% w. b.)

C = Drained weight of rehydrated sample (g)

D = Test weight of dehydrated sample (g)

3.7.2 Tomato powder

Tomato powder was obtained by grinding the dried slices of tomato sample in food processor. The specification of food processor is given in Appendix J.

Due to hygroscopic nature, the tomato powder was immediately packed in air tight plastic container.

3.7.3 Colour measurement of Tomato powder

One of the important parameters for consumers' acceptability of product is its colour. Although pigment lycopene has no nutritional value yet its presence is responsible for red colour in tomato. Testing of colour of dried tomato was done with the help of Hunter lab colourflex colourimeter. Plate 3.3 shows pictorial view of Hunterlab Colourflex colourimeter. Specifications of the instrument are given in appendix G. All the samples of tomato powder were tested on colourimeter. Colorimeter index (L, a, b) was analysed further for calculating tomato colour index (T.C.I.). The value of colour index for tomato powder was calculated with the help of equation given by Shukla and Singh (2004).

$$TCI = 100 \times \left(\frac{21.6}{L} - \frac{7.5b}{L \times a}\right)$$

Where L, a and b are colour index of tomato powder obtained from colorimeter.

3.7.4 Chemical analysis of tomato powder for Ascorbic acid

In the present study, the fresh tomato puree and dried tomato powder samples were chemically analyzed by volumetric method to determine and compare the presence of ascorbic acid (vitamin C).

Volumetric method for determining the quantity of Ascorbic acid in a sample described by Berwal *et al.* (2004) is an easy and fast method. Hence Determination of ascorbic acid was done by volumetric method.

(a) Principle

Ascorbic acid reduces oxidation reduction dye, 2 6-dichlorophenol indophenol dye to a colourless solution and oxidized to dehydro-ascorbic acid. At the end point excess untreated dye give pink colour in acid solution. Vitamin was extracted and titrated in presence of metaphosphoric acitic acid solution to maintain proper acidity for reaction and to avoid auto oxidation of ascorbic acid.

(b) Reagents Used

(i) **Metaphosphoric-acetic acid solution**: **-** 15 g of Metaphosphoric acid (pellets) weighed and added to 40 ml acetic acid followed by addition of 200 ml distilled water. When

Plate 3.3 Hunter lab colorflex colorimeter.

Plate 3.4 Sartorius Moisture analyzer

Metaphosphoric-acetic acid completely dissolve the volume of solution was made 500 ml by addition of distilled water and stored in colored bottle.

(ii) Ascorbic acid standard solution (1 mg/ml):- 50 mg of ascorbic acid was added to 50 ml of Metaphosphoric-acetic acid solution and stored in coloured bottle.

(iii) 2, 6 dichlorophenol indophenol standard solution: - 50 mg of 2, 6 dichlorophenol indophenol and 42 mg of sodium bicarbonate were mixed with 50 ml of distilled water. The solution was shaken vigorously and the volume was made to 200 ml by addition of distilled water. Solution was stored in coloured bottle.

(iv) Sample aliquot: - 5 g of tomato powder was weighed and added into 100 ml conical flask. 50 ml of Metaphosphoric-acetic acid was added into it. The solution was shaken and pH of the solution was adjusted to 1.5. The solution was filtered through Whatman No.1 and diluted to 100 ml with metaphosporic acetic acid solution.

(c) Experimental procedure

2 ml each of sample aliquot, Metaphosphoric-acetic acid solution and standard ascorbic acid solution were taken into three different conical flasks. Then 5 ml of metaphosphoric acetic acid solution was added into each conical flask. The solutions were titrated against the 2, 6 dichlorophenol indophenol.

The fresh tomato juice and eight tomato powder samples were chemically analysed to determine the ascorbic acid content. The retention of ascorbic acid in tomato powder samples as compared to fresh puree was also determined. The detailed procedure for conducting the chemical analysis test has been given in methodology.

The volume of dye consumed in titration against 2 ml of working standard solution, with ascorbic acid content of 0.001mg/ml was found to be 31.5ml. The volume of dye consumed in titration against equivalent volume of test sample solution(Y ml) and blank solution (B ml) was determined. The weight of test sample was 5 gram. The three replications were titrated to eliminate experimental error.

Calculations:

$$\text{Ascorbic acid}\,(\text{mg}/100\text{g}) = \frac{Y - B}{S - B} \times \frac{V}{2} \times \frac{100}{W}$$

Where,

W = Weight of sample, g

V = Volume of aliquot made, ml

S = Volume of dye used against standard, ml

B = Volume of dye used against blank, ml

Y = Volume of dye used against sample, ml

CHAPTER IV

RESULTS AND DISCUSSION

The present study was conducted to evaluate the effect of air recirculation in batch type convective tray dryer. Experimental analysis of the dryer was done with dehydration of tomato. During preliminary work, the physical properties of the tomatoes such as unit weight and moisture content were determined. Based on the recommendation of previous researchers, tomatoes were pretreated by dipping in freezing mixture of crushed ice and salt crystals and secondly in crushed ice followed by blanching in hot NaCl solution. One centimeter thick (selected thickness) slices of tomato were dried at 70^0C for first one hour and at 60 ^{0}C thereafter in a re-circulatory type convective tray dryer.

The effect of different temperatures and recirculation rates on performance index of dryer and drying characteristics of tomatoes were studied. Drying test without any recirculation (0% recirculation) of exit air was carried out for comparative study.

During second phase of study, the reconstitutional qualities of dried slice were studied. The tomato powder was obtained by grinding the dried slices of eight samples. Tomato color index (TCI) of tomato powder and fresh tomato juice was determined with the help of colourflex meter. The fresh tomato juice and tomato powder were chemically analysed for retention of ascorbic acid.

The results of present study are reported and discussed in this chapter.

4.1 Physical Properties

The tomato of hybrid variety Pusa Rubi was found to be oval in shape. It had uniform deep red colour as observed in plate 4.1. Evenly matured, fresh tomatoes had firm texture, wrinkle free, glossy surface and a sweet sour flavour.

4.1.1 Average weight

The tomatoes were individually weighed with the electronic weight balance having least count of 0.1 g. The average weight of fruit was evaluated from ten replications. The data are given in table 4.1.

Table 4.1 Average weight of tomato

Replication Number	Weight (g)
R1	113.50
R2	93.50
R3	111.50
R4	90.50
R5	103.50
R6	88.90
R7	95.90
R8	92.50
R9	120.00
R10	89.00
Average weight	**99.88**

The weight of tomato varied from 88.90 to 113.50 g, with an average value of 99.88 g. Thus 1.0 kg tomato contains 10 to 11 fruits.

4.1.2 Moisture content

Initial moisture content of pretreated tomatoes was determined by oven drying method as described in methodology. The relevant data are presented in Table 4.2.

The average initial moisture content of untreated tomatoes, on wet basis was found to be 94.02 per cent, ranging from 93.86 to 94.23. The dry basis moisture content varied from 1476.62 to 1486.64 per cent with the average value of 1477.67 per cent.

Table 4.2 Initial moisture content of tomato samples

Temp. ºC	Recirculation Rate (%)	I.M.C. (% w.b.)			Avg. I.M.C. (%)
		Replic.:I	Replic.:II	Replic. :III	
70/60	0	93.15	94.59	94.95	94.23
	50	92.80	94.05	93.50	93.45
	75	94.50	93.20	94.33	94.01
	90	93.65	94.03	93.90	93.86
70/65	0	94.82	93.56	94.01	94.13
	50	93.95	95.01	93.40	94.15
	75	95.25	93.15	94.20	94.20
	90	94.13	93.80	94.55	94.16

Final moisture content of dried tomato slices was determined directly on Sartorius Moisture analyzer. The values of moisture content on the wet basis were directly read from the moisture meter. The average of three readings were taken to eliminate any error. The relevant data are presented in table 4.3.

Table 4.3 Final moisture content of dehydrated tomato slices

Temperature ºC	Recirculation Rate (%)	Final moisture content (% w.b.)			Avg. (% w.b.)
		Replic. :I	Replic. :II	Replic. :III	
70/60	0	1.7	1.8	1.9	1.8
	50	2.7	2.2	2.6	2.5
	75	2.1	1.9	2.1	2.1
	90	2.6	2.3	2.6	2.5
70/65	0	2.1	2.4	2.1	2.3
	50	2.5	2.4	2.6	2.5
	75	2.3	2.3	2.3	2.3
	90	1.8	1.9	2	1.9

The average final moisture content (%) of untreated tomatoes on wet basis was found to be 2.23 per cent, ranging from 1.8 to 2.5.

4.2 Preliminary Drying Experiment

One kilogram of sorted good quality tomatoes were pretreated with the freezing mixture crushed ice and salt followed by dipping in hot NaCl solution followed by peeling. Slices of 1.0 cm thickness were cut with sharp knife. It was found that 3-4 slices of 1.0 cm thickness could be prepared from one tomato. Slices were spread uniformly in drying trays.

During preliminary operation dryer was made ready for drying experiment by attaching required instruments at particular data acquisition points. The scientific mercury thermometer was attached at dryer exhaust and temperature sensing cord of multi-span digital thermometer was attached at heater inlet inside the air mixing chamber. Temperature controller knob of dryer was set at required drying air temperature. Single phase energy meter was attached to get the reading of electrical energy consumption supplied to heater and blower. Dryer was operated approximately for half an hour under no load condition to establish thermal equilibrium. Pre-calibrated recirculation gate was fixed on the exhaust pipe of dryer with the help of wire frame to obtain desired recirculation rate.

After loading the trays in the drying chamber readings of weight loss of water for each half an hour was recorded. The drying time and moisture loss data were then analyzed to study drying characteristics of tomatoes in re-circulatory type dryer. The relevant data of drying characteristics have been presented in Appendix A.

Also temperature reading at dryer exhaust and heater inlet were taken two times within half hour interval and averaged over that interval of time. In the similar way readings of exhaust air humidity was taken with the help of digital thermo hygro-meter and recorded. The ambient air temperature and relative humidity was also recorded during each experiment. The data of temperature, humidity and energy (kW.h) obtained from drying experiment was used to study dryer performance. The relevant data of drying experiment was presented in Appendix B.

Experiment was conducted at two temperature levels and at four recirculation ratios. First experiment was carried out at 70/60^{0}C temperature (70^{0}C for first one hour and 60^0 C thereafter) and second experiment was carried out at 70/65^{0}C (70^{0}C for first one hour and 65^{0}C thereafter) under four recirculation rates (0, 50, 75 and 90%).

4.3 Dehydration Characteristics of Tomato Slices

Tomatoes treated with freezing mixture crushed ice and salt in the ratio 10: 1 followed by dipping in hot NaCl solution were peeled. Slices of 1.0 cm thickness were cut with sharp knife. The cut samples were spread uniformly in the tray and trays were placed properly in the dryer. Data of weight loss and drying time is analyzed as moisture content versus time for different drying air conditions in following sub sections.

4.3.1 Effect of process variables on moisture content

Hot air drying characteristics of tomato slices were studied at two levels of drying air temperatures and under four recirculation rates (0, 50, 75 and 90%). The initial moisture content (IMC) of tomato slices varied from 93.45 to 94.23% (w.b.). The samples were dried till they attained almost constant weight. Final moisture content of dried samples was measured with the help of moisture meter (Sartorius AG Gottingen, Germany). The final moisture content of dried tomato slices varied between 1.8 (%w.b.) to 2.5 (%w.b.). The variation of moisture content with time is graphically represented in figure 4.1 and 4.2 from which it is clear that moisture content decreased with drying time and loss of moisture was drastic initially as compared to later part for each drying curve under given drying air conditions.

Percentage decrease in moisture content at drying air temperature 70/60^{0}C for first four hours was about 75, 68.8, 66.16 and 64.2%, under 0, 50, 75 and 90% recirculation rates respectively. Also under drying air condition 70/65^{0}C, percent decrease in moisture content for first four hours was about 76.7, 73.7, 78.1 and 69.9% under 0, 50, 75 and 90% recirculation rates respectively. Thus much of the water was evaporated during initial stage of drying.

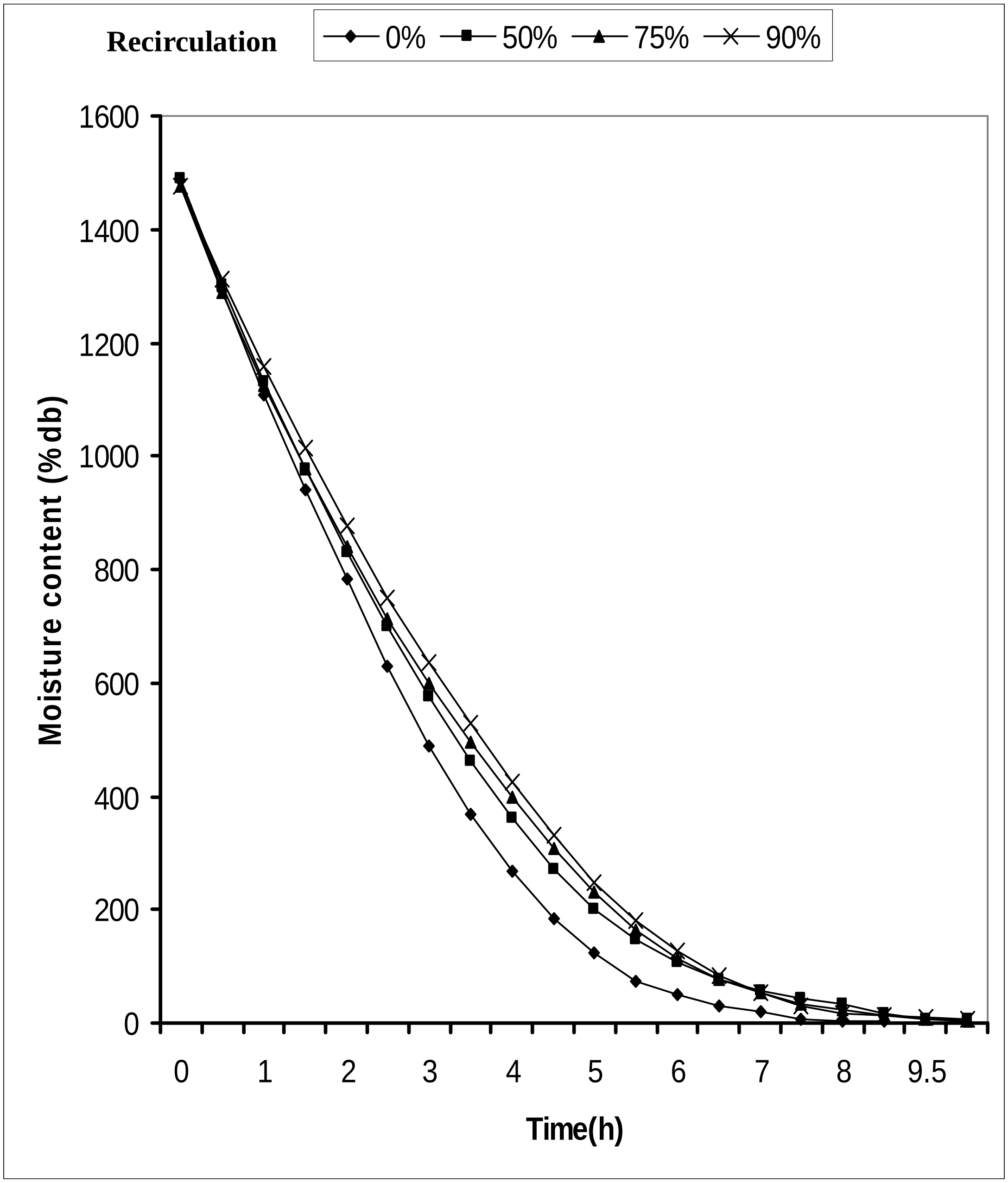

Fig. 4.1 Variation of moisture content with time for dehydration of tomato slices at drying air temperature 70/60^{0}C and different recirculation rates.

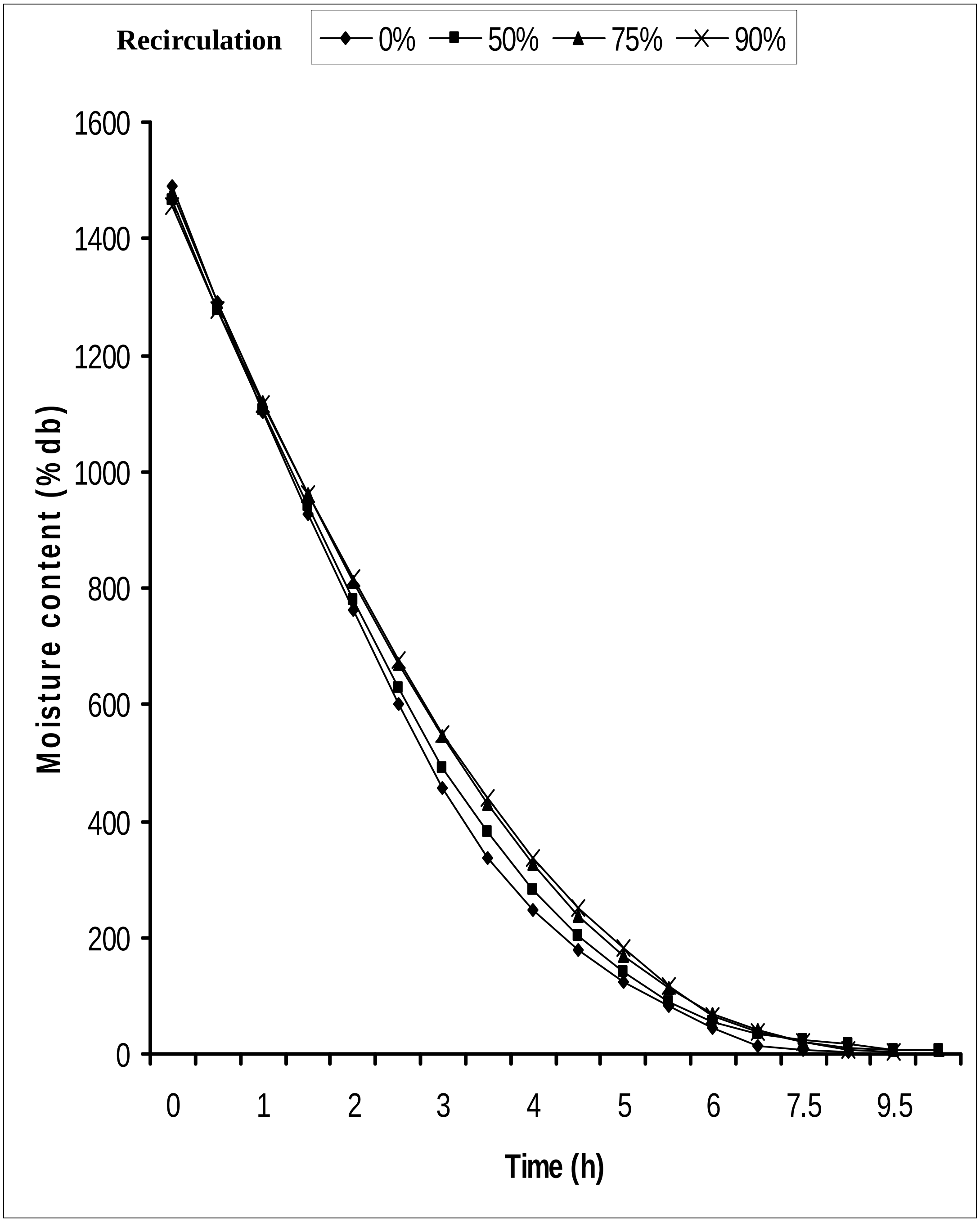

Fig. 4.2 Variation of moisture content with time for dehydration of tomato slices at drying air temperature 70/65^{0}C and different recirculation rates.

This was in agreement with trend that was observed for high moisture content agricultural commodities by different researchers i.e. drying of button mushroom with initial moisture content (I.M.C.) 90% (Pandey et. al, 2000), Pear with I.M.C. 92% (Lahsasni *et al.*, 2003), Parchment Coffee with I.M.C. 90% (Mwithiga, 2003), Spinach with I.M.C. 95% (Tan *et al.*, 2003) and for winter vegetables such as Peas, Spinach, Carrot and Cabbage (Mandhyan *et al.*, 1987).

Moisture content of drying sample varied progressively with respect to drying time. The samples depicted higher value as recirculation rate increased from 0% to 90% from starting till 4 to 5 h (approximately half of the drying time). This increased difference in the moisture content of drying sample during initial period was due to lower moisture picking potential of drying air as humidity got increased with increased recirculation rate. But during next half period of drying process difference in moisture content of sample illustrated decrease till final moisture content was reached. This might be because during later part of drying period, moisture removed per unit time for each recirculation rate decreased to great extent as compared to initial drying period. So that dryer inlet air approaches to constant drying air conditions with respect to humidity for each recirculation rate.

The total drying time required at temperature 70/60^{0}C was observed to be 10.0, 11.0, 11.0 and 10.5 hours and that at 70/65^{0}C was 9.0, 9.5, 10.0 and 9.5 hours for 0, 50, 75 and 90% recirculation rate respectively.

4.3.2 Effect of process variables on drying rate

Variation of drying rate as a function of moisture content for different drying air condition was shown in figure 4.3 and 4.4. It was observed that under drying air temperature 70/60 ^{0}C average drying rate for first one hour was 3.72, 3.49, 3.43 and 3.13 kg. of water evp./kg of BDM.h for 0, 50, 75 and 90% recirculation ratio respectively. There was considerable difference in drying rate and it decreased as recirculation rate increased. This might be due to higher humidity of recirculated air due to higher evaporation rate during initial phase of drying which decreases moisture pickup potential of mixed air. The similar phenomena were observed for first one hour at drying air temperature of 70/65^{0}C. The average drying rate for first one hour was 3.8, 3.54, 3.55 and 3.35 kg. of water evp./kg of BDM.h for 0, 50, 75 and 90% recirculation ratio respectively. It was observed that the drying rate at temperature 70/65^{0}C was higher than that at 70/60^{0}C throughout the drying period. Therefore, it was clear that drying rate increased considerably with increase in drying air temperatures; thus a higher drying air temperature produced higher drying rate and consequently moisture content of drying sample decreased. This result was in agreement with observations reported by Lahsasni *et al.* (2003).

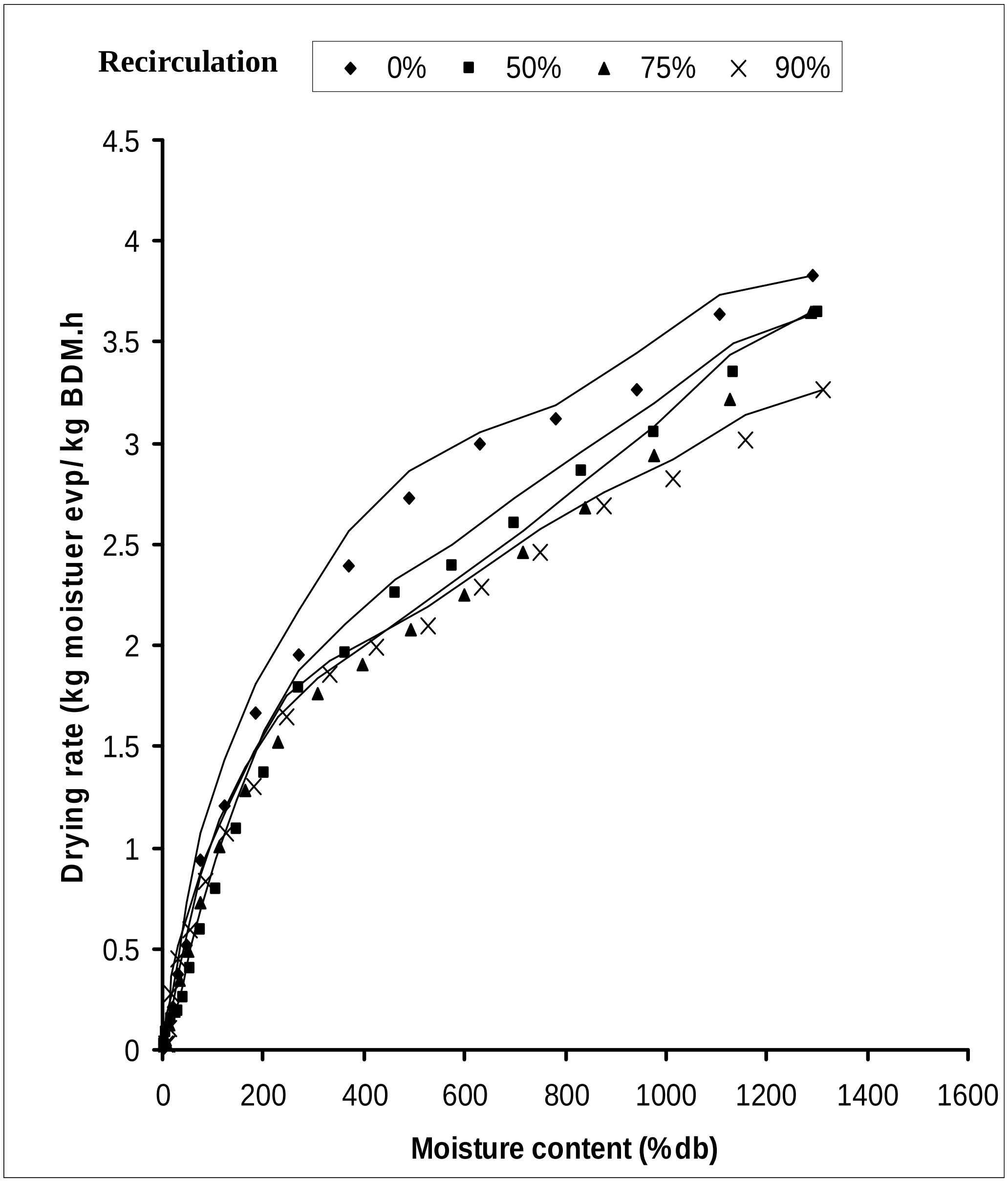

Fig. 4.3 Plot of variation of drying rate versus moisture content (%w.b.) for dehydration of tomato slices at drying air temperature 70/60^{0}C and different recirculation rates.

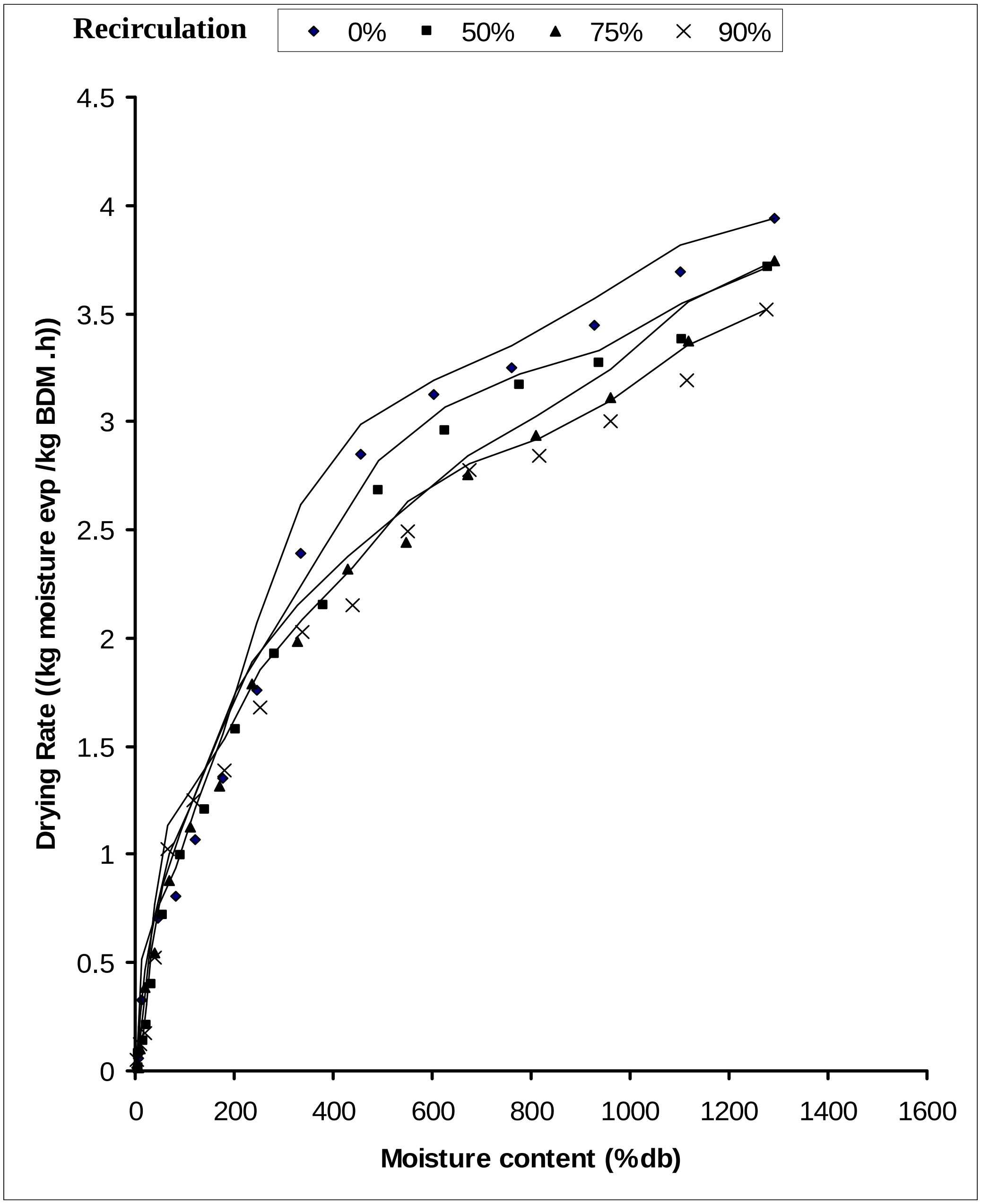

Fig. 4.4 Plot of variation of drying rate versus moisture content (%w.b.) for dehydration of tomato slices at drying air temperature 70/65^{0}C and different recirculation rates.

Recirculation ratio had shown considerable effect on drying rate during drying at 70/60^{0}C. But during drying at 70/65^{0}C air temperature conditions temperature had marked effect on drying rate than recirculation rate. All the drying rate versus moisture content curves follows similar trend irrespective of recirculation rates.

From both the plots it could be seen that drying rate curve depicted only falling rate drying period, though drying sample contains high initial moisture. Constant rate drying period was absent through out the drying process of tomato slices under any recirculation ratio. This result was in agreement with that observed by numerous researchers such as for vegetables e.g. Peas, Spinach and Carrot (Mandhyan *et al.*, 1988), Sweet Potato chips and grates (Tan *et al.*, 2001), Button Mushroom (Pandey *et al.*, 2000) *etc.* This might be due to fact that for vegetable products, moisture transferred to the surface during first stage only by capillary mechanism. Due to the shrinkage, the rate of drying was not constant (Brennan *et al.*, 1990).

Dry matter recovery in percent was observed to be 6.54, 6.6, 6.6 and 6.8 under 70/60^{0}C and 6.5, 6.76, 6.67 and 6.63 under 70/65^{0}C for 0, 50, 75 and 90% recirculation rate respectively. It revealed that dry matter recovery remained unaffected irrespective of drying under different recirculation rates.

4.3.3 Effect of process variables on diffusivity

The diffusion process could be described using Ficks law of diffusion, which stated that the mass flux per unit area of component was proportional to its concentration gradient (Singh and Heldman, 2004). By applying the Ficks law to the observed drying data, a plot of ln (MR) versus time was plotted as shown in figure 4.5 and 4.6. The straight line equation fitting to the data was presented for each independent curve. The slope of straight line was used to calculate the diffusivity. The diffusivity values of tomato slices dried under different drying air conditions are given in table 4.4.

Table 4.4 Effect of drying process variables on diffusivity of tomato slices.

Temp. ºC	Rec. Rate (%)	Diffusivity m^2/s	Temp. ºC	Rec. Rate (%)	Diffusivity m^2/s
70/60	0	6.04×10^{-10}	70/65	0	6.43×10^{-10}
	50	4.55×10^{-10}		50	5.19×10^{-10}
	75	4.42×10^{-10}		75	5.13×10^{-10}
	90	4.35×10^{-10}		90	5.62×10^{-10}

The observed diffusivity values for 70/ 60^{0}C drying air temperature were 6.04×10^{-10} m^2/s, 4.55×10^{-10} m^2/s , 4.42×10^{-10} m^2/s and 4.35×10^{-10} m^2/s for 0, 50, 75 and 90% recirculation rate respectively. Also for drying air temperature 70/65^{0}C observed diffusivities were 6.438×10^{-10}

m^2/s, 5.19 x 10^{-10} m^2/s, 5.13 x 10^{-10} m^2/s and 5.62 x 10^{-10} m^2/s for 0, 50, 75 and 90% recirculation rate respectively. Thus diffusivity values observed during experiment of dehydration of tomato slices were slightly lower than that observed by Charles *et al.* (2005). This might be due to the higher drying air temperature (75^0C) used for drying of tomato slices by Charles *et al.* (2005). Also it was observed from diffusivity values that recirculation of exit air had little effect on diffusivity value at constant drying air conditions. It was recorded that with increase in drying air temperature there was increment in diffusivity value. This might be due to the temperature dependency of moisture diffusivity in dehydration process as stated by Singh and Heldman (2004).

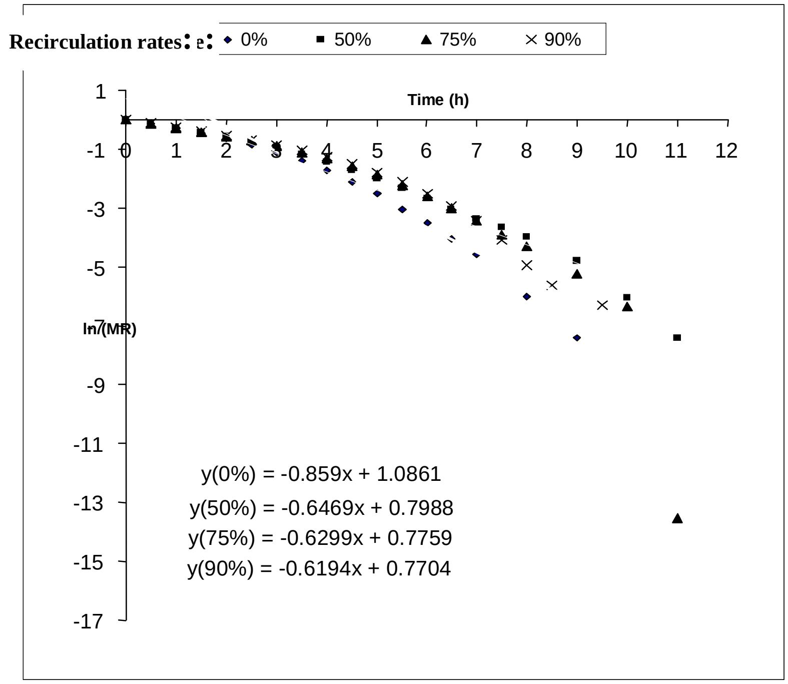

Fig. 4.5 Relationship of ln[MR] with time at drying air temperature 70/60^{0}C at different drying air conditions.

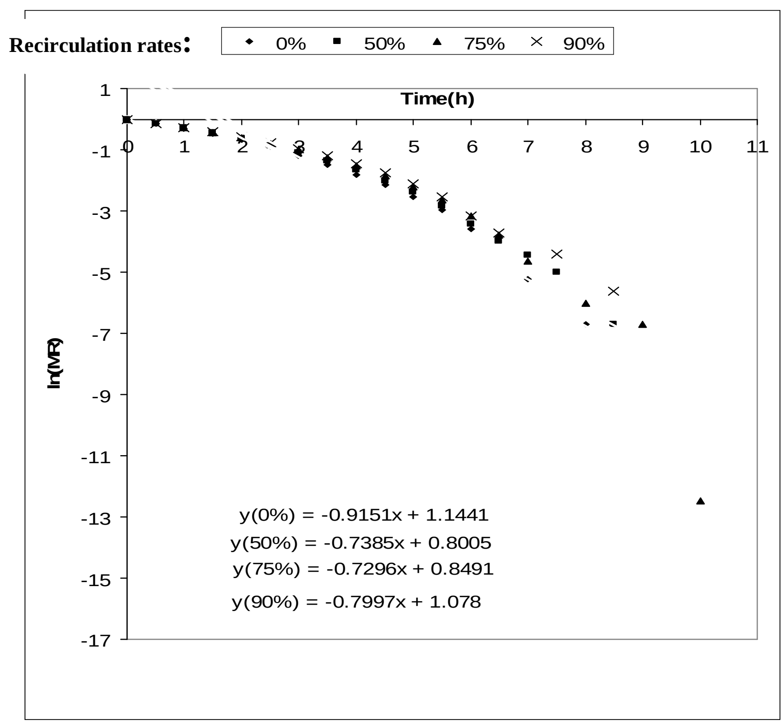

Fig. 4.6 Relationship of ln[MR] with time at drying air temperature 70/65^{0}C at different drying air conditions.

4.3.4 Effect of process variable on drying time

The tomato treated with mixture of crushed ice and salt followed by dipping in hot sodium chloride solution were dried under different drying air conditions.

Time required for dehydration of tomato at drying air temperature 70 /60^0 C and 70 /65^0 C under different recirculation rate is presented in table 4.5.

Table 4.5 Effect of process variables on drying time of Tomato slices.

Temp. ºC	Rec. Rate (%)	Drying Time (h)	Temp. ºC	Rec. Rate (%)	Drying Time (h)
70/60	0	10.0	70/65	0	9
	50	11.0		50	9.5
	75	11.0		75	10
	90	10.5		90	9.5

It is observed from results as denoted in table 4.5 that drying time requirement for dehydration of tomato slices at drying air temperature of 70/60^{0}C was 10, 11, 11 and 10.5h under recirculation rate of 0, 50, 75, and 90%. Thus increment in drying time for 50, 75 and 90% as compared with 0% is 10, 10 and 5%. Also at drying air temperature 70/65 ^{0}C observed drying time requirement for dehydration of tomato slices was 10, 11, 11 and 10.5h under recirculation rate of 0, 50, 75, and 90% with percent increment in drying time as compared to 0% recirculation rate is 5, 10 and 5%.

It is clear from table 4.5 that time required for dehydration of tomato slices at 70/65^{0}C was less than that required for 70/60^{0}C. Thus, with 5^{0}C increment in drying air temperature at 70/65^{0}C there was 10 , 13.6, 10 and 9.5% saving in drying time as compared to drying at 70/60 ^{0}C for 0, 50, 75 and 90% recirculation rate, respectively.

Also it is observed that time required for drying under 70/60^{0}C at 50% and 75 % recirculation rate is same, because from plot of moisture content versus drying time it is cleared that major part of the moisture was evaporated during first four hours of drying process. Hence during next half period of drying process, difference in moisture content of sample illustrated decrease till final moisture content was reached. This might be because during later part of drying period, moisture removed per unit time for each recirculation rate to great extent as compared to initial drying period. Thus during next half part of drying process moisture content of drying sample under 50% recirculation and 75% recirculation approached the same value at 7.5 hr of drying process and due to similar drying air conditions at prevailing time required for drying might be same.

It is observed that under 70/60^{0}C and 70/65^{0}C drying air temperature conditions time required for drying under 90% recirculation is less than that 75% recirculation. This might be because of higher drying rate observed at 90% recirculation rate at 90% than 75% recirculation rate observed during latter party of drying process. The higher drying rate observed at 90% recirculation might be due to reduced shrinkage effect.

4.4 Qualitative Evaluation of Dehydrated Product

4.4 .1 Reconstitutional qualities of dried tomato slices

Evaluation of reconstitutional qualities of dehydrated tomato slices was made by conducting rehydration test as described in methodology. The dehydrated slices absorbed water during rehydration and became soft, mushy and swollen. Plate 4.3 shows distinction between fresh, dehydrated and rehydrated tomato slices. Three replications of each sample were rehydrated to avoid any experimental error. The average value of rehydration characteristics of all eight samples were presented in table 4.6.

Table 4.6 Rehydration characteristics of dehydrated tomato slices.

Temp. ºC	Rec. Rate (%)	Rehydration ratio	Coefficient of rehydration	Rehydrated. Sample M.C. (%w.b.)
70/60	0	3.48	0.2045	71.2644
	50	3.87	0.2604	74.1602
	75	4.05	0.2478	75.3086
	90	3.67	0.2311	72.7520
70/65	0	3.55	0.2133	71.8310
	50	3.90	0.2340	74.3590
	75	4.15	0.2464	75.9036
	90	3.65	0.2175	72.6027

The relevant data of rehydration of dehydrated tomato slices were given in Appendix N. The observed rehydration ratio at 70/60^{0}C drying air temperature was 3.48, 3.87, 3.85 and 3.47 for 0, 50, 75 and 90% recirculation rate respectively. Also for drying tests carried at 70/65^{0}C the observed rehydration ratio was 3.55, 3.9, 4.15 and 3.65 for 0, 50, 75 and 90% recirculation rate respectively. The maximum values were observed for the test carried out under 75% recirculation rate for both drying air temperature conditions. It could be revealed from the data that the samples dried under any recirculation rate gave higher rehydration ratio than that samples dried without any recirculation (0%) of exit air. Ultimately the moisture content and coefficient of rehydration values of sample dried under recirculation of exit air were higher than that dried without any recirculation. Thus the samples dried under re-circulated drying air conditions had better reconstitution characteristics than that dried without any recirculation

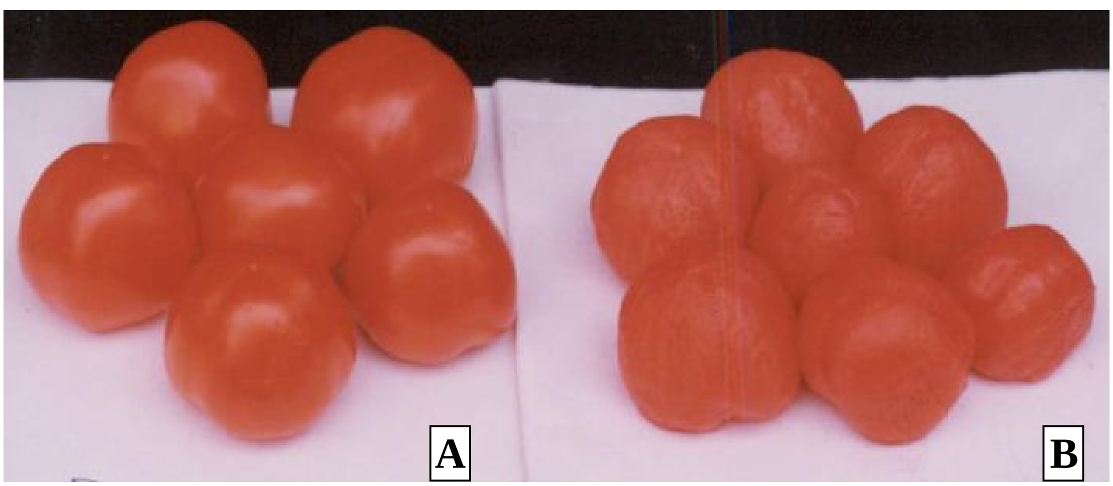

Plate 4.1 Tomatoes before and after peeling

A. Untreated

B. Untreated and peeled

4.4.2 Tomato colour index (T.C.I.)

Colour is often used as an indication of quality and freshness for food products, including tomato products for which the perception is "the redder the better". Hence it has become important for tomato processors to be able to evaluate and grade their products based on color (Hunterlab, 2005). Plate 4.4 shows the distinction of colour among eight samples of tomato powder.

Colour values measured using colourflex were relative to the absolute values of perfect reflecting diffuser as measured under the same geometric conditions (ASTM method). The colorimeter set up selected consists of illuminant as D65 and 10^0 observer, Set up-97 and colour scale was day light colour. Reading taken were absolute values of colour. Readings (L*, a* and b*) were taken at room temperature 33.5 ^{0}C and 25% relative humidity. L* represents lightness index, a* and b* represents redness and yellowness of the product. The physical significance of the colour indices are as represented in plate 4.2 Tomato color index (T.C.I.) that calculated with the help of equation as described in methodology is tabulated for all tomato powder samples in table 4.7.

Table 4.7 Tomato colour index (T.C.I.) of tomato powder

Temperature ºC	Rec. Rate (%)	Colour Meter Reading			TCI
		L*	a*	b*	
70/60	0	51.52	22.74	35.52	19.187

	50	52.46	23.6	35.17	19.869
	75	44.92	25.42	32.07	27.021
	90	52.65	23.78	36.51	19.155
70/65	0	52.32	22.15	35	18.633
	50	52.78	22.37	35.46	18.400
	75	46.29	22.94	33.99	22.656
	90	51.35	20.48	36.64	15.934
Fresh Tomato Juice (ambient air conditions)		33.88	30.34	24.32	46.010

Plate 4.2 Colour Scale representing relationship of colour index (L*, a*, b*).

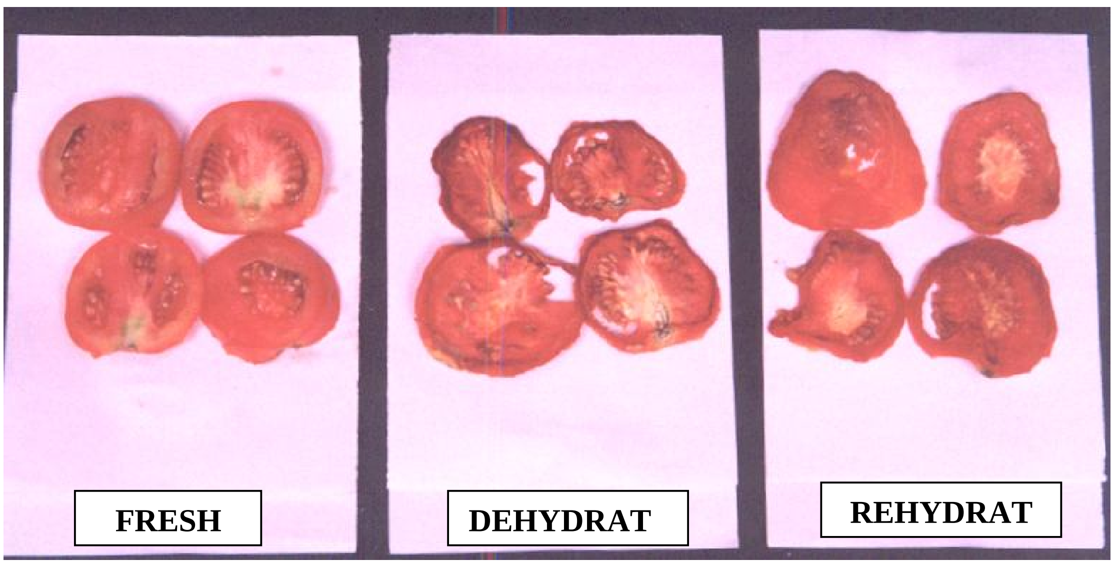

Plate 4.3 Tomato Slices

Graphical representation of the T.C.I. for all samples were given in figure 4.7. It was cleared from the chart that observed T.C.I. for powder samples dried at drying air temperature

70/60^{0}C was higher than that observed for samples dried under 70 /65^{0}C. Thus it was clear that temperature has significant effect on the color of final product.

The observed Tomato colour index (T.C.I.) at 70/60^{0}C drying air temperature was 19.18, 19.86, 27.02 and 19.15 for 0, 50, 75 and 90% recirculation rate respectively. Also for drying tests carried at 70/65^{0}C the observed T.C.I. was 18.63, 18.40, 22.65 and 15.93 for 0, 50, 75 and 90% recirculation rate respectively. Thus, for samples dried at drying air temperature 70/60^{0}C observed highest T.C.I. was 27.021 for 75 % recirculation. This T.C.I. was 58% of that observed for fresh tomato juice. Under same drying air condition (70/60^{0}C) for all recirculation ratio observed standard deviation of a*, b* and L* is 0.97, 1.66 and 3.18. Thus, with higher standard deviation L* had played key role for differentiating the T.C.I. of sample dried under 75% recirculation than others. Lower value of L* indicates that product wsa lighter than others conversely other samples are darker than that of sample dried under 75% recirculation rate. As reported by researchers the darkness of tomato powder is due to the black colour developed during dehydration process due to oxidation reaction (EDIS, 1988). The same phenomenon was observed for sample powder dehydrated at drying air temperature 70/65^{0}C. Thus highest T.C.I. was obtained under 75% recirculation rate for tomato powder dried at 70 /60^{0}C and 70 /65^{0}C.

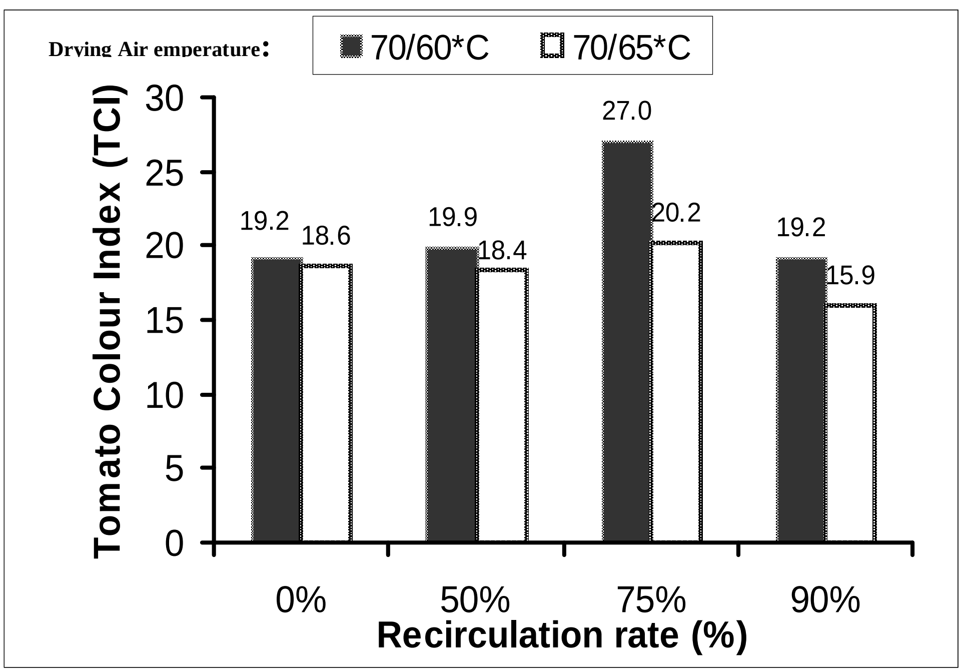

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Fig. 4.7 Tomato Colour index of tomato powder dried at different air conditions

4.4.3 Chemical analysis for Tomato powder for Ascorbic acid retention

Ascorbic acid is lost during the drying process because it is an air-soluble nutrient and food drying is an air-based process. When a food is sliced and its cells are cut, the surfaces that are exposed to air loose some vitamin C content. The retention of the ascorbic acid depends upon the water content, sugar content, the size of the piece of food, the amount of air circulation when the food is dried, the level of humidity in the air entering the dehydrator and the air temperature inside the dehydrator (Mary Bell, 2005).

The relevant data of experiment are given in Appendix M. The results were presented in table 4.8

Table 4.8 Ascorbic acid content of tomato powder.

Drying air Temp. ºC	Recirculation. Rate (%)	Ascorbic Acid content (mg /100g sample)
70/60	0	9.08
	50	10.67
	75	9.90
	90	9.90
70/65	0	7.65
	50	8.39
	75	8.75
	90	8.52
Fresh Tomato Juice		25.00

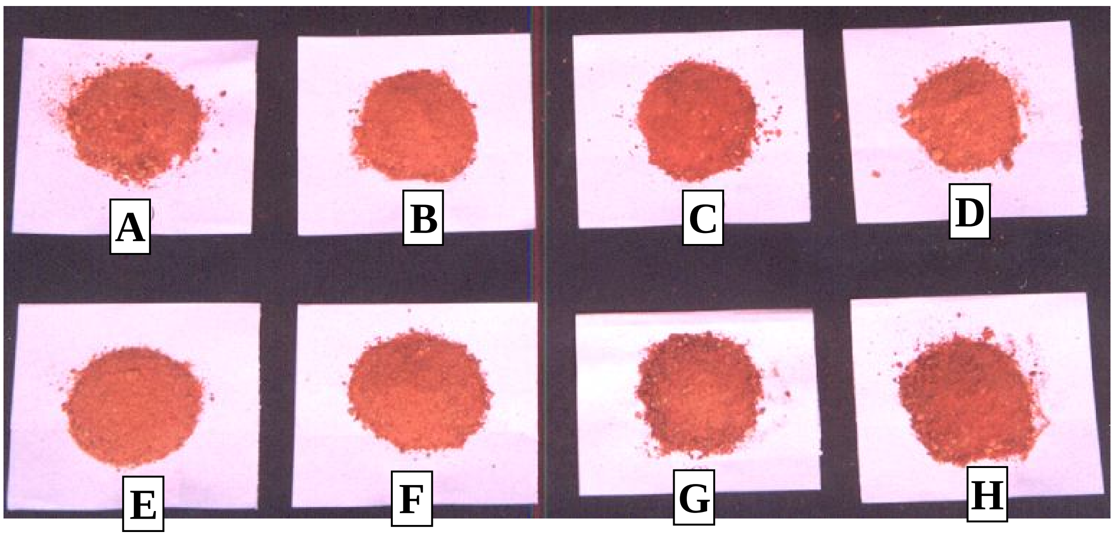

Plate 4.4 Tomato powder samples obtained by grinding the dehydrated tomato slices.

[A]- Sample dried at 70/60^{0}C, 0% recirculation

[B]- Sample dried at 70/60^{0}C, 50% recirculation

[C]- Sample dried at 70/60^{0}C, 75% recirculation

[D]- Sample dried at 70/60^{0}C, 90% recirculation

[E] - Sample dried at 70/65^{0}C, 0% recirculation

[F] - Sample dried at 70/65^{0}C, 50% recirculation

[G] - Sample dried at 70/65^{0}C, 75% recirculation

[H] - Sample dried at 70/65^{0}C, 90% recirculation

100 g fresh tomato juice contained 25 mg of ascorbic acid. The powder obtained from tomatoes dried under drying air temperature 70/60^{0}C had ascorbic acid content of 9.08, 10.67, 9.90 and 9.90 mg per 100 g of sample for 0, 50, 75 and 90% respectively. Also powder obtained from dehydration of tomato slices dried under drying air temperature 70/65^0 C was found to be 7.65, 8.39, 8.75 and 8.52 mg/100g of powder sample for 0, 50, 75 and 90% respectively. From the figures it is cleared dehydration of tomato in recirculatory convective dryer had no significant effect on ascorbic acid retention of tomato powder. Also it could be observed that ascorbic acid retention was affected by drying air temperature. As drying air temperature increased, ascorbic acid content of final dried product decreased. Highest retention of ascorbic acid (10.67 mg/100g of sample) was found in powder sample obtained from tomato slices dried at drying air temperature 70/60^{0}C and under 50 % recirculation and at 70/65 ^{0}C it was highest (8.75 mg/100g of sample) under 75% recirculation rate. The comparative retention of ascorbic acid in four samples was presented in figure 4.8.

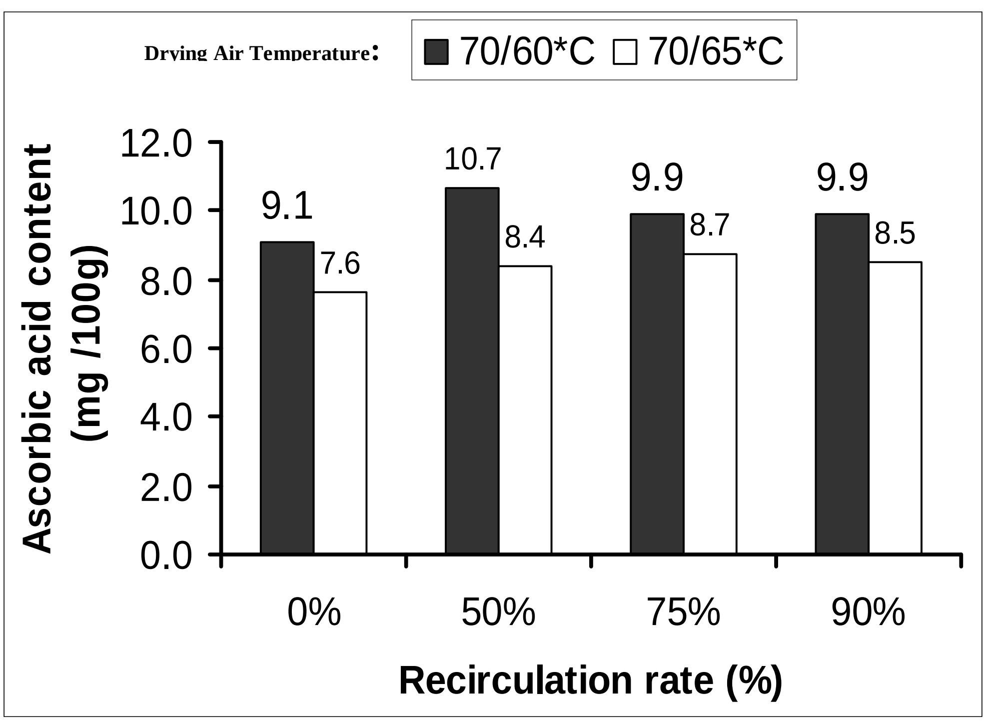

Fig.4. 8 Retention of ascorbic acid in tomato powder samples as compared to fresh tomato Juice

4.5 Evaluation of Dryer Performance

4.5.1 Effect of process variables on exhaust air temperature

The temperature and relative humidity of exhaust air is an indication utilization of drying potential of drying air (Shukla and Singh, 2003). It is an accepted fact that dehydration process in the convective dryer is an adiabatic process of heat transfer, i.e. heat required for evaporation of the moisture from wet material is solely supplied by the air through convection (conduction, radiation heat transfer to the surrounding is negligible) (Brennan *et al*., 1990).

A plot of temperature of exhaust air versus time was plotted as shown in figure 4.9 and 4.10 for each recirculation rate and at different drying air temperatures. It was observed from the figures that exhaust air temperature vary from 50.5^{0}C to 60^{0}C during drying process at temperature 70/60^{0}C and variation was 57.5^{0}C to 65^{0}C for drying process at drying air temperature 70/65^{0}C. The minimum temperature attained during drying process at drying was temperature 70/60^{0}C is 54^{0}C, 53^{0}C, 52^{0}C and 50.5 ^{0}C and that at 70/65^{0}C is 60^{0}C, 59^{0}C, 58^{0}C and 57.5 ^{0}C for 0, 50, 75 and 90% recirculation rate respectively. Hence it was clear that as recirculation rate increased exhaust air temperature of the dryer decreased. Thus, Drying potential of the drying air was harnessed maximum at higher recirculation ratio.

Also it was clear that during initial part of the drying process the difference in exhaust temperature was maximum for different recirculation rate but as the time progress the difference in the temperature decreased. During last part of the drying process the temperature of the exhaust air remains constant irrespective of the recirculation. Thus during last phase of convective drying process air condition with respect to humidity were similar for every recirculation rate irrespective of recirculation rate.

There was constant increment of exhaust air temperature through out drying process (initial to final stage) at drying air temperature 70/60^{0}C an 70/65^{0}C temperature for any recirculation ratio. None of the period shows constant exhaust air temperature. This indicates that the drying air was still having some drying potential which was not harnessed as it was observed by Walker and Wilhelm (1995).

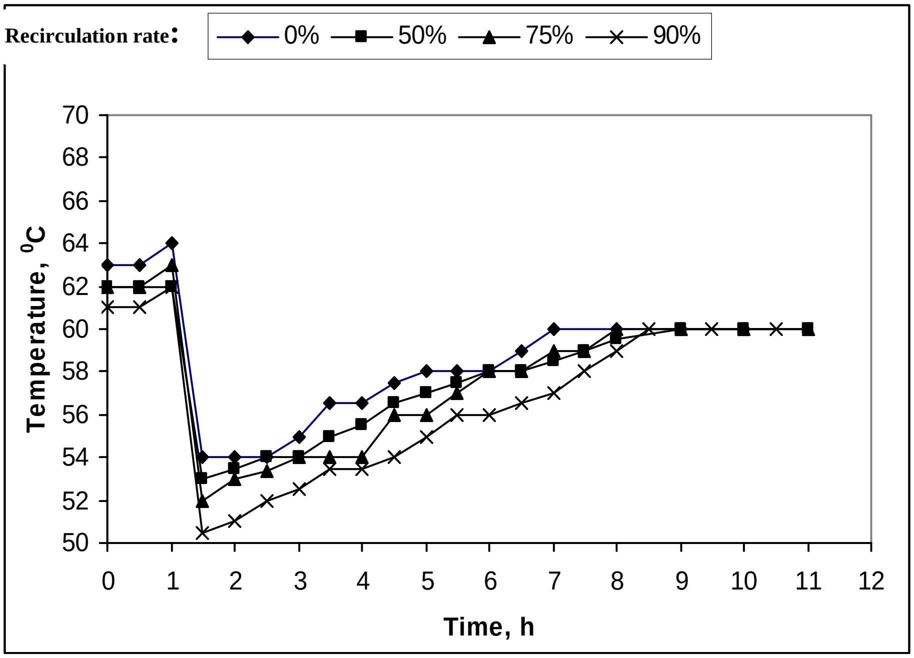

Fig. 4.9 Exhaust air temperature variation with time at 70/60^{0}C drying air temperature and different recirculation rate.

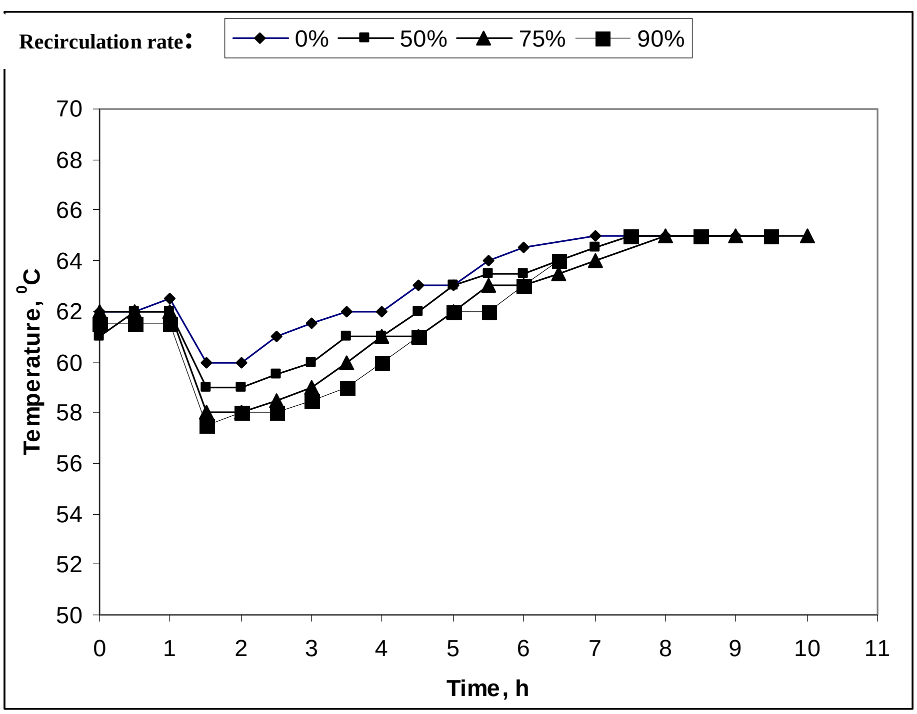

Fig. 4.10 Exhaust air temperature variation with time at 70/65^{0}C drying air temperature and different recirculation rate.

It was combination of different drying variables such as product load; air flow rate and drying temperature which is need to be optimized for improving the drying efficiency of the dryer.

4.5.2 Effect of process variables on thermal efficiency of dryer

Fuel and power are major considerations in minimizing the operational cost of dryer. Hence thermal efficiency is an important parameter while evaluating the dryer performance.

Giner and Michlies (1988) studied fluidized bed dryer and reported that one of the way to improve the thermal efficiency of the dryer was to increase the air temperature at the heater inlet over ambient temperature by means of recirculation of drier exit air. The variation of the thermal efficiency with respect to different drying air conditions is shown in figure 4.11. At drying air temperature 70/60^{0}C, the observed thermal efficiency was 13.75, 17.95, 21.48 and 24.61% for 0, 50, 75 and 90% recirculation rate respectively. Also at drying air temperature 70/65^{0}C, the observed thermal efficiency was 15.59, 18.07, 22.93 and 25.4 % for 0, 50, 75 and 90% recirculation rate respectively.

The thermal efficiency of the dryer increased with recirculation rate which was in accordance with findings of Giner and Michelis (1988). The highest thermal efficiency observed at 90 % recirculation rate which was 24.6 % at 70/60^{0}C and 25.4% at 70/65^{0}C drying air temperature.

However, the low values of thermal efficiency under both drying air temperature sets might be due to much more loss of heat through un-insulated heater chamber. It may also be due to the dependency of thermal efficiency on product characteristics and its initial moisture content (Shukla and Singh, 2003).

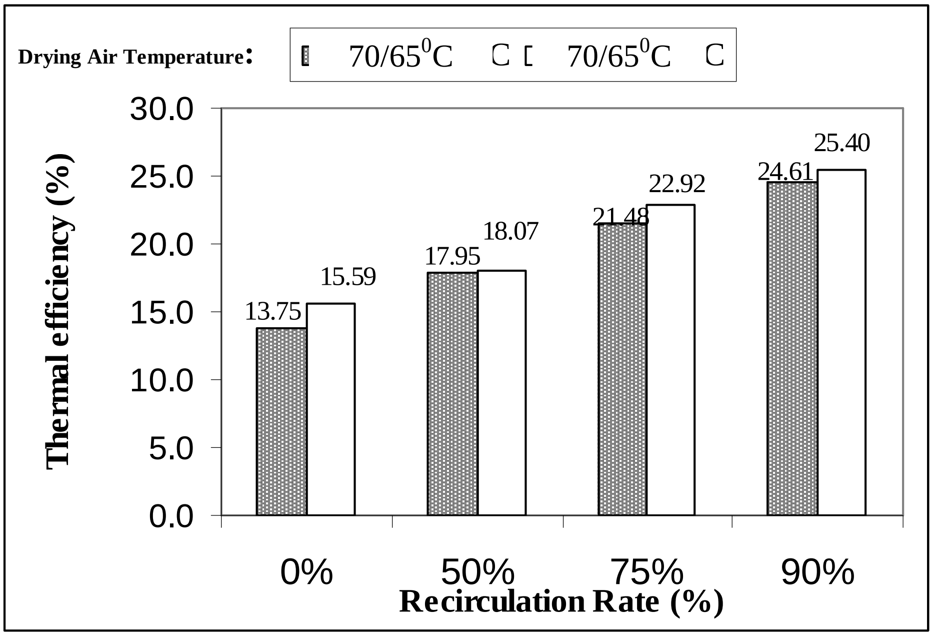

Fig. 4.11 Dryer thermal heat efficiency (T.H.E.) under different drying air conditions.

4.5.3 Effect of process variables on heat utilization factor

Heat utilization factor (H.U.F.) is the ratio of heat utilized to total heat supplied and thermal heat efficiency is the ratio of heat utilized to total heat available. Data with respect to H.U.F. and T.H.E. obtained from experimental results is tabulated in the table 4.9.

Table 4.9 Heat utilization factor and thermal efficiency of recirculatory type dryer

Temp. ºC	Recirculation Rate (%)	H.U.F. (Fraction)	Heat utilization efficiency (%) (H.U.F.) x100	T.H.E (%)
70/60	0	0.13	13.8	13.75
	50	0.20	20.0	17.95
	75	0.26	26.0	21.48
	90	0.37	37.0	24.61
70/65	0	0.12	12.0	15.59
	50	0.18	18.0	18.07
	75	0.25	25.0	22.92
	90	0.33	33.0	25.40

Observed data showed that heat utilization efficiency varied between 13.8 % to 37.0 % for drying at 70/60^{0}C drying air temperature and at 70/65^{0}C it varied between 12.0 % to 33.0%. It was revealed from the data that heat utilization factor under particular recirculation rate was nearly equal irrespective of the drying air temperature. Thus it cleared that heat utilization factor of dryer remained unaffected with respect to drying air temperature. The fact cleared more in the figure 4.12 which shows comparison of heat utilization factor of dryer under different drying air condition.

Also it was observed that heat utilization efficiency showed numerically higher value than that thermal heat efficiency this clearly indicates that there was more difference between heat available and heat supplied. This was because large mount of heat loss from un-insulated heater chamber. Hence in order to improve the thermal heat efficiency of the dryer loss of heat from heating chamber should be minimized with the help of proper insulation.

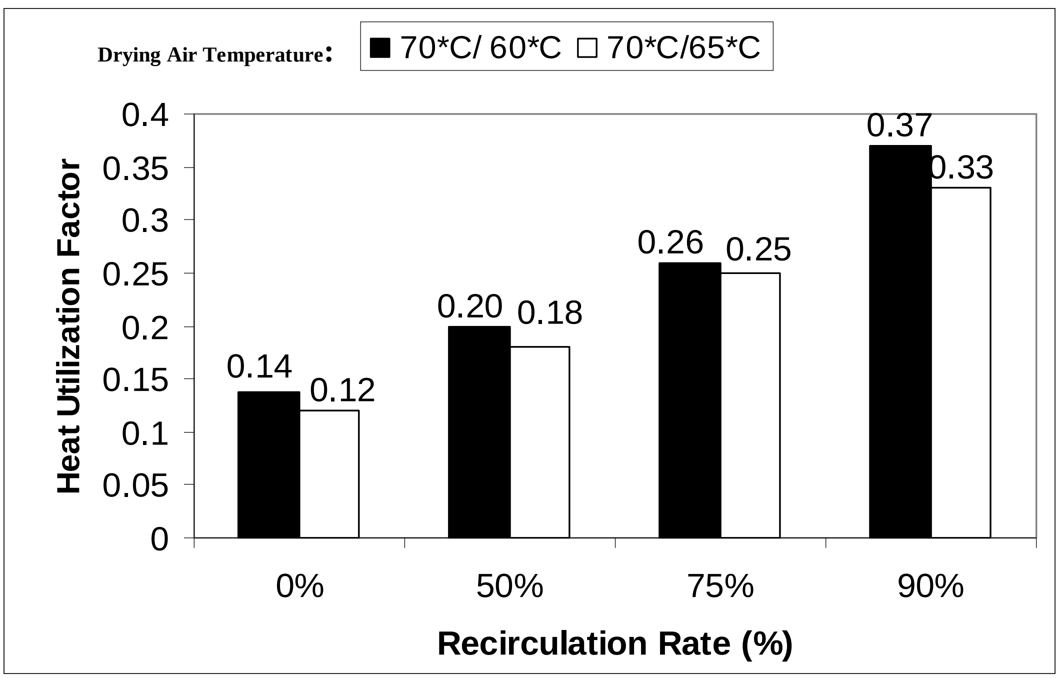

Fig. 4.12 Heat utilization factor of dryer at different drying air temperature

4.5.4 Effect of process variables on energy consumption

A plot of cumulative energy consumption versus drying time was shown graphically in figure 4.13 and 4.14 for drying air condition 70/60^{0}C and 70/65^{0}C respectively. It was cleared from both the figure that for tomato drying cumulative energy consumption as a function of recirculation rate tended to follow a linear relationship for each rate. Table 4.10 summarizes effect of recirculation rate upon energy consumption during tomato drying.

Table 4.10 Specific energy consumption of tomato drying process under different drying air conditions.

Temp. ºC	Recirculation Rate (%)	Specific Energy kW.h/kg fresh tomato
70/60	0	4.15
	50	3.25
	75	2.7
	90	2.35
70/65	0	3.7
	50	3.15
	75	2.5
	90	2.25

Data in the table revealed that increased recirculation resulted in lower energy consumption for batch drying of tomato slices. Energy use steadily decreased with increased recirculation rate at both drying air temperature (70/60^{0}C and 70/65^{0}C).

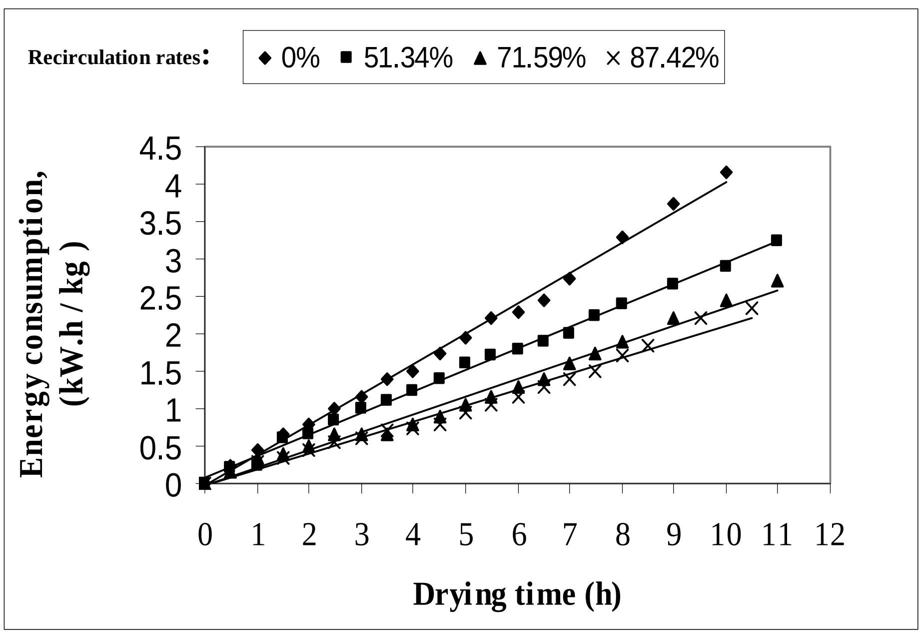

Fig. 4.13 Plot of cumulative energy use at different recirculation rates for 70/60^{0}C drying air temperature.

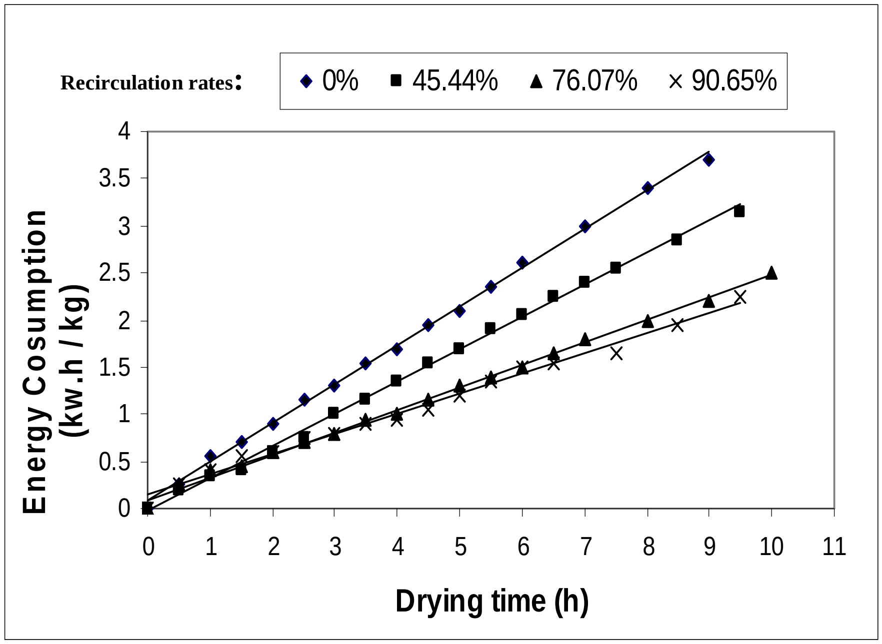

Fig. 4.14 Plot of cumulative energy use at different recirculation rates for 70/65^{0}C drying air temperature.

This result was in agreement with the results obtained previously by Walker and Wilhelm (1995) for dehydration of apple and peaches and Jain (2003) for dehydration of spinach, *etc.* It was cleared from the observed data of drying of tomato that energy required for all recirculation ratios at drying air temperature 70/60^{0}C was more than that observed at drying air temperature 70/65^{0}C. This may be due to the fact that time required for drying under 70/65^{0}C was less than that at 70/65^{0}C.

Saving of energy in drying process under recirculation as compared to drying without any recirculation at 70/60^{0}C drying air temperature was 21, 34 and 43% and at 70/65^{0}C it was 14 %, 32% and 39 % under 50, 75 and 90% recirculation respectively. The highest energy saving were observed at 90% recirculation rate under both drying air conditions. The maximum specific energy consumption observed for tomato dehydration was for drying without any recirculation which was 4.15 kW.h/kg at 70/60^{0}C and 3.7 kW.h of fresh tomato at 70/65^{0}C. This value was some what higher than that observed by Zimmerman (1988) (2.91 kW.h/Kg) for dehydration of tomato in convective dehydrator. This might be due to the fact of lower operating thermal heat efficiency (T.H.E.) of the dryer. Lowest observed specific energy consumption were 2.35 and 2.25 kW.h/kg of fresh tomato dried under 90% recirculation rate at 70/60^{0}C and 70/65^{0}C respectively.

4.5.5 Economic evaluation of recirculatory system of drying

It is essential to know weather the technology is economically viable or not for the success and commercialization of new technology. Therefore an attempt has been made to determine the economics of the recirculatory dryer. The economic evaluation of the dryer has been made for dehydration of tomato as described in methodology.

Economic evaluation of the dryer over period of one year was described with the help of annualized cost (AC) of operation and annualized energy saving (AES). The data of AC and AES is presented in table 4.10. The calculation of AC and AES are shown in Appendix I.

Table 4.10 Effect of process variables on annualized cost and annualized energy savings.

Temp. ºC	Rec. Rate (%)	Annualized cost (Rs.)	Annualized energy savings (kW.h)
70/60	0	6028.00	-
	50	4960.30	328.5
	75	4307.90	529.2
	90	3892.76	657.0
70/65	0	5494.20	-
	50	4841.76	200.7
	75	4070.70	438.0
	90	3774.14	529.2

It was observed from the table 4.10 that annualized cost of operation of the dryer at drying air temperature 70/60^{0}C was rupees 6028, 4960.3, 4307.9 and 3892.76 and that at temperature 70/65^{0}C was rupees 5494.20, 4841.76, 4070.70 and 3774.14 for 0, 50, 75 and 90% recirculation ratio respectively. Thus it was clear that as recirculation rate increased the annualized cost of operation of the dryer decreased. Also similar relationship has been observed for annualized energy savings. The maximum energy savings as compared to 0% recirculation rate was observed for 90% recirculation rate which was 657 kW.h and 529.2 kW.h at drying air temperature 70/60^{0}C and 70/65^{0}C, respectively.

CHAPTER V

SUMMARY AND CONCLUSIONS

Considering economical factors, best drying method is one, which is least expensive, and provides required quality and characteristics in the products. A majority of industrial dryers use steam, diesel, LPG, kerosene, electricity for heating. The financial value of energy varies enormously with its grading. Electrical energy which has highest energy grading of all and more scarce and costly hence effective energy management is required. Recirculating some of heated air through the dehydrator allows for significant energy savings thus reducing the operating energy costs. Partial recirculation of exhaust air does have other beneficial implications also. The main advantages associated with recirculating some of the heated air in dehydrators are saving heat and fuel, adding moisture to the air, lowering drying costs and increasing quality of dried products.

5.1 Summary

Dehydration of tomato with initial moisture content about 94 % was selected for testing of recirculation system. During preliminary drying experiment average weight of tomato was found to be 99 g. The average initial moisture content of untreated tomatoes, on wet basis was found to be 94.02 per cent, ranging from 93.86 to 94.23. It was found that 3-4 slices of 1.0 cm thickness could prepared from one tomato. After preliminary operations dehydration tests were carried out at different temperatures and at different drying air conditions.

Moisture loss data during dehydration of tomato slices revealed that percentage decrease in moisture content at drying air temperature 70/60^{0}C for first four hours was about 75, 68.8, 66.16 and 64.2% under 0, 50, 75 and 90% recirculation rate, respectively. Also under drying air condition 70/65^{0}C percent decrease in moisture content for first four hours was about 76.7, 73.7, 78.1 and 69.9% under 0, 50, 75 and 90% recirculation rate respectively. During drying process samples depicted higher value of moisture content as recirculation rate increased from 0% to 90% from starting till 4 to 5 h (approximately half of the drying time). But during next half period of drying process difference in moisture content of sample shown decrease with respect to recirculation rate till final moisture content was reached.

At drying air temperature 70/60^{0}C average drying rate for first one hour was 3.72, 3.49, 3.43 and 3.13 kg of water evp./kg of BDM.h and that at 70/65 ^{0}C was 3.8, 3.54, 3.55 and 3.35 kg. of water evp./kg of BDM.h for 0, 50, 75 and 90% recirculation ratio respectively. Dry matter recovery during dehydration experiment of tomato was 6.54, 6.6, 6.6 and 6.8 at 70/60^{0}C drying air temperature and 6.5, 6.76, 6.67 and 6.63 under 70/65^{0}C for 0, 50, 75 and 90% recirculation rate, respectively.

The observed diffusivity values for 70/ 60^{0}C drying air temperature were 4.55 x 10^{-10} , 4.42 x 10^{-10} and 4.35 x 10^{-10} m^2/s and that at 70/65^{0}C it was 6.43 x 10^{-10}, 5.19 x 10^{-10}, 5.13 x 10^{-10} and 5.62 x 10^{-10} m^2/s under 50, 75 and 90% recirculation rate respectively. Rehydration ratio at 70/60^{0}C drying air temperature was 3.48, 3.87, 3.85 and 3.47 and at 70/65^{0}C it was 3.55, 3.9, 4.15 and 3.65 under 0, 50, 75 and 90% recirculation rate respectively.

Tomato colour index (T.C.I.) of tomato powder at 70/60^{0}C drying air temperature was 19.18, 19.86, 27.02 and 19.15 and that at 70/65^{0}C was 18.63, 18.40, 22.65 and 15.93 under 0, 50, 75 and 90% recirculation rate respectively. Tomato powder obtained from dried tomato slices under drying air temperature 70/60^{0}C had ascorbic acid content of 9.08, 10.67, 9.90 and 9.90 mg per 100 g and at drying air temperature 70/65^{0}C it was found to be 7.65, 8.39, 8.75 and 8.52 mg/100g of powder sample under 0, 50, 75 and 90% recirculation rate respectively.

The minimum temperature attained during drying process at drying air temperature 70/60^{0}C was 54, 53, 52 and 50.5 ^{0}C and that at 70/65^{0}C is 60, 59, 58 and 57.5 ^{0}C for 0, 50, 75 and 90% recirculation rate respectively. The maximum specific energy consumption observed for tomato dehydration was for drying without any recirculation which was 4.15 kW.h/kg at 70/60^{0}C and 3.7 kW.h of fresh tomato at 70/65^{0}C.

Annualized cost of operation of the dryer at drying air temperature 70/60^{0}C was rupees 6028, 4960.3, 4307.9 and 3892.76 and that at temperature 70/65^{0}C was rupees 5494.20, 4841.76, 4070.70 and 3774.14 for 0, 50, 75 and 90% recirculation ratio respectively.

5.2 Conclusion:

Following specific conclusion were made after analysis of the data obtained from dehydration experiment of tomato slices in air recirculation system.

1. Moisture content was decreased with drying time and loss of moisture was drastic initially as compared to later part of drying process.
2. Drying rate at temperature 70/65^{0}C was higher than that at 70/60^{0}C throughout the drying period. Higher drying air temperature produced higher drying rate and consequently moisture content of drying sample decreased more rapidly.
3. Dehydration of tomato slices depicted only falling rate drying period, though initial moisture content of drying sample was high. Constant rate drying period was absent through out the drying process of tomato slices under any recirculation rate.

4. Recirculation had very little effect on diffusivity values of tomato slices under constant drying air conditions. At constant drying air temperature increase in recirculation rate from 50 to 90 % showed slight decrease in diffusivity value. At constant recirculation rate, increase in drying air temperature showed increment in diffusivity value.
5. Samples dried under recirculation of exit air had higher rehydration ratio than the samples dried without any recirculation (0%) of exit air. The maximum values were observed for the test carried out under 75% recirculation rate under both drying air temperature conditions.
6. Increase in recirculation rate decreased exhaust air temperature of the dryer. Thus, drying potential of the drying air could be harnessed maximum during higher recirculation rate.
7. Thermal efficiency and heat utilization factor of the dryer increased with increased recirculation rate.
8. During tomato drying, cumulative energy consumption as a function of recirculation rate tended to follow a linear relationship for each recirculation rate. With increase in recirculation rate there was significant decrease in energy consumption.
9. Saving of energy in drying process under recirculation as compared to drying without any recirculation at 70/60^{0}C drying air temperature was 21, 34 and 43% and at 70/65^{0}C it was 14 %, 32% and 39 % under 50, 75 and 90% recirculation, respectively.
10. Dehydration of tomato slices under 75 % recirculation rate at both drying air temperature (70/60^{0}C and 70/65^{0}C) resulted in best product with respect to colour, rehydration ratio.
11. Highest retention of ascorbic acid (10.67 mg/100g of sample) was found in powder sample obtained from tomato slices dried at drying air temperature 70/60^{0}C under 50 % recirculation and at 70/65 ^{0}C it was highest (8.75 mg/100g of sample) under 75 % recirculation.

SUGGESTIONS FOR FUTURE WORK

1. Drying experiment should be carried out with insulation of drying chamber, recirculation duct and air mixing chamber for further study of energy saving.
2. Effect of recirculation on energy saving need to be tested for dehydration of various products.

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