CHAPTER I

INTRODUCTION

Drying process has been practice since ancient time by Chinese, Hindus, Persians, Greek, Egyptians, and Thai. The ancient people dried herbs, fruits, and vegetables by the sun and the wind five thousand years ago. And until now, the drying process is one of the most important ways to preserve perishable agricultural products throughout the world including Thailand. There are several researches that attempted to develop new dryers with new technologies instead of the sun and the wind drying in order to increase the quality of the dried products. Although the new dryers have been developed, there are a few agro-factories which would like to change their old dryers because of high investment costs. Therefore, this dissertation attempts to increase the quality of the dried products with the traditional dryers.

The outline of this chapter is organized as follows: Firstly, the general background is explained to provide the situation of Thai agricultural products, agro-industry, and dried products. Secondly, the statement of the problem is addressed. In this section, the problem of the drying process is also illustrated. Thirdly, the objective of this dissertation is proposed. The dissertation scopes and contributions are given in the fourth and the fifth sections of this chapter. Then the dissertation methodology is presented. The outline of this dissertation is framed in the final section.

1.1 General Background

The agricultural sector is a major element of human history. It has been a crucial factor in worldwide socio-economic change including wealth-building and militaristic specialization rarely seen in hunter-greater cultures. In addition, an estimated 42% of the world's workers are employed in the agricultural sector. However, the agricultural products account for less than five percent of the gross world product because of the fluctuations in the environment and the price of produced commodities devastating on the entire economy.

In Thailand, the export value of the agricultural products is also less than the manufacturing products. Figure 1.1 illustrates the difference between the export values of the agricultural and the manufacturing products. It shows that the manufacturing export value has surged up quickly, while the agricultural export value has increased slowly. The unit price of the agricultural products is very lower than the manufacturing products. It always depends on several uncontrolled factors affecting the quality of the products such as climate, thin soil, land fragmentation, and seasonality. Therefore, it is necessary to increase the value of the agricultural products and agro-industry is an appropriate way to increase the value of the agricultural products.

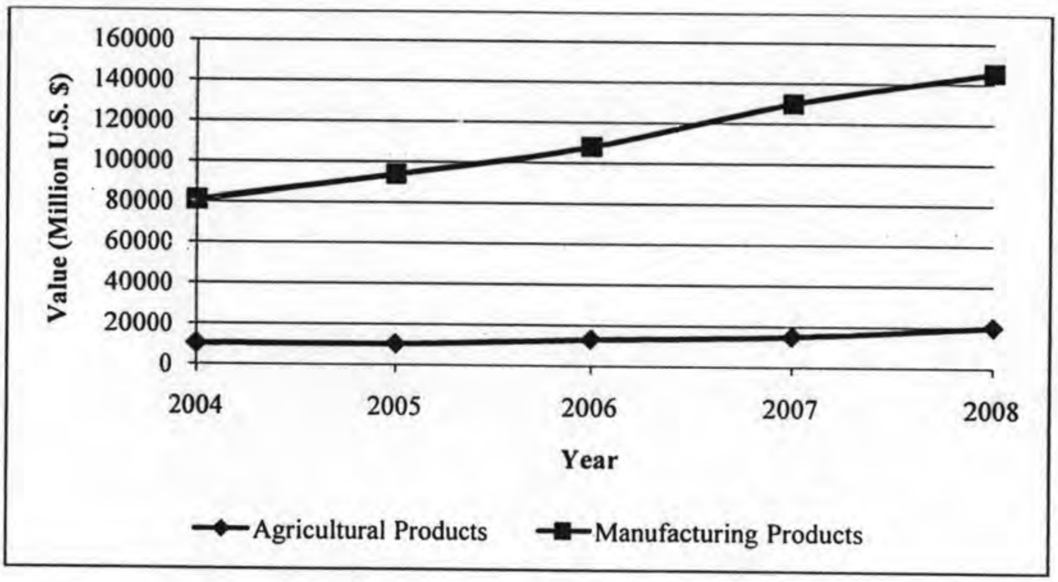

Figure 1.1 Thai export values of the agricultural and the manufacturing products

Agro-industry is the generic term applied to any industrial processing of raw materials from the agricultural products including forestry and fishing as well as crop production and animal husbandry (Brown, 1994; Marsden and Garzia, 1998). The agro-industry is very important to Thai economy. Firstly, it can help to increase the value of the agricultural products as its raw materials (Figure 1.2). Secondly, it can help Thailand to increase the demand for the agricultural products. Thirdly, income and urban population grow and create market for a greater volume and diversity of processed goods. Finally, it can increase farm income and labor productivity.

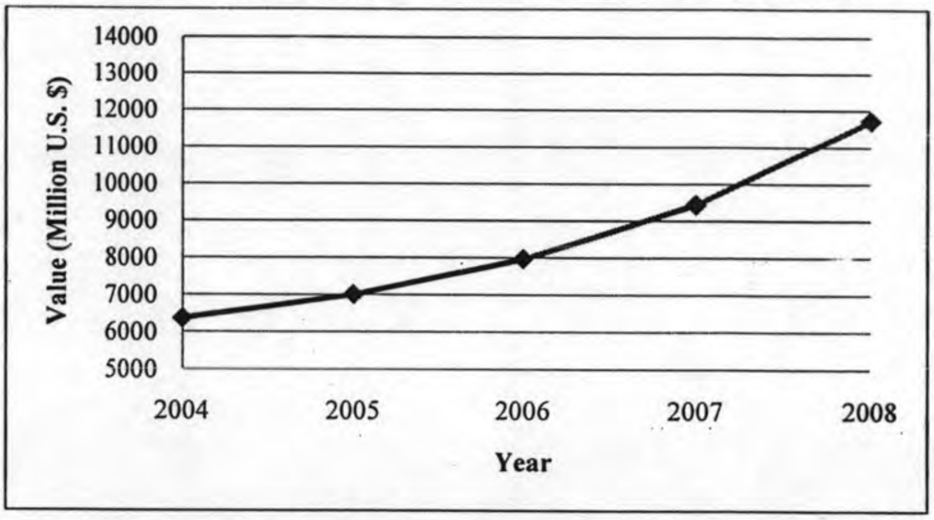

Figure 1.2 Thai export values of the agro-industrial products

Generally, the agro-industry consists of three major units as inputs, processes, and agro-industrial product as shown in Figure 1.3. The inputs or the raw materials from the agricultural products are comprised of a very varied group such as fruits, vegetables, milk, meat, apparel fibers, rubbers, tobacco, and forest products. They are transformed into the agro-industrial products by any processes.

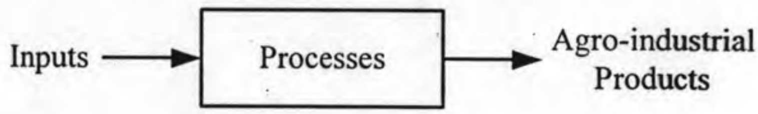

Figure 1.3 General model of the agro-industrial production

There are several types of the process for transforming the raw materials into the agro-industrial products such as drying, freezing, vacuum packing, canning and bottling, irradiation, and adding preservatives or inert gas. Some processes not only can help to preserve the products but they can also help to add flavors into the products such as pickling, salting, sugaring, and smoking (Table 1.1.).

Table 1.1 Examples of process for agro-industry

Process	Objective	Applications
Drying	To use high temperature level to reduce water activity sufficiently in order to delay or prevent bacterial growth.	Meat, milk, vegetables, fruits, eggs, and cereal grains
Smoking	To dry food without cooking and add the aromatic hydrocarbons from the smoke preserve the food.	Meat and fish
Freezing	To use low temperature level to reduce water activity sufficiently in order to delay or prevent bacterial growth.	Food stuffs
Vacuum packing	To kill aerobic bacteria.	Nuts
Salting	To draw moisture contents from meat though an osmosis process.	Meat
Sugaring	To draw moisture contents from fruits though an osmosis process.	Fruits
Pickling	To reduce pH by adding a substance killing bacteria and other micro-organisms.	Vegetables
Canning and Bottling	To kill or weaken any remaining bacteria as a form of pasteurization.	Food stuffs
Irradiation	To kill bacteria, moulds, and insect pests.	Meat and fruits

Although there are several processes for the agro-industrial production, one process cannot be used for every type of the raw materials. For example, canning and bottling cannot be used for eggs. Smoking is not suitable for adding the aroma into fruits. Sugaring is suitable used for only fruits while salting is suitable used for meat and fish. However, there is one process which can be used for various types of the raw materials – drying process. Figure 1.4 (Van Arsdel, et al., 1973) illustrates that the drying process can be used for various types of the raw materials such as meat, milk, vegetables, fruit, eggs, and cereal grain.

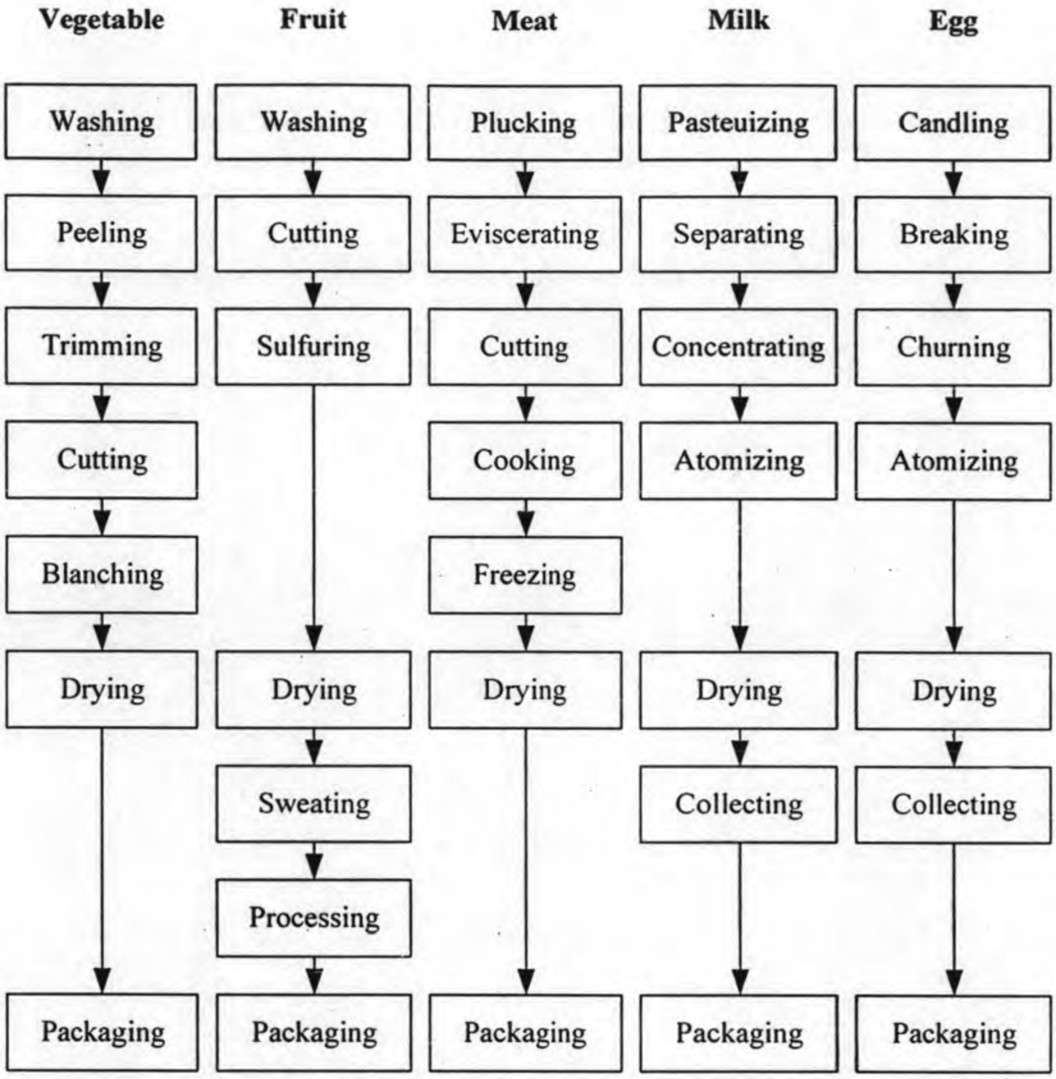

Figure 1.4 Principal operations in the production of typical dried foods

In Thailand, the drying is a very important process for the agro-industry because Thailand is in the tropical hot and wet zone. The humid weather is a cause of the high moisture problem in the products. Thus the drying process is necessary to use for reducing the moisture content of the products into the target for safe during storage. Moreover, Table 1.2 shows that there are about 56% of Thai agro-factories using the drying process for their productions. Furthermore, Figure 1.5 illustrates that Thai export value of the dried products has increased continuously. It can conclude that the dried products are more needed from other countries.

Table 1.2 Numbers of agro-industry using the drying process

Product	Numbers of Agro-factory
Paddy and rice	3,216
Bean	102
Maize	81
Spices	23
Vegetables	69
Cassava	2,385
Cereal grain	22
Fruits	40
Coffee and tea	72
Longan	65
Tobacco	110
Cashew nut	25
Seeds	418
Flour	216
Total	**6,844**

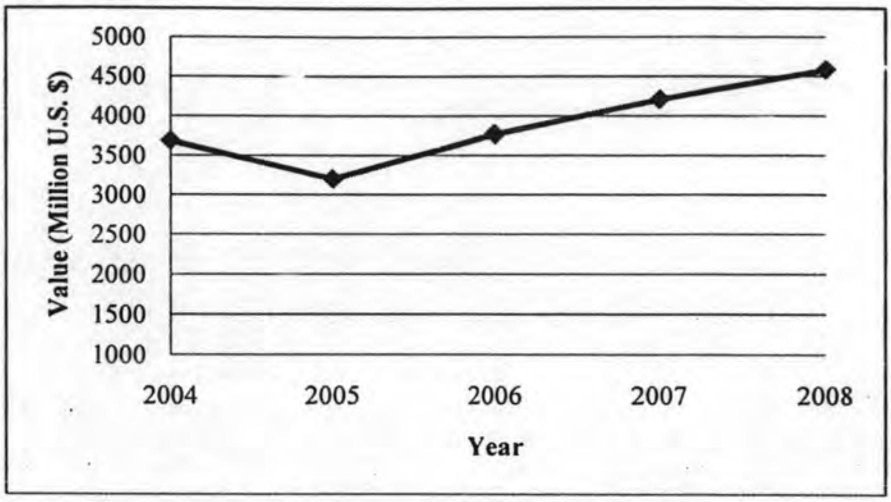

Figure 1.5 Thai export values of the dried products

1.2 Statement of the Problem

Drying is one of the most important process of transformation and preservation of the products. It is based on the mass and heat transfer principles resulting in the removal of the moisture content with various dewatering methods and application of thermal energy to produce dried product of desired moisture content within a particular period of time (Dufour, 2006; Ceylan, et al., 2007). In the drying process, quality improvement and operational cost reduction are two main objective that, in some cases, are conflicting ones. Hence, both optimization method and criterion have to be carefully chosen (Olmos, et al., 2002).

Production of the dried product in Thailand has expanded vigorously for a long time. Commodities which enjoyed a large market growth have been paddy rice, cassava, cereal grain, vegetables, and fruits. The most important reason why the drying process is frequently used in Thai agro-industry is that it can help to prolong the shelf life of the dried products (Van Arsdel, et al., 1973). As a result, transportation and storage costs are lower than other fresh products. It is not necessary to use express deliveries with higher costs such as air delivery because the shelf life is longer than others. Moreover, refrigeration cost is not needed in the dried products while other fresh products need the refrigeration to prevent from any decay.

However, there are some disadvantages of the drying process (Van Arsdel, et al., 1973). Firstly, its unit processing costs are higher than others because of the need for unique machines and methods for producing the dried products. Although, its costs are very high, its quality is still poor. When the quality is poor, the dried products have to be redried in order to control the moisture content of the dried products into the target. Therefore, the operational costs are increased by redrying.

Poor quality of the dried product is a very serious problem. Sources of the poor quality are raw material, process, and environment (Mevik, et al., 2001). The first source of the poor quality is from the raw materials. It is very difficult to control the quality of the raw materials consistently since they depend on several uncontrolled natural factors. The uncontrolled natural factors are climate, weather, and seasonality. Therefore, the raw material is the first major source of the quality variation of the dried products which cannot avoid.

Due to inconsistent quality of the raw materials, the manufacturers have to vary and adjust the drying process following the quality of the raw materials in order to meet the quality target. Although this is the easiest method to control the quality of the dried products, this method is costly because energy consumption for drying will be increased following the adjustment.

Furthermore, environment factor also affects the quality of the dried products. Air humidity and air temperature are main parameters of this factor. It can affect both of the raw material quality and the dried product quality. The moisture contents of the raw material and the dried products are very sensitive to this factor. However, it is very difficult to control this source of the variation but operation in the closed system is the most effective alternative but costs will be increased.

There are several researches attempting to improve the quality of the dried product. Most of researches were still focused on developing the dryers with the new technologies. While the studies of the drying process control are hardly found. For the meantime, the major cost of the dryers is not in the initial investment (design and assembly) but in the daily operation. The drying process control is very important to obtain the quality of the dried product and to save the drying energy. Therefore, this dissertation focuses only the drying process control with two considerations as the raw material and the drying process.

1.2.1 Raw Material Consideration

In fact, the characteristics of the raw material of any agro-industrial productions are always changed and varied by the environment factors, but most of researchers assumed that they are constants. In the same way, the moisture content of the raw materials in the drying process is always changed and varied. However, most of researchers assumed the moisture content of the raw material in their studies as a constant or a narrow range of the moisture content shown in Table 1.3.

Table 1.3 Review of moisture content of raw material for drying process

Author(s)	Year	Type of raw material	Moisture content
Y. Tirawanichakul, et al.	2004	Paddy rice	18.5-20.6% w.b.
Prachayawarakorn, et al.	2005	Paddy rice	30, 35% w.b.
Yong, et al.	2006	Cassava	700% d.b.
Yu and Wang	2006	Paddy rice	24.9-25.1% w.b.
Bie, et al.	2007	Paddy rice	25, 28, 30% w.b.
Iguza and Virseda	2007	Paddy rice	19% w.b.
Martinez-Bustos, et al.	2007	Cassava	55-60% w.b.
Meeso, et al.	2007	Paddy rice	25-29% w.b.
Varith, et al.	2007	Longan	490-500% d.b.
Tirawanichakul, et al.	2007	Rubber	35-40% w.b.
Jaisut, et al.	2008	Paddy rice	28.0-33.0% w.b.
Janjai, et al.	2008	Longan	71% w.b.

Table 1.3 Review of moisture content of raw material for drying process (continued)

Author(s)	Year	Type of raw material	Moisture content
Lertworasirikul	2008	Cassava	33% d.b.
Pan, et al.	2008	Paddy rice	20.6-25.0% w.b.
Dong, et al.	2009	Paddy rice	35.3 % d.b.

1.2.2 Drying Process Consideration

In the drying process, there are three phases which are related to dry the products as heating phase, drying with a constant rate phase, and drying with falling rate phase. But none of the literatures concerned the drying process with all of three phases of drying because they assumed that the raw materials have the same characteristics in the same batch. Table 1.4 shows that previous researches were considered in the drying with a constant rate phase, and the drying with falling rate phase. The heating phase was neglected to study.

Table 1.4 Review of the studies of drying phase

Author(s)	Year	Type of raw material	Drying Phase
Jason	1958	Fish	Constant-rate phase
Saravocos	1962	Fruit and vegetables	Constant-rate phase
Suzuki, et al.	1977	Fruits	Constant-rate phase
Tirawanichakul, et al.	2004	Paddy rice	Falling-rate phase
Prachayawarakorn, et al.	2005	Paddy rice	Falling-rate phase
Yu and Wang	2006	Paddy rice	Falling-rate phase
Yong, et al.	2006	Cassava	Falling-rate phase

Table 1.4 Review of the studies of drying phase (continued)

Author(s)	Year	Type of raw material	Drying Phase
Bie, et al.	2007	Paddy rice	Falling-rate phase
Iguza and Virseda	2007	Paddy rice	Falling-rate phase
Martinez-Bustos, et al.	2007	Cassava	Falling-rate phase
Meeso, et al.	2007	Paddy rice	Falling-rate phase
S. Tirawanichakul, et al.	2007	Rubber	Falling-rate phase
Varith, et al.	2007	Longan	Falling-rate phase
Jaisut, et al.	2008	Paddy rice	Falling-rate phase
Janjai, et al.	2008	Longan	Falling-rate phase
Lertworasirikul	2008	Cassava	Falling-rate phase
Pan, et al.	2008	Paddy rice	Falling-rate phase
Dong, et al.	2009	Paddy rice	Falling-rate phase

From the problem of the drying process, thus this dissertation focuses on increasing the quality of the drying process with two issues as:

(1) The moisture content of the raw materials is not assumed as a constant; and

(2) All of three drying phases for the drying process are studied.

1.3 Dissertation Objective

The objective of this dissertation is to develop mathematical models for managing the quality variation for the drying process in Thai agro-industry. Theses mathematical models can help to reduce and minimize the quality variation of the dried products in order to increase the quality of the dried products.

1.4 Dissertation Scopes

In the drying process, there are several factors affecting the quality variation of the dried product. Therefore, it is necessary to scope the study area in this dissertation. The factors which are scoped in this dissertation are quality of drying, drying characteristics, drying parameters, types of dried product, and types of dryers. They are described as below.

1.4.1 Quality of Drying Process

The moisture content of the product is the most important characteristic for evaluating the quality of the drying process of the product. It generally refers to the presence of the water in the dried product, often in trace amounts. The excess of the moisture content can promote bacterial growth, decay, mould, and rotting over time. These can be causes of the deterioration of the dried product. On the contrary, over drying can help to eliminate or stop bacterial growth, decay, mould, and rotting over time, but it cannot help to reduce the production costs. The water in the dried product is evaporate so excessive that the dried products do not meet the weight requirement and the manufacturing have to add more dried products in order to meet the weight requirement.

There are two methods to calculate the moisture content of the dried product. The first method is to use the dry basis and the second method is use the wet basis. In this dissertation, the wet basis is used to calculate the moisture content of the dried product as Equation (1.1)

$$\text{Moisture Content (\% w.b.)} = \frac{\text{Mass of the dried product}}{\text{Mass of the raw material}} \qquad (1.1)$$

1.4.2 Drying Characteristic

Drying process has a special characteristic to dry any products. The characteristic of the drying process consists of three drying phases as heating, drying with a constant rate, and drying with falling rate phases (Tamon, 2005). Three drying phases directly affect the moisture content and the temperature level of the dried product. The effects can be illustrated as Figure 1.6 for the moisture content and the temperature level of the dried product respectively.

From the Figure 1.6, the first phase can be called heating phase. The raw materials are heated with unchanged moisture content during this phase. In the second phase or drying with a constant rate phase, the moisture contents of the heated raw materials from the first phase are reduced with a constant drying rate. Therefore, the moisture content in this phase is reduced linearly. After the heated raw materials are dried with the second phase, they are transferred to the third phase or drying with falling rate phase. The drying rate in this phase is not a constant value. It is decreased gradually. Therefore, the moisture content is reduced with nonlinear behavior. However, all of drying phases are performed with two major assumptions as:

(1) Drying medium has a constant humidity; and

(2) Drying medium velocity is also constant.

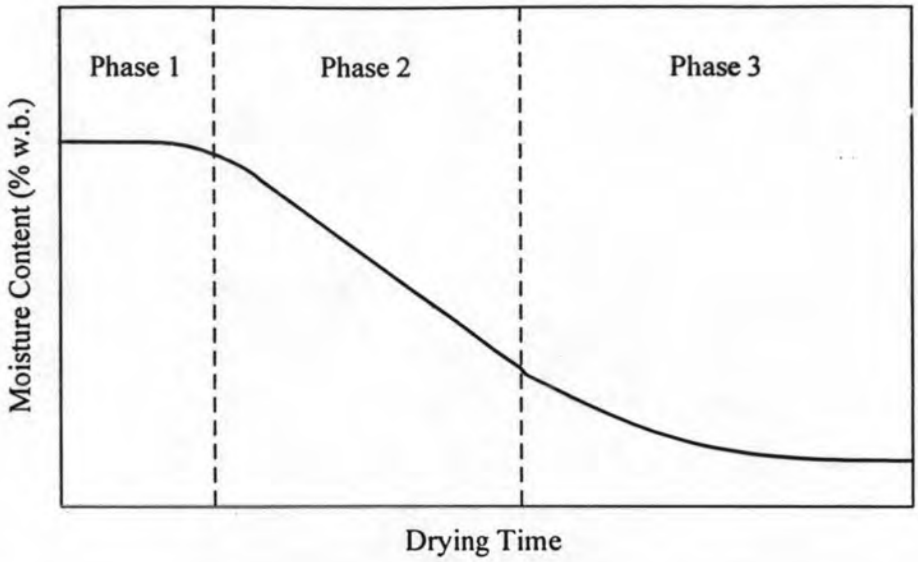

Figure 1.6 Behavior of the moisture content during three drying phases

1.4.3 Drying Parameters

In the drying process, there are several parameters affecting the quality variation of the dried products such as the moisture content of the raw material, the drying temperature level, the drying time, the velocity of the drying medium, the temperature and humidity of the environment and so on. Thus, it is necessary to scope the drying parameters for studying in this dissertation. Four major drying parameters affecting the quality variation of the dried products are scoped to study. They are shown in Table 1.5. Moreover, the seasonality can affect the quality of the drying process, but it is assumed that there is no effect from the seasonality.

Table 1.5 Scoped drying parameters

Type of Variable	Type of Factor	Drying Parameters
Dependent	Output	Moisture content of the dried product
Independent	Uncontrollable	Moisture content of the raw material
	Controllable	Drying temperature
		Drying time

1.4.4 Types of Dried Product

There are a lot of types of the dried product in Thailand. Therefore, some types of the dried product are selected to be case studies with three criteria. The criteria used to select the case studies are (1) numbers of factories, (2) average of export values, and (3) shapes of the dried product.

Four types of the dried product are selected as paddy rice, cassava chip, tobacco, and longan. Their details can be shown in Table 1.6 and described as below.

Table 1.6 Case studies

Product	Numbers of Factory	Average of export value (Million U.S. $)	Shape
Paddy rice	3,216	2,732.65	Grain
Cassava chip	2,385	82.13	Solid
Tobacco	110	24.31	Texture
Longan	65	12.51	Fruit

(1) Paddy Rice

The first case study is conducted with the jasmince rice KDML 105 from a rice trader in Chain Mai provice of Thailand. The initial moisture content of paddy rice is in a range of 22-29% w.b. And the output moisture content after drying is desired to 14% w.b.

(2) Cassava Chip

The second case study was conducted with the cassva chip production with a cassava trader in Nakhon Ratchasima province of Thailand. In this dissertation, cassava transformed into cassava chip is Rayong 90. The initial moisutre content of cassava is in a range of 40-73% w.b. The output moisture content after drying was also desired to 14% w.b.

(3) Tobacco

The third case study was conducted with tobacco bleding production with a trader in Chiang Mai province of Thailand. Tobacco in this dissertation is Burley with the initial moisture content in a range of 15-22% w.b. The output moisture content after drying was also desired to 12.5% w.b.

(4) Longan

The last case study was conducted with the dried longan production with a trader in Lamphun province of Thailand. In this dissertation, E-Dor as a type of logan is used to study. The initial moisture content is in a range of 84-97% w.b. The output moisture content after drying was also desired to 18% w.b.

1.4.5 Types of Dryer

In the drying process, there are several types of the dryer. However, in this dissertation, there are two types of the dryers as fluidized-bed and superheated steam are used to dry the products. Specifications of two dryers are descirbed as following the types of the dried product.

(1) Paddy Rice

In this dissertation, the drying process of paddy rice consists of two fluidized-bed dryers as shown in Figure 1.7. The first dryer is used for heating and drying paddy rice with a constant drying rate. Its specifications are shown in Table 1.7. The second dryer is used for tempering or drying paddy rice with falling drying rate. Its specifications are shown in Table 1.8.

Figure 1.7 Fluidized-bed dryer for drying paddy rice

Table 1.7 Specifications of the fluidized-bed dryer for drying paddy rice with a constant drying rate

Specifications	Details
Dimension (width × length × height)	3.0 × 11.0 × 8.0 meters
Capacity	15 tons/hour
Power motor	75 HP
Hot air temperature	100 – 150°C
Hot air velocity	2.0 m/s

Table 1.8 Specifications of the fluidized-bed dryer for tempering or drying paddy rice with falling drying rate

Specifications	Details
Dimension (width × length × height)	3.0 × 11.0 × 8.0 meters
Capacity	15 tons/hour
Power motor	75 HP
Hot air temperature	50 – 70°C
Hot air velocity	2.0 m/s

(2) Cassava Chip

In this dissertation, the drying process of cassava chip consists of only one fluidized-bed dryer as shown in Figure 1.8. Its specifications are shown in Table 1.9.

Figure 1.8 Fluidized-bed dryer for drying cassava chip

Table 1.9 Specifications of the fluidized-bed dryer for drying cassava chip

Specifications	**Details**
Dimension (width × length × height)	0.5 × 0.5 × 1.2 meters
Capacity	100 Liters
Power motor	6.5 HP
Hot air temperature	90 – 130°C
Hot air velocity	4.0 m/s

(3) Tobacco

In this dissertation, the drying process of tobacco consists of a superheated-steam dryer as shown in Figure 1.9. Its specifications are shown in Table 1.10.

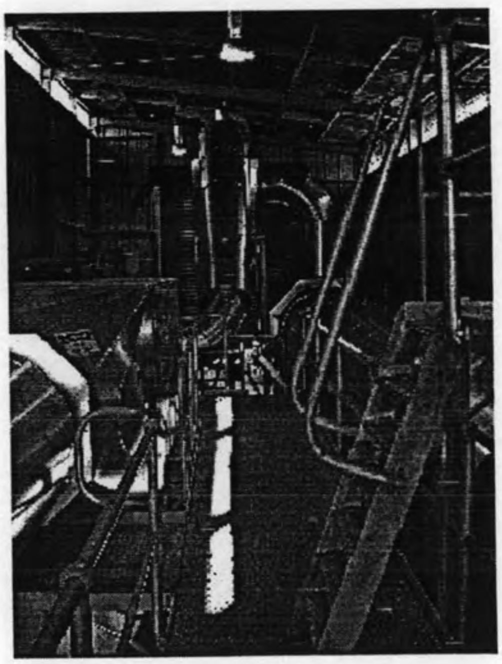

Figure 1.9 Superheated-steam dryer for drying tobacco

Table 1.10 Specifications of the superheated-steam dryer for drying tobacco

Specifications	Details
Capacity	50 tons/hours
Percentage of Steam	55%
Hot air temperature	40 – 70°C
Steam velocity	2.5 m/s

(4) Longan

In this dissertation, the drying process of longan consists of a fluidized-bed dryer as shown in Figure 1.10. This drying process uses superheated steam as the drying medium instead of hot air. Its specifications are shown in Table 1.11.

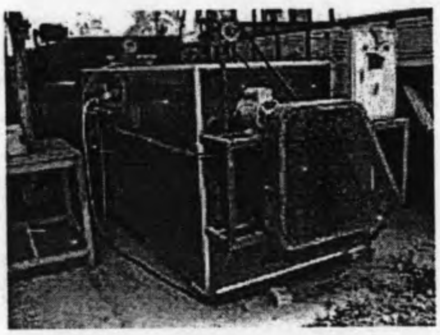

Figure 1.10 Fluidized-bed dryer for drying longan

Table 1.11 Specifications of the fluidized-bed dryer for drying longan

Specifications	Details
Dimension (width × length × height)	0.8×1.5×1.5 meters
Capacity	100 kg/time
Blower	2 ½ inches
Hot air temperature	60 – 100°C
Steam velocity	5.0 m/s

1.5 Dissertation Contributions

The major contribution of this dissertation is to develop the mathematical models for managing the quality variation of the drying process in Thai agro-industry. These mathematical models deal with the reduction and minimization of the dried product quality variation. The mathematical models can propose two additional contributions as:

(1) Illustrating the statistical relationship between the dried product quality variation and the source of the quality variation (the raw material and the process); and

(2) Proposing how to control and adjust the drying process for managers or engineers in order to control the quality of the dried products.

1.6 Dissertation Methodology

The objective of this dissertation is to develop the mathematical models for managing the quality variation for the drying process in Thai agro-industry. To achieve the objective, this dissertation is conducted as the following steps (Figure 1.11).

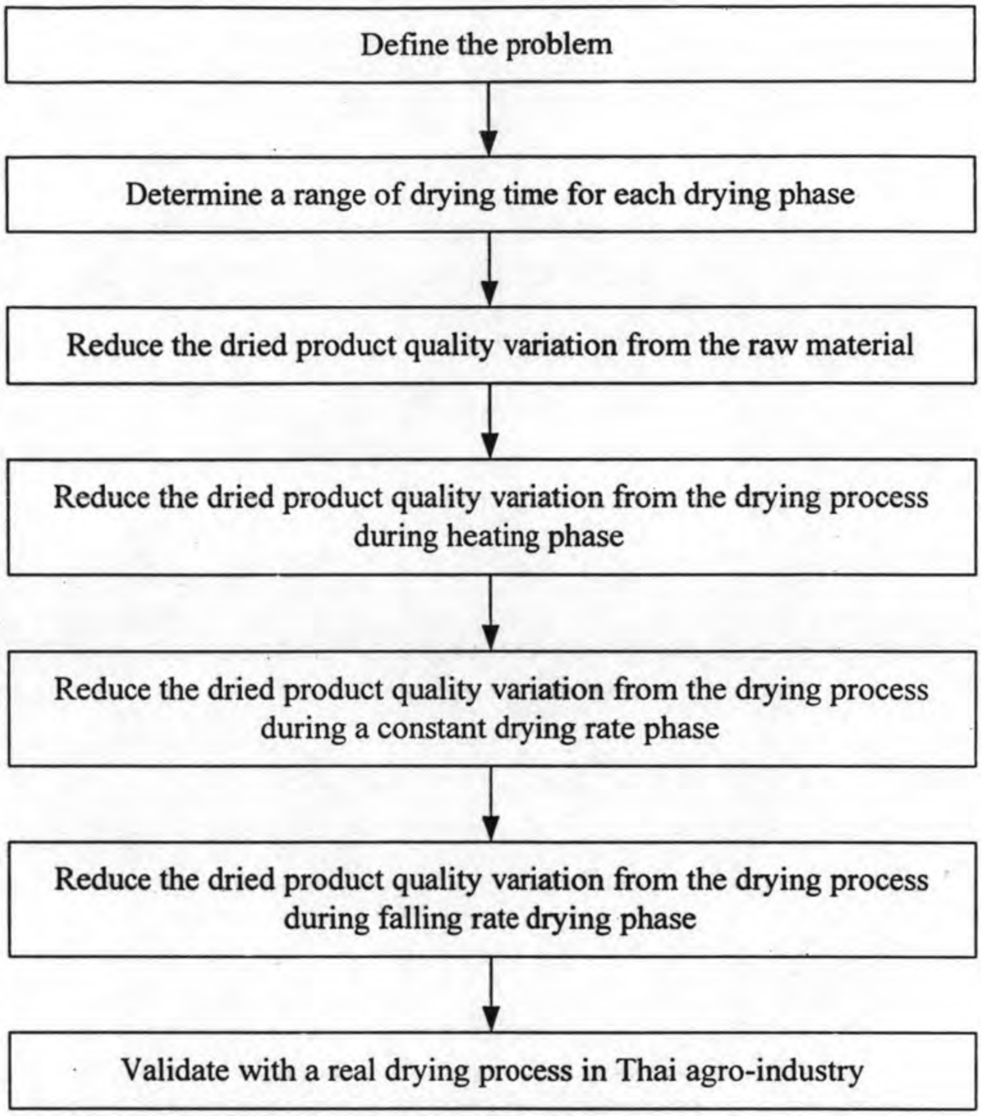

Figure 1.11 Dissertation methodology

1.6.1 Defining the Problem

Once getting an idea from literature review, the drying process of the agro-industry is very important to Thai economy. However, it is very difficult to control and improve their qualities because of several uncontrolled factors from the nature. Thus quality variation management for the drying process in Thai agro-industry is defined as the problem of this dissertation. Drying parameters (moisture contents of the raw material and the dried product, drying temperature and drying time) are also defined to study. Moreover, four types of the dried product (paddy rice, cassava chip, tobacco, and longan) are conducted in this dissertation.

1.6.2 Determining a Range of Drying Time for Each Drying Phase

Drying time for each drying phase is necessarily determined for the drying process. Hence, the aim of this step is to find the optimal drying time for each drying phase. In this step, the raw materials are dried with the conventional method. The optimal drying time from this step is used for next experiments.

1.6.3 Reducing the Dried Product Quality Variation from Raw Material

Raw materials of the agro-industry are from the agricultural products. It is very difficult to control their qualities because of several uncontrolled factors from the nature. This is a cause of the product quality variation including the dried product. Hence, the aim of this step is to reduce the dried product quality variation from the raw material.

The method used to reduce the dried product quality variation from the raw material is the clustering technique. The clustering technique can help to reduce the variety of the raw material. The raw materials with same quality are organized to the same cluster. After clustering, the raw materials are transferred to the drying process with the heating phase.

1.6.4 Reducing the Dried Product Quality Variation from the Drying Process during Heating Phase

In this step, the raw materials from clustering are heated without changing the moisture content. Therefore, the aim of this step is to find the optimal heating temperature levels which can minimize the quality variation in the heating phase. After finding the optimal heating temperature levels, the mathematical models are constructed. These mathematical models are used to represent the relationship between the moisture contents of the dried products and the heating times within the optimal heating temperature levels. When the raw materials are already heated, they are transferred to drying process during a constant drying rate phase.

1.6.5 Reducing the Dried Product Quality Variation from the Drying Process during a Constant Drying Rate Phase

In this step, the heated raw materials are dried with a constant drying rate. Their moisture contents are reduced to their targets of the moisture content within a specific period time. Therefore, the aim of this step is to find the optimal drying temperature levels which can minimize the quality variation in the drying with a constant rate phase. After finding the optimal drying temperature levels, the mathematical models are constructed. These mathematical models are used to represent the relationship between the moisture contents of the dried products and the drying times within the optimal drying temperature levels. When the raw materials are already dried in this phase, they are transferred to drying process during falling drying rate phase.

1.6.6 Reducing the Dried Product Quality Variation from the Drying Process during Falling Drying Rate Phase

In this step, the dried raw materials from the second phase are dried with falling drying rate. Their moisture contents are reduced to their moisture content targets of the dried products within a specific period time. Therefore, the aim of this step is to find the optimal drying temperature levels which can minimize the quality variation in the drying with falling rate phase. After finding the optimal drying temperature levels, the mathematical models are constructed. These mathematical models are used to represent the relationship between the moisture contents of the dried products and the drying times within the optimal drying temperature levels.

1.6.7 Validation

It is very necessary to implement the results to ensure that they can work for the real situation. Hence, after the temperature level and the mathematical models are constructed, they are tested with the real industries using the drying process to transform the products.

1.7 Dissertation Outline

The outline of this dissertation is organized as follows. The relevant literature is reviewed in Chapter 2. In Chapter 3, the methodology of this dissertation is defined to be a research direction. After defining the methodology, the optimal drying time for each drying phase is the first experiment of this dissertation. Its result is shown in Chapter 4.

After finding the optimal drying time for each drying phase, reducing the dried product quality variation from the raw material is proposed in Chapter 5. In this Chapter, the optimal numbers of the clustering is proposed for classifying the raw materials. The optimal numbers of the clustering can help to reduce the dried product quality variation from the raw material.

After dealing with the raw materials, reducing the dried product quality variation from the drying process is proposed. The results of the reducing the dried product quality variation from the drying process during heating phase is shown in Chapter 6. In this chapter, the optimal heating temperature levels and the mathematical models of the heating phase are also proposed. After heating the raw materials, the results of the reducing the dried product quality variation from the drying process during a constant drying rate phase is shown in Chapter 7. Moreover, the optimal drying temperature levels and the mathematical models of this phase are illustrated for minimizing the dried product quality variation. The results of the reducing the dried product quality variation from drying process during falling drying rate phase is shown in Chapter 8. The optimal drying temperature levels and the mathematical models are also proposed to minimize the dried product quality variation.

To ensure that the results from the Chapter 5, 6, 7, and 8 can be used for the real drying process, implementation in Chapter 9 is necessary to validate. Finally, conclusion of this dissertation and further research is described in Chapter 10.