CHAPTER II

LITERATURE REVIEW

Relevant literature is reviewed in this chapter. It can be divided into two major sections. In Section 2.1, the agro-industry is reviewed to explain its classification, characteristics, and improvement of its product quality. In Section 2.2, drying process which is the major topic of this dissertation is described. This section can be divided into four parts as quality in drying, drying method, drying behavior, and study topics of the drying process. However, the study topics of the drying process can be divided into two subsections as drying process design and drying process control.

2.1 Agro-industry

Agro-industry has been one of the leading growth sectors, especially in developing countries such as Thailand. Moreover, it has stimulated the growth and modernization of the trade sectors and of related services. Its product diversification and quality have widened consumer choice and improve the quality of life of people. This section describes and reviews the agro-industry in terms of classification, characteristics and improvement its product quality.

2.1.1 Classification

The agro-industry is the generic term applied to industrial process of raw materials from the agricultural sector including forestry and fishing as well as crop production and animal husbandry (Brown, 1994; Marsden and Garzia, 1998). It can be classified with various criteria. However, food and non-food criteria are often used to classify the agro-industry (Marsden and Garzia, 1998).

Food industry is much more homogeneous and easier to classify than non-food industry. Most of its raw materials are perishable food which is a very varied group such as fruits, vegetables, milk, meat, and fish. However, the food industry can be classified roughly into three groups as crop, livestock, and fish products (Marsden and Garzia, 1998). Otherwise, input-output analysis can be used to classify the food industry (Leeuwen, 2000). It concerns with studying the interdependence of the producing unit an economy and with showing the interrelationships among different.

Non-food industry, in the contrast, it is more difficult to classify than the food industry. However, it can be classified into two groups as consumed products and utilized products. The consumed products are such as tobacco leaf, and herbal medicines. The utilized products are such as rubber, and fiber apparel. From both of them, a high degree of processing is required to produce all products.

2.1.2 Characteristics

The agro-industry can be characterized typically as three main stages. Three main stages are consisted of raw material preparation, agro-processing, and packaging and distribution (Figure 2.1). The detail of each stage can be described as below.

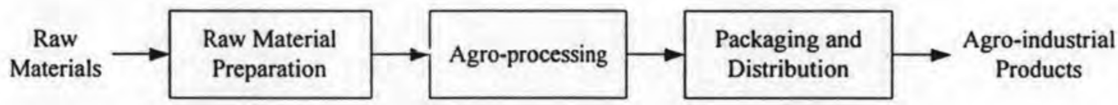

Figure 2.1 General characterization of the agro-industry

(1) Raw Material Preparation

The function of this stage is to provide the right quantity and quality of the raw materials to the agro-processing. Moreover, they are provided in a timely manner and at a reasonable cost. The raw materials are examined with several criteria such as quantity, quality, timing, and cost for each specification (Brown, 1994; Braun, 2003). Although there are several criteria used to examine the raw materials, the quality is the most important criterion for examining.

Quality of the raw materials of the agro-industry is directly related to the planting or breeding material, husbandry, fertilizers or feeds, pesticides or disease control, harvesting, and post-harvesting handling (Mizzi, 1993). Moreover, the quality of the raw materials depends on several uncontrolled factors such as climate, thin soils, and land fragmentation.

There are some researches attempting to reduce the quality variation from the raw materials. Robust optimization was used to seek and reduce the effects of such variation by identifying the settings of only adjustable factors (Mevik, et al., 2001). Furthermore, the optimization of the agricultural product quality and minimization of the quality variation in controlled climate operation were studied and developed (Verdijck, et al., 2005). The optimal climate of the preservation sought from this study can control and minimize the variations before transferring the agricultural product to the raw materials of the agro-industry. Although there are the researches finding methods to control and minimize the quality variation of the raw materials during preservation, it is very difficult and costly to do with their methods in the real productions.

(2) Agro-processing

Agro-processing is an operation or series of operations performed on the raw materials from the agricultural products. It is used to change forms of the raw material or compositions into the agro-industrial products. This processing can be as simple as cleaning, grading, and packaging fresh product. There are two basic process employed for transforming into the agro-industrial products. The first process is separation and the second process is preservation (Brown, 1994).

On the one hand, the separation consists of isolating desirable components such as seed, oil, and fiber from the parent material occurring in the nature. Another process as the preservation consists of converting the raw materials into a form less subject to deterioration. Preservation is often used in Thai agro-industry; for example, canning, smoking, sugaring, drying, and so on.

Canning is a method of preserving food in which the food is processed and sealed in an airtight container. This process was first developed as a French military discovery (Fellows, 2000). It involves cooking fruits or vegetables, sealing them in sterile cans, and boiling the containers to eliminate any remaining bacteria. Various agro-industrial products have varying degrees of natural protection against spoilage and may require that the final step occur in a pressure cooker.

Smoking is used to preserve and flavor meat, fish, and some other foods. It combines heating to dry the food with adding the aromatic hydrocarbons from smoke in order to preserve the products (Riddervold and Ropeid, 1988).

Sugaring is always used to preserve fruits. Sugar is dissolved in the water either as syrup or as crystallized form (Riddervold, 1998). Generally, fruits preserved by sugaring are such as apple, pear, peach, apricot, and plum.

Drying is one of the oldest processes because it can be used for every type of the products such as seeds, meat, fiber, fruits, vegetables, and so on. Drying food, agricultural and biological active material, is a major operation in the drying industry. It is used to improve the preservation properties of the product, to reduce transportation costs, and to facilitate the utilization of the product (Quirijns, 2006).

The agro-processing differs in specificity of production processes and the heterogeneity of the raw materials due to seasonal harvesting and natural variation. The appropriate degree of processing will depend on physical factors which are blending and health, and safety standards (Brown, 1994). It means that the adjustment of the degree of the processing is always needed.

(3) Packaging and Distribution

As the most of the agro-industrial products have short shelf life; therefore, it is necessary to find methods or processes to prolong the shelf life. However, packaging and distribution can help to prolong the shelf life of the agro-industrial products (Mangina and Vlachos, 2005). The manufacturer will be making some discretionary decisions regarding the shelf life of its products. Moreover, these decisions must be taken into account in designing the packaging and distribution (Brown, 1994).

From all characteristics of the agro-industry, they can be summarized in Table 2.1. The comparison with the conventional industries is also shown in this Table.

Table 2.1 Comparison of the agro-industry and the conventional industries

Issue	Factor	Agro-industry	Conventional Industries
Raw material	Quantity and quality	Depends on climate, thin soils, and land fragmentation	Depends on performance of supplier
	Timing	Depends on seasonality	Depends on performance of supplier
	Cost	Uncontrollable cost	Controllable cost
Processing	Degree of processing	Depends on quality of the raw material	Standard product process
Packaging and distribution	Shelf life and durability	Affect shelf life and durability	Affect only durability

2.1.3 Quality Improvement

Unfortunately, there are few researches concerned the quality improvement of the agro-industrial product because of its complexity. The complexity can be a cause of the product quality variation directly affecting the product quality and losses (Miller, 1998). However, in the recent year, the quality improvement of the agro-industrial product is more concerned and realized.

ISO 9000 and Hazard Analysis Critical and Control Point or HACCP are most used to establish the quality management system in order to control and improve the product quality and safety (Rohitratana and Boon-itt, 2001). Furthermore, there are several researches attempting to develop measures for evaluating the success of the implementation of the quality and safety system (Van Der Spiegel, et al., 2003; Kritchanchai, 2004; Ade-Omowaye, et al., 2006; Nwokah and Maclayton, 2006; Van Der Spiegel, et al., 2006).

Statistical process control or SPC is the most often technique to control and improve the product quality of every industry including the agro-industry. Control chart is the most often used in SPC. It focuses on the variation from the average. However, if the average is not equaled to the quality target, true variation cannot be identified. Thus, there are some researches focusing on the variation from the quality target (Glaeser, 2003; de Vries and Conlin, 2005; Srikaeo, et al., 2005). Glaseser (2003) proposed an approach to control the water content of the diary product. The control data obtained by the dairy should fulfill requirements regarding the sample size. De Vries and Colnlin (2005) develop two new control charts as the less known cumulative sum (cusum) and non-parametic control chat. They are compared with the traditional control chart through stochastic simulation. Moreover, Srikaeo et al. (2005) used statistical technique to control the raw material and the product quality variation.

Another technique – Neural Network or NN is also applied to control and improve the agro-industrial product quality because some characteristics of the product quality are in nonlinear relationship (Paquet, et al., 2000; Liu, et al., 2006). Paquet et al. (2000) used NN to build the model for predicting pH and acidity for the industrial cheese production. However, NN is good for predicting the value, but it cannot identify the relationship between the variables. So Liu et al. (2006) developed Neural Network Partial Least Squares (NNPLS) which can identify the relationship between the output and the input variables.

To design the agro-industrial products and processes with the lowest loss, there are some previous researches related this design (Noronha, et al., 1996;

Mevik, et al., 2001; Thurairajasingam, et al., 2002; Verdijck, et al., 2005). Noronha et al. (1996) studied the retort which is a critical control point for the food canning industry. They attempted to find the optimal temperature level for the retort process. Mevik et al. (2001) used the optimization to control the operational conditions in order to minimize the uncontrollable variation from the raw materials. Moreover, Verdijck et al, (2005) extended the operational conditions to the climate factors. Thurairajasingam et al. (2002) developed a mathematical model for a continuous pressing operation where biscuit shape is formed. This model identified a functional relationship and predicted the pressing parameters.

From previous researches, the agro-industry has to be studied and improved the quality of its products. However, there are several types of the agro-processing in Thai agro-industry. In this dissertation, drying process is selected as the major agro-processing to study.

2.2 Drying Process

Drying process has been applied for a long time to transform and preserve the perishable agricultural products. Salunkhe et al. 1991 (Quirijns, 2006) reported that the drying process was practice in ancient time by Chinese, Hindus, Persians, Greeks, and Egyptians. The ancient Chinese and Hindus used the drying process to dry herbs, fruits, and vegetables by the sun and the wind five thousand years ago. Until now, the drying process is one of the most important and oldest processes to preserve the perishable agricultural products throughout the world.

2.2.1 Quality Measure in Drying Process

Drying perishable agricultural products is a major operation in the agro-industry. It can improve the preservation properties of the product by reducing the moisture content and increasing the temperature of the product during drying (Quirijns, 2006). In the optimal drying control, the quality of the raw material is the most important aspect. Since the dried products are used in various situations and in various forms; moreover, it is obvious that the corresponding quality characteristics are different. The quality characteristics are linked to the measures of the product quality. Therefore, there are several researchers defining the quality measure to evaluate the quality of the dried product (Janarun, 1998; Madhiyanon, et al., 2001a; Soponronnarit, et al., 2001a; Olmos, et al., 2002; Quirijns, 2006).

Janarun (1998) defined the quality of the dried product in terms of chemical and biological aspects. On the one hand, the chemical aspect consisted of the moisture content, and quantity of acid, sugar, vitamin C, ash, fiber, tannin, fat, and phosphorous. On the other hand, the biological aspect was the quantity of E.coli coliform.

Soponronnarit et al. (2001a) measured the quality of the dried soybean by taking the moisture content in a high temperature treatment. More chemical aspect was measured additional to Janarun as the change of pH resulting the action of urea converting to ammonia and soluble protein. Moreover, cracking was visually assessed.

For the paddy rice, the moisture content is the most often used to evaluate the quality. Moreover, head yield is also measured to appraise the success and failure of a grain-drying system (Madhiyanon, et al., 2001a; Olmos, et al., 2002).

In addition to the traditional quality measures – the moisture content and the product temperature, Quirijns (2006) developed another quality measure during drying as enzyme reaction.

Among several proposed quality measures of the dried product, the most important measure is the moisture content. It directly affects the dried product because it is used to identify the level of the water in the dried product. Therefore, the moisture content is used as the quality measure in this dissertation.

2.2.2 Drying Method

In the ancient age, the drying process depended on heat from the sun, but this method has some disadvantages like the slowness of the process, the exposure to the environmental contamination, and the hand labor requirement (Njie and Rumsey, 1998; Doymaz, 2005). From these disadvantages, the quality of the dried product may be low. Hence, several methods for drying the product have been developed in order to improve the quality of the dried product.

(1) Direct or Convective Drying

Well-known direct drying is the use of hot air as a media to dry the products. The water inside the product is convected by the hot air. Besides, higher temperatures can speed up diffusion of the water inside the products, so drying is faster. However, the applicable rise of the hot air temperature is limited by the considerations of the dried product quality (Teeboonma, et al., 2003). This means that higher drying temperature level cannot dry the product with higher quality than the lower drying temperature level. Overheated air is a cause of the pores of the product's surface. However, the direct method is the most frequently used in Thailand (Janarun, 1998; A. Adchariyaviriya, et al., 2001; Ceylan, et al., 2007) because it is the most suitable for various types of vegetable and fruit.

Janarun (1998) studied the drying of the vegetables and fruits by heat pump dryer. This study aimed at finding the method for drying fresh vegetables and fruits in order to meet the customer satisfaction. Five types of the fresh vegetable (Chinese kale, celery, pumpkin, and carrot) and three types of the fresh fruits (banana, jackfruit, and pineapple) were selected to study.

Longan, an important commercial fruit in the Northern Thailand, is often dried by hot air. Adcharuyaviriya et al. (2001) studied the characteristics and quality of longan flesh drying via hot air drying method.

Ceylan et al. (2007) designed a heat pump for drying tropical fruits as kiwi, avocado, and banana. In this study, a constant drying temperature level at 40°C is set to find the optimal hot air velocity and drying time. To find these optimal parameters, statistical method is used to construct an empirical model for drying.

(2) Indirect or Conductive Drying

This drying method is operated by heating the wall of the dryer as the drying media. This method is such as drum drying, and vacuum drying. Milk is an example of the used of the drum drying. However, it is hardly found the researches related to the indirect or conductive drying in Thailand.

(3) Dielectric Drying

Radiofrequency or microwave is used as the drying media for dielectric drying. Water molecules inside the product are stimulated and evaporated by energy from the radiofrequency or microwave. However, this drying method is often used with other drying method such as hot air drying. Edamames is an dried product example for using the combination of microwave, vacuum, and hot air to dry (Hu, et al., 2006).

(4) Supercritical Drying

An example of this drying method is the use of superheated steam as the drying medium. It seems impossible that the superheated steam can be used to dry the product. However, there are several researchers studying how to use the superheated steam to dry the agricultural products such as paddy rice (Taechapairoj, et al., 2003; Pakowski, et al., 2004; Rordprapat, et al., 2005; Soponronnarit, et al., 2006a; Soponronnarit, et al., 2006b), shrimp (Prachayawarakorn, et al., 2002), and tobacco (Pakowski, et al., 2004).

Normally, the paddy rice is often dried by hot air drying, but the drying with the superheated steam is developed to be an alternative approach instead of the conventional hot air drying (Taechapairoj, et al., 2003; Pakowski, et al., 2004; Rordprapat, et al., 2005; Soponronnarit, et al., 2006a; Soponronnarit, et al., 2006b). The head yield rice from the superheated-steam drying is greater than the conventional method, while the whiteness is poorer.

From the review of the drying methods, eacn method has own advantages differing from others. Therefore, the selection of the drying method is very important because it can affect the dried product quality.

2.2.3 Drying Phases

In the drying process, any dried products have to be transferred through three drying phases shown in Figure 2.2. Three drying phases are usually observed as heating phase where period of *AB*, drying with a constant rate phase where period of *BC*, and drying with falling rate phase where period of *CD*.

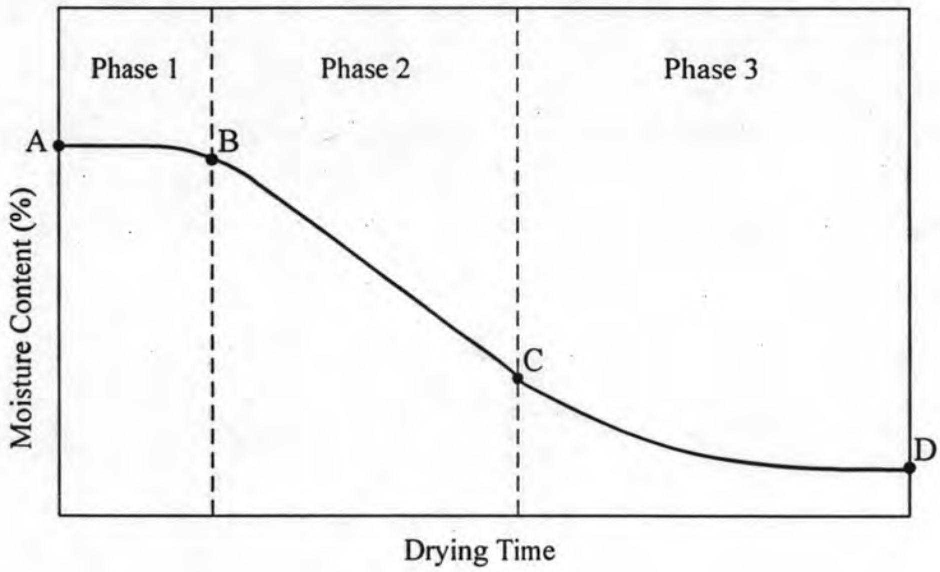

Figure 2.2 Drying phases

From the Figure 2.2, the period of *AB* is the first drying phase called the heating phase. The raw materials are heated but their moisture contents are not reduced. The aim of this phase is to heat the raw materials without the change of their moisture contents. A drying criterion of this phase can be shown in Equation (2.1).

$$\frac{dM_t}{dt} = 0, \qquad A \le t < B \qquad (2.1)$$

After the raw materials are heated, they are transferred into another drying phase called the drying with a constant rate phase in the period of *BC*. From the Figure 2.2, the moisture content of the heated raw materials from point *B* is reduced to point *C* which is called *the critical moisture content*. At this point, the moisture content is not sufficient to saturate the entire surface. The aim of the drying with this phase is to reduce the moisture content of the heated raw materials to the critical moisture content with a constant drying rate. Drying with this phase have been reported for sweet potato, carrot, agar gel (Suzuki, et al., 1977), fish (Jason, 1958), and several fruits and vegetables (Saravocos, 1962). However, a drying criterion of this drying phase can be shown in Equation (2.2).

$$\frac{dM_t}{dt} = \text{constant}, \qquad B \le t < C \qquad (2.2)$$

After the raw materials are reduced their moisture contents to the critical moisture content at point *C*, they are transferred to the last drying phase as the drying with falling rate phase in the period of *CD*. During this phase, the drying rate is less than during the second phase. The limiting moisture content at this phase to which a material can be dried under a giving condition is referred to as *the equilibrium moisture content*. Most modern drying researches have been focused on the drying with falling rate phase such as paddy rice (Olmos, et al., 2002; Tirawanichakul, et al., 2004; Bie, et al., 2007; Iguza and Virseda, 2007; Dong, et al., 2009), longan (A. Adchariyaviriya, et al., 2001; Varith, et al., 2007; Janjai, et al., 2008), and cassava (Martinez-Bustos, et al., 2007; Lertworasirikul, 2008). However, a drying criterion of this drying phase can be shown in Equation (2.3).

$$\frac{dM_t}{dt} < 0, \qquad C \le t < D \qquad (2.3)$$

From all literature of the drying phases, there is no one considering all of three drying phases especially the heating phase. Therefore, all of three drying phases are considered and studied by this dissertation.

2.2.4 Study Topics in Drying Process

Drying process aims at reducing the moisture content within a product by application of thermal energy to produce dried products of desired attributes or quality characteristics (Dufour, 2006). During drying, the most important objective is to find or adjust some of the drying conditions while achieving the main final overall performances required. The required performances are classified into two measures as increasing the product yield and reducing the production cost. In order to satisfy these performance measures, two topics of the drying process as drying process design and drying process control have been studied and developed.

(1) Drying Process Design

Drying process design is the problem about how to design the optimal dryer to dry various types of the product, but it is very difficult to design the drying process to dry all types of the agricultural product. Each type of the agricultural product has its specific characteristics such as shape, and texture. However, there are several researches showing their attempts to study and develop new technologies for drying process described as below (S. Adchariyaviriya, et al., 2000; Soponronnarit, et al., 2000a; Soponronnarit, et al., 2000b; A. Adchariyaviriya, et al., 2001; Wetchacama, et al., 2001; Madhiyanon, et al., 2001a, 2001b; Soponronnarit, et al., 2001b; Poomsa-ad, et al., 2002; Prachayawarakorn, et al., 2002; Taechapairoj, et al., 2003; Teeboonma, et al., 2003; Pakowski, et al., 2004; Doymaz, 2005; Hu, et al., 2006).

Soponronnarit et al. (2000a) studied to design, construct, and test a rice husk furnace for a commercial fluidized bed paddy dryer with a constant capacity. To design this husk furnace, two performance measures were used to evaluate the successive of the design as efficiency of design parameters and carbon conversion efficiency. Efficiency of the design parameters was determined as air flow rate of mixed air between fresh air and flue gas, specific heat of air, ambient air temperature, temperature of the mixed air between fresh air and flue gas, rice husk feed rate, and high heating value of rice husk. Another performance measure as the carbon conversion efficiency was determined in terms of the percentage of carbon in ash and the percentage of carbon in rice husk.

Moreover, Soponronnarit et al. (2000b) also studied how to design and construct a heat pump for drying paddy rice. In this design, it consisted of an 18 kW evaporator, 20 kW internal and external condensers, a 3.7 kW two-piston compressor, a 5 kW electrical heater, a 1.5 kW forward curved blade centrifugal fan and a mixed-flow columnar drying cabinet. This drying was operated as open-loop, fixed drying time, and constant capacity. It can result that open-loop system was suitable for paddy seed heat pump drying, and the quality in terms of germination and vigor obtained was very good.

Madhiyanon et al. (2001a) developed a prototype of spouted bed dryer with a capacity of around 3,500 kg/h. This prototype was applied to dry paddy rice in continuous production line. It performed well in reducing the moisture content of the paddy and yields high product quality in term of the milling quality. However, with the limitation of the existing drying chamber length, a high percentage of moisture reduction corresponding to high paddy feed rate could not be achieved.

Soponronnarit et al. (2001a) developed a prototype of vibro-fluidized bed paddy dryer with a capacity of 2.5 – 5.0 ton/hour. Optimum operating parameters were determined by a mathematical model which was developed to study the behavior of drying paddy rice. Two performance measures, final moisture content and energy consumption were optimized to be a condition for paddy drying in a vibro-fluidised bed paddy dryer. After developing, the prototype was compared with traditional fluidized bed dryer. It could be concluded that it is a dryer which is better than traditional dryer in terms of moisture reduction and energy consumption.

Poomsa-ad *et al.* (2002) proposed two stages of drying paddy rice. This study differs from other studies because this study was concerned two phases of drying. The second phase was emphasized to study in order to find the optimal drying time with high drying rate. Finally, the drying temperature was the most significant contribution to tempering period.

Taechapairoj et al. (2003) proposed a new methodology to dry paddy. Superheated steam was proposed to instead of hot air drying. Steam pressure was very important because it was used to determine the minimum velocity required for fluidizing in the superheated steam when its pressure dropped. Head rice yield, whiteness and white bell were determined as performance measures for this study. From this study, the minimum velocity for paddy in superheated steam is approximately 2.6 m/s. Moreover, this new method was more stable than traditional method.

Beans are often studied. Doymaz (2005) presented the thin layer drying experiments and mathematical modeling of green bean grown in Turkey. This study was experimented with hot air drying. The influence of drying air temperature in the range of 50 – 70°C and 1.0 m/s of air velocity for green beans were studied. It could be resulted that the drying rate and effective diffusivity increases with air temperature increases.

Soponronnarit et al. (2001b) modelled the drying rate of soybean in a fluidized bed and the effect of fluidized bed drying on quality aspects of soybean in terms of cracking and breakage, urease activity (ΔpH), and moisture content. Three thin layer models of the drying rate of soybeans were fitted to the data, namely Newton's Law of cooling, Page's model, and Sharaf-Eldeen et al. All of models are exponential with depending on drying time. This study was concluded that

- the minimum fluidized bed velocity of dry soybean is 1.9 m/s. In addition, Page's model was found to predict the drying rate of soybean very well;
- the percentage of cracking and breakage of soybean increased with drying temperature and drying time, but at a

temperature of 140°C, they did not increase greater than the standard level of animal feed industry.

- At the same temperature, there was no effect on protein quality because urease activity was reduced to the standard value of the animal feed industry.

Edamames is a type of seed which is studied by Hu et *al.* (2006) who presented a combination of hot air stage and vacuum microwave stage. It can be concluded that in the conventional hot air drying process, the drying rate was fast in the beginning stage, but decreased sharply in the last stage. In microwave drying process, the drying rate increased with increasing of microwave power and vacuum degree,. and decreasing of mass loads. The combination of this study was higher performance than only one technique.

Corn or maize is one of the most important agricultural products in Thailand. The need of corn in the feed mill and the other food industries tend to be increased considerably. Madhiyanon et al. (2001b) developed a combination of non-equilibrium and non-isothermal model for corn drying. Four measures which are solved with differential equations in order to find the optimum parameters were mass balance, heat balance, heat transfer and drying rate.

Wetchacama et al. (2001) studied how to develop a mathematical model for predicting drying rate. It was developed on three models as Wang and Sigh's model, Page's model and Lewis' model. However, Page's model was the best prediction by determining maximum R^2. The drying rate model was based on two important factors as specific airflow rate an inlet drying air temperature. Moreover, quality issues were determined in this study. *Aflatoxin* content, percentages of breakage and stress crack, and color change were quality issues in this study. *Aflatoxin* content is a toxic measure from fungus. Only high temperature can eliminate it. But this study could not get rid of it from corn because drying temperature (130 – 170°C) was not high sufficiently to eliminate. Breakage and cracking depended on final moisture content and were relatively dependent to temperature. Tempering provided the improvement of color while inlet air temperature has no effect.

Papaya and mango glacé were studied by developing diffusion models with regression analysis of the experimental data to drying kinetic equation. S. Achariyavirya et al. (2000) proposed four alternative diffusion models. Their study was assumed with constant drying air velocity with hot air over at 103°C for 72 hours. From this study, drying can be divided into two phases as early and final periods of drying. In the early period, product moisture content was decreased with constant drying rate as model 1 and 2. And in the final period, drying rate was decreasing with time as model 3. Model 4 was not suitable.

In year 2003, Teeboonma et al. (2003) determined how to find the optimum conditions of heat pump fruit dryers and to minimize heat pump drying cost. Papaya and mango were also used in this experiment by developing mathematical models to study their drying behavior. There were three mathematical models for solving this problem as drying model, heat pump model and optimization model. From this study, physical properties of fruit was the most important effect to the optimum conditions which are airflow rate, evaporator bypass air ratio, dying air temperature, recycle air ratio, and annual total cost per evaporating water.

A. Achariyaviriya et al. (2001) developed three alternative diffusion models based on modifying the Arrhenius factor and/or the energy of activation as a function of moisture content. In addition, the characteristics and quality of longan flesh drying were studied by regression analysis with experimental data. From this study, it could be concluded that the characteristics of drying was an exponential function. Specific air flow rate and drying air temperature affected significantly on specific energy consumption. And drying air temperature affected significantly on product quality. The drying air temperature of 65°C was recommended to produce desirable color.

Shrimp is a dried meat which is processed in Thai drying industry. Prachayawarakorn (2002) used superheated steam to dry shrimp. Percent of shrinkage and color were determined in this study. This experiment was conducted at 120°C, 140°C, and 160°C with superheated steam. The percent of shrinkage from this method was less than hot air method. But the dried shrimps using the superheated steam at temperatures between 120°C and 160°C provided the slight differences of color as compared to the commercial product.

Pakowski et al. (2004) proposed that the role of drying in modern technology is not only to remove moisture but also to control solid properties in a predetermined way. The quality of cut tobacco could be improved when they were expanded; for example, when their specific volume was increased. This effect could be achieved by means of a flash dryer. The dryer used superheated steam as a drying and expanding agent and was composed of a drying pipe, cyclone, circulating fan, and indirect steam superheater.

(2) Drying Process Control

Dufour (2006) showed that there are two problems related to the drying process control as regular and optimization problems. In the regular problem, a constant set-point vector is defined such as the desired final mean moisture contents. The problem is to choose and design a controller that tunes the decision variables, such that the considered controlled variable tracks as best as possible their respective set-points and with a minimum variability during drying. In the recent problems, there are few researches because most of current drying systems are dynamic system. In the optimization problem, the idea is initially to state the criteria accounting for the controlled variables and/or the manipulated variables and/or the available state variables which contain all the dynamic characteristics of the drying. Then, an optimization procedure adjusts the manipulated variables as to minimize these criteria. Constraints dealing with process limitations; for example, actuator magnitude has upper and lower bounds, process safety which is a maximum known surface temperature beyond which final quality is too altered may be explicitly incorporated in to this formulation. In this section, the optimization problems are reviewed as below (Banga and Singh, 1994; Themelin, et al., 1997; Frydman, et al., 1999; Olmos, et al., 2002; Ceylan, et al., 2007; Nath and Chattopadhyay, 2007).

Banga and Singh (1994) proposed an optimization of air drying of foods. The main objective of this research was to formulate different optimization problems related with the air drying of foods:

- maximization of nutrient and/or enzyme retention;
- maximization of nutrient retention with a constraint on the final retention of an enzyme;minimization of process time with a constraint on the final quality; and
- maximization of energy efficiency with a constraint on the retention of nutrients.

Multicriteria optimisation of food processing combining soaking prior to air drying was studied Thenelin *et al.* (1997). It aimed at characterizing the influence of the product's history on its behavior during final drying, and presenting a method for the combined process optimization on the ground of total time duration, energy consumption, texture and final color of the product. Apples were used to be example for this study.

Frydman et al. (1999) presented a numerical simulation and experimental validation of a spray dryer using superheated steam instead of air as drying medium, modelized with a computational fluid dynamics (CFD) code. The model described momentum, heat and mass transfer between two phases – a discrete phase of droplets and a continuous gas phase – through a finite volume method. For the simulation, droplet size distribution was represented by six discrete classes of diameter, fitting to the experimental distribution injected from the nozzle orifice, taking into account their peculiar shrinkage during drying. This model was able to predict the most important features of the dryer: fields of gas temperature and gas velocity inside the chamber, droplets trajectories and eventual deposits on to the wall. The results of simulation were compared to a pilot scale dryer, using water. In the absence of risk of powder ignition in steam, high steam inlet temperature has been tested, thus obtaining a high volumic efficiency. This type of model can be used for chamber design, or scale up. Using superheated steam instead of air in a spray dryer can allow a high volumic evaporation rate, high energy recovery, and better environment control.

Olmos et al. (2002) studied how to improve the drying of paddy rice quality degradation expressed as a yield kernel yield, leading to significant commercial depreciation of the product. A mathematical model of the drying and of the quality degradation process was combined with a dynamic optimization to determine the drying conditions (air temperature and relative humidity as functions of time) that ensured the highest possible final product quality for a specified drying time and specified final moisture content. The compromise between the highest achievable final quality and the allowed total drying time was studied. The combination of simulation and optimization yielded a new insight in the rice drying process and in the quality preservation strategies.

Tropical fruits as kiwi, avocado, and banana were studied to find the optimum conditions in order to design and construct a heat pump fruit dryer by Ceylan et al. (2007). Proportional-Integral-Derivative controller (PID) was used in this study to design and produce a heat pump. Drying temperature was controlled by PID controller. PID controller is a generic control loop feedback mechanism widely used in industrial control systems. It attempted to correct the error between drying temperature and a set point by calculating and then outputting a corrective action that can adjust the process accordingly. Heat pump dryer was experimentally tested in drying tropical fruits. Drying air temperature was kept at 40°C.

Ready-to-eat potato-soy snacks were developed with high temperature short time air puffing proves followed by oven toasting for increasing crispness (Nath and Chattopadhyay, 2007). Oven toasting experiments were conducted with varying temperature (85.86-114.14°C) and time (12.69-35.31 min) based on central composite rotatable design. The final product was evaluated in terms of quality attributes such as crispness, moisture content, ascorbic acid loss, color values and overall acceptability. The optimum product qualities in terms of crispness, moisture content, ascorbic acid loss, color, and overall acceptability were obtained at temperature of 104.4°C and time 27.9 min.