CHAPTER VI

QUALITY VARIATION MANAGEMENT IN DRYING PROCESS WITHIN HEATING PHASE

From previous chapter, the dried product quality variation in the raw materials is minimized by organizing the raw materials into three clusters as low, medium, and high initial moisture contents. This organizing can help to reduce the variety of the raw material as a cause of the high value of the dried product quality variation in the raw materials. After clustering, the raw materials are transferred to heating phase which is the first phase of the drying process. The raw materials are heated without reducing the moisture content. Therefore, quality variation management in the drying process within heating phase is scoped for this chapter as Figure 6.1. Moreover, the aims of this chapter are to find the optimal temperature levels for heating the raw materials and to construct the mathematical models for representing the behavior of the moisture content during the heating period time.

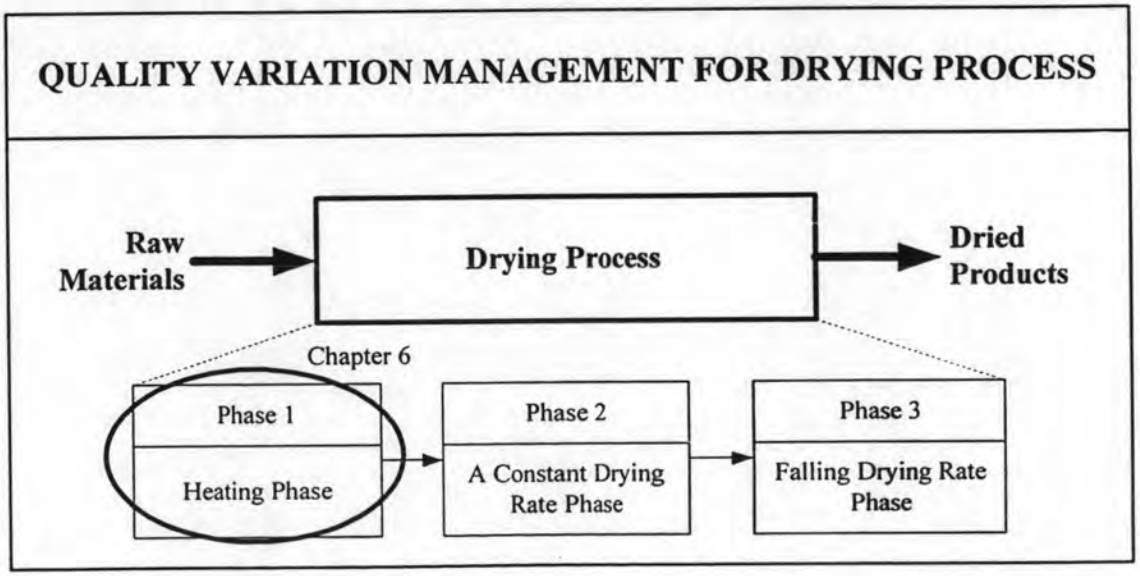

Figure 6.1 Scope of quality variation management in drying process within heating phase

The outline of this chapter is organized into five sections. In Section 6.1 to 6.4, experimental results of paddy rice, cassava chip, tobacco, and longan are explained and discussed respectively. In each section, heating temperature is varied to find the optimal heating temperature level; moreover, the mathematical models are constructed to represent the relationship between the moisture content and heating time. In the last section 6.5, all experimental results are concluded and summarized.

6.1 Experimental Results of Paddy Rice

In this phase, paddy rice is heated within 30 seconds by varying levels of heating temperature. The experimental results are shown as following clustering of the raw materials.

6.1.1 Low Moisture Content

Paddy rice within low moisture content is sampled at an average initial moisture content of 23.9% w.b. It is heated with varying levels of temperature at 55, 60, and 65°C. The experimental results are explained as below.

(1) Heating Temperature Level at 55°C

From Figure 6.2, the initial moisture content of paddy rice is at 23.9% w.b. During heating within 20 seconds, the moisture content is still same as the initial moisture content at 23.9% w.b. After heating within 30 seconds, the moisture content is reduced to 23.7% w.b. *MSD* is equaled to 0.041 (% w.b.)^2.

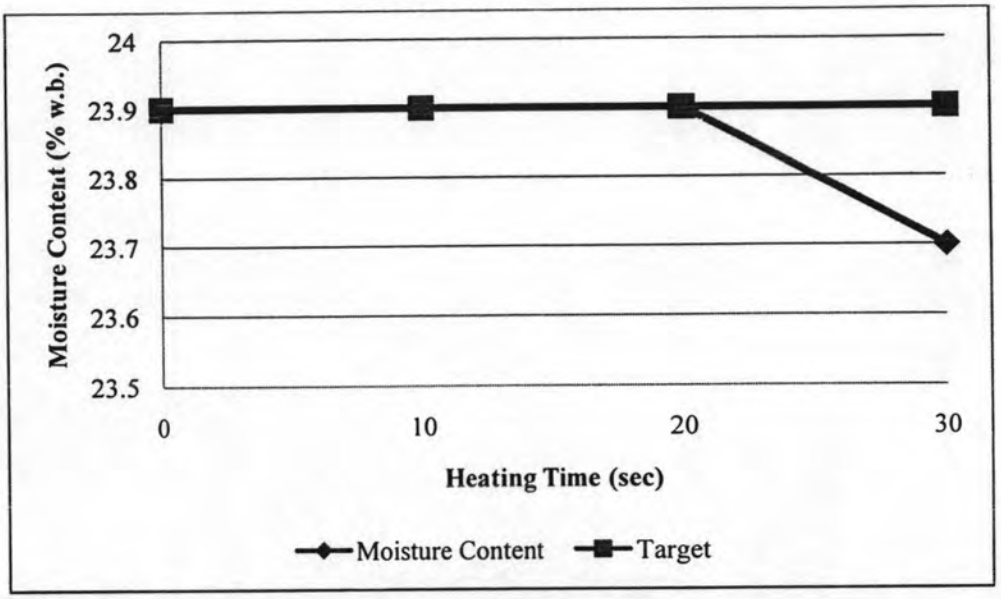

Figure 6.2 Heating result of paddy rice within low moisture content at 55°C

(2) Heating Temperature Level at 60°C

From Figure 6.3, the initial moisture content of paddy rice is at 23.9% w.b. During heating within 20 seconds, the moisture content is still same as the initial moisture content at 23.9% w.b. After heating within 30 seconds, the moisture content is reduced to 23.5% w.b. *MSD* is equaled to 0.172 (% w.b.)^2.

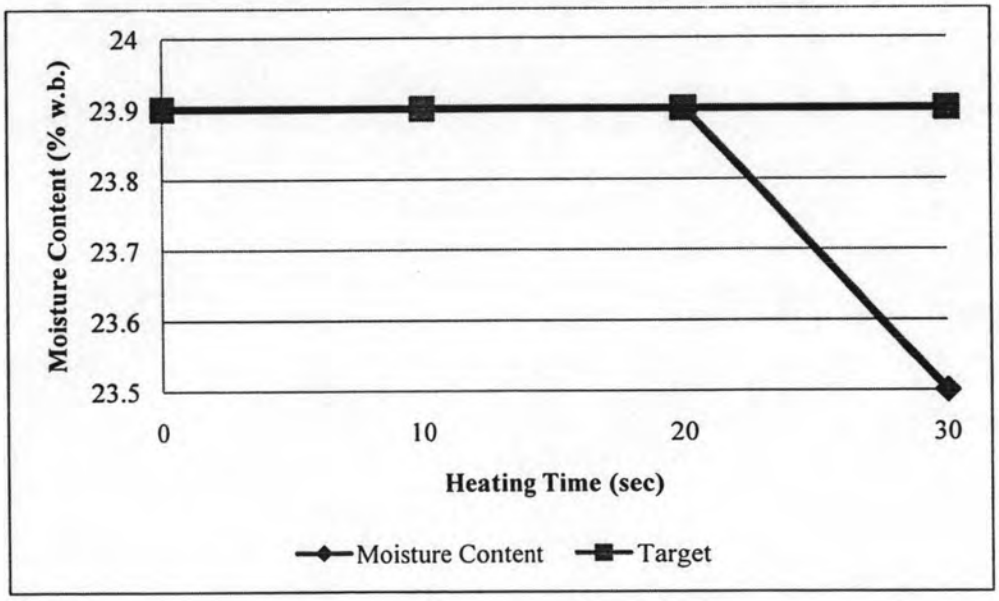

Figure 6.3 Heating result of paddy rice within low moisture content at 60°C

(3) Heating Temperature Level at 65°C

From Figure 6.4, the initial moisture content of paddy rice is at 23.9% w.b. During heating within 10 seconds, the moisture content is still same as the initial moisture content at 23.9% w.b. After heating within 10 seconds, the moisture content is reduced continually. At 20th second, the moisture content is reduced to 23.7% w.b. and at 30th second, the moisture content is reduced to 23.5% w.b. After heating, *MSD* is equaled to 0.209 (% w.b.)^2.

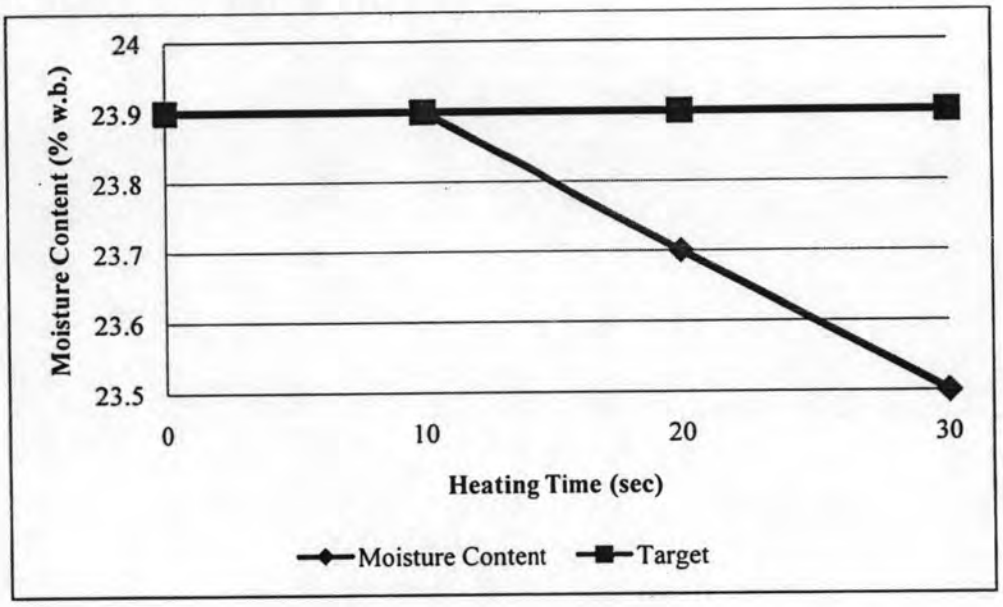

Figure 6.4 Heating result of paddy rice within low moisture content at 65°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.5. It shows that *MSD* from heating temperature level at 55°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating paddy rice within low moisture content is at 55°C.

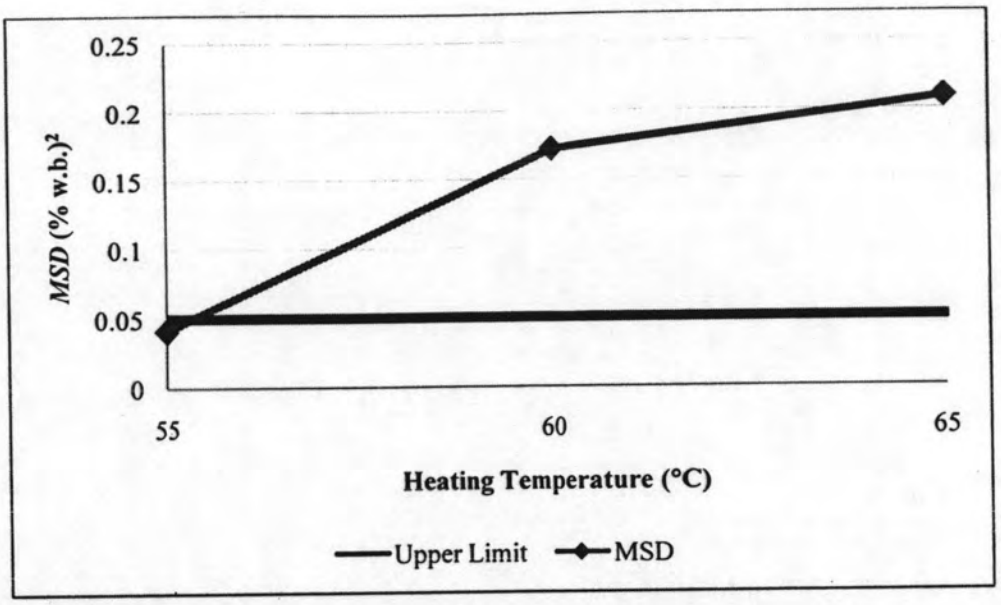

Figure 6.5 *MSD* from heating paddy rice within low moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating paddy rice within low moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.1).

$$M(t)_1 = 23.9, \qquad 0 \le t \le 30 \tag{6.1}$$

where

$M(t)_1$ = the moisture content during heating phase at time t

t = heating time in seconds

6.1.2 Medium Moisture Content

Paddy rice within medium moisture content is sampled at an average initial moisture content of 26.6% w.b. It is heated with varying levels of temperature at 55, 60, and 65°C. The experimental results are explained as below.

(1) Heating Temperature Level at 55°C

From Figure 6.6, heating time with 55°C is consumed more than 30 seconds while the operation is designed to heat within 30 seconds. Therefore, heating with 55°C cannot be used to heat paddy rice within medium moisture content.

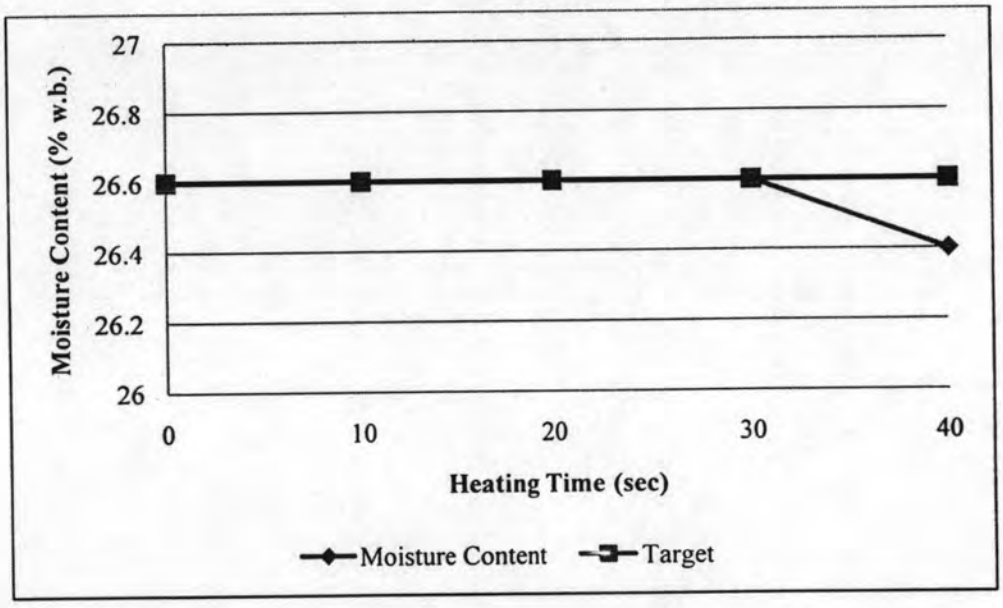

Figure 6.6 Heating result of paddy rice within medium moisture content at 55°C

(2) Heating Temperature Level at 60°C

From Figure 6.7, the initial moisture content of paddy rice is at 26.6% w.b. During heating within 20 seconds, the moisture content is still same as the initial moisture content at 26.6% w.b. After heating within 30 seconds, the moisture content is reduced to 26.5% w.b. *MSD* is equaled to 0.027 (% w.b.)^2.

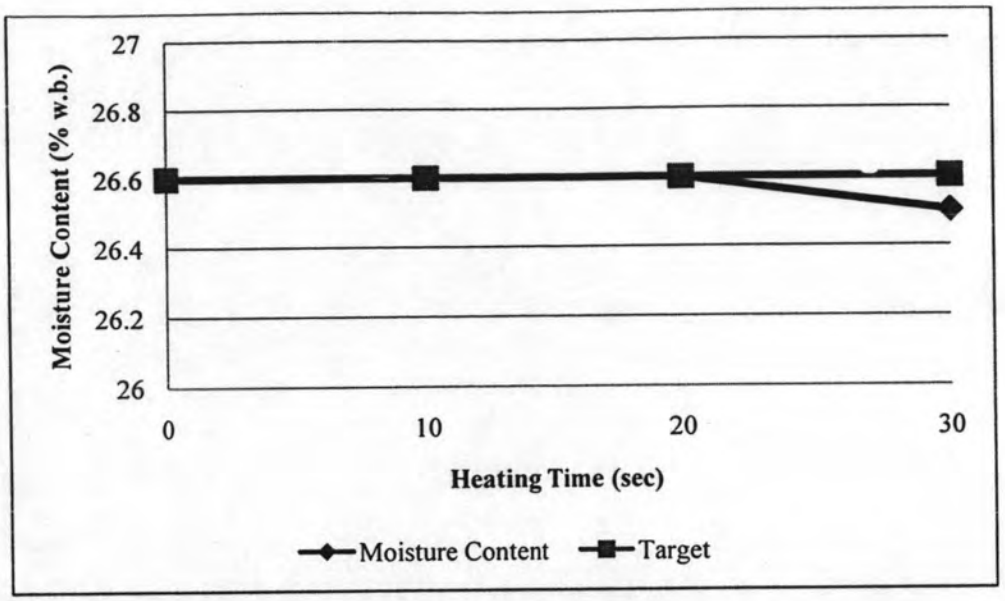

Figure 6.7 Heating result of paddy rice within medium moisture content at 60°C

(3) Heating Temperature Level at 65°C

From Figure 6.8, the initial moisture content of paddy rice is at 26.6% w.b. During heating within 20 seconds, the moisture content is still same as the initial moisture content at 26.6% w.b. After heating within 30 seconds, the moisture content is reduced to 26.3% w.b. *MSD* is equaled to 0.099 (% w.b.)^2.

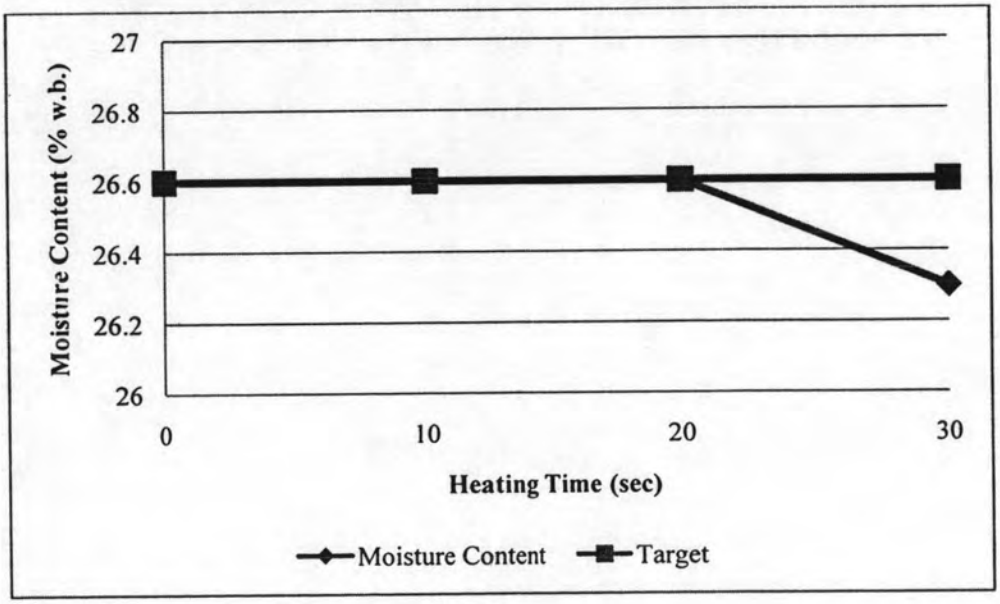

Figure 6.8 Heating result of paddy rice within medium moisture content at 65°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.9. It shows that *MSD* from heating temperature level at 60°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating paddy rice within medium moisture content is at 60°C.

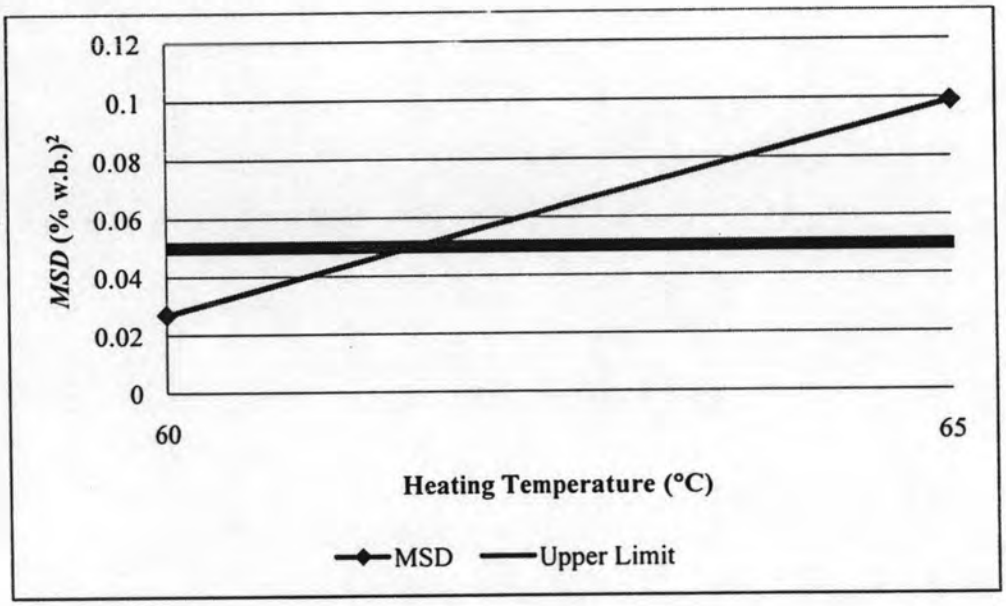

Figure 6.9 *MSD* from heating paddy rice within medium moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating paddy rice within medium moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.2).

$$M(t)_1 = 26.6, \qquad 0 \le t \le 30 \tag{6.2}$$

6.1.3 High Moisture Content

Paddy rice within high moisture content is sampled at an average initial moisture content of 27.8% w.b. It is heated with varying levels of temperature at 60, 63, and 65°C. The experimental results are explained as below.

(1) Heating Temperature Level at 60°C

From Figure 6.10, heating time with 60°C is consumed more than 30 seconds while the operation is designed to heat within 30 seconds. Therefore, heating with 60°C cannot be used to heat paddy rice within high moisture content.

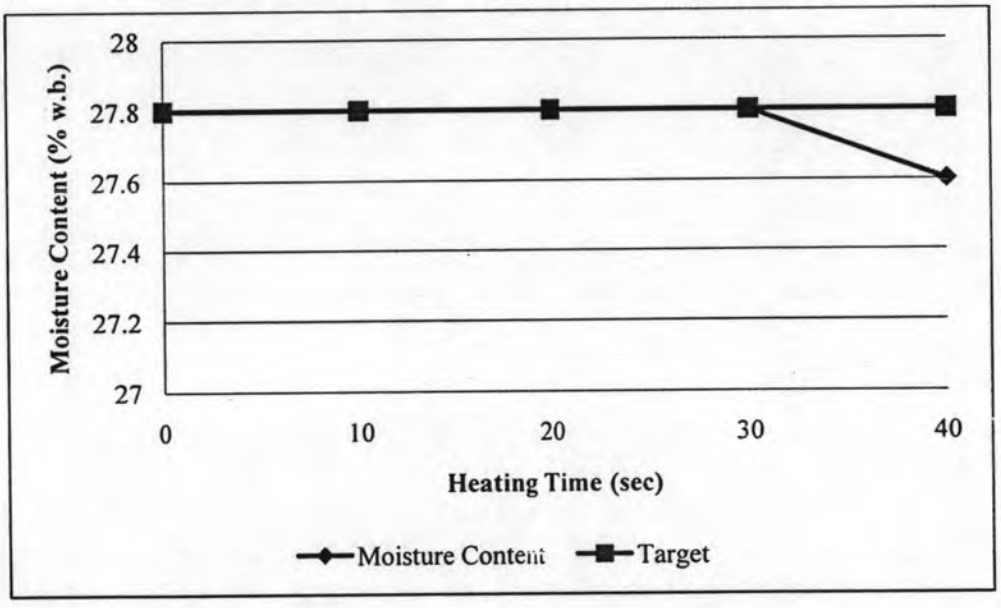

Figure 6.10 Heating result of paddy rice within high moisture content at 60°C

(2) Heating Temperature Level at 63°C

From Figure 6.11, the initial moisture content of paddy rice is at 27.8% w.b. During heating within 20 seconds, the moisture content is still same as the initial moisture content at 27.8% w.b. After heating within 30 seconds, the moisture content is reduced to 27.6% w.b. *MSD* is equaled to 0.033 (% w.b.)^2.

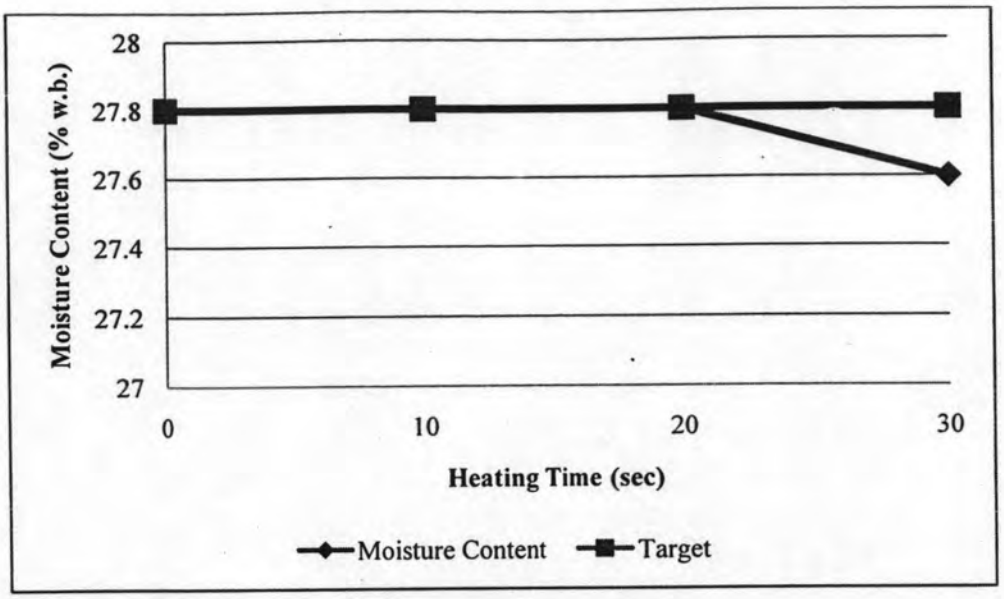

Figure 6.11 Heating result of paddy rice within high moisture content at 63°C

(3) Heating Temperature Level at 65°C

From Figure 6.12, the initial moisture content of paddy rice is at 27.8% w.b. During heating within 20 seconds, the moisture content is still same as the initial moisture content at 27.8% w.b. After heating within 30 seconds, the moisture content is reduced to 26.5% w.b. *MSD* is equaled to 0.094 (% w.b.)^2.

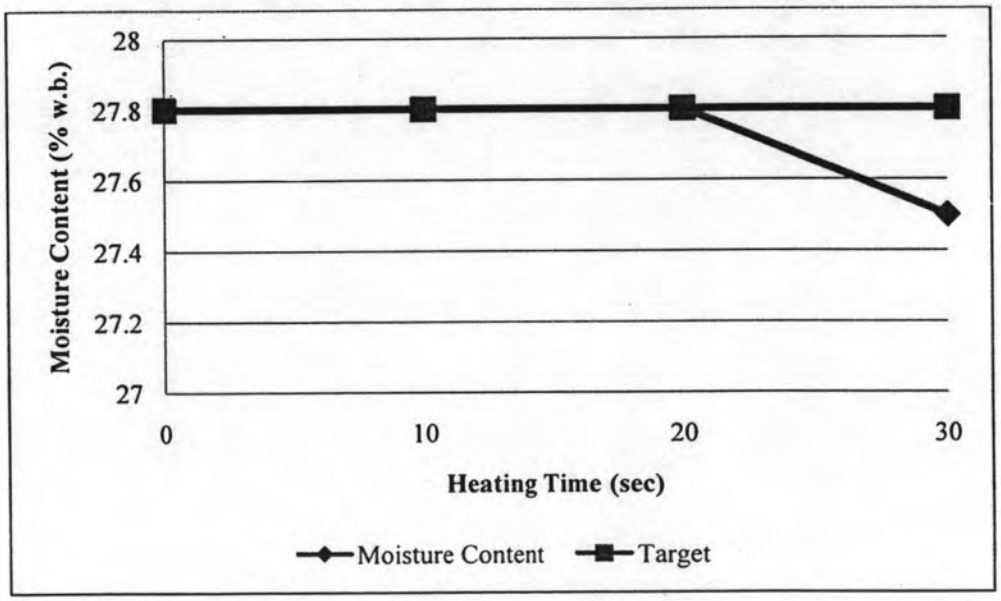

Figure 6.12 Heating result of paddy rice within high moisture content at 65°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.13. It shows that *MSD* from heating temperature level at 63°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating paddy rice within high moisture content is at 63°C.

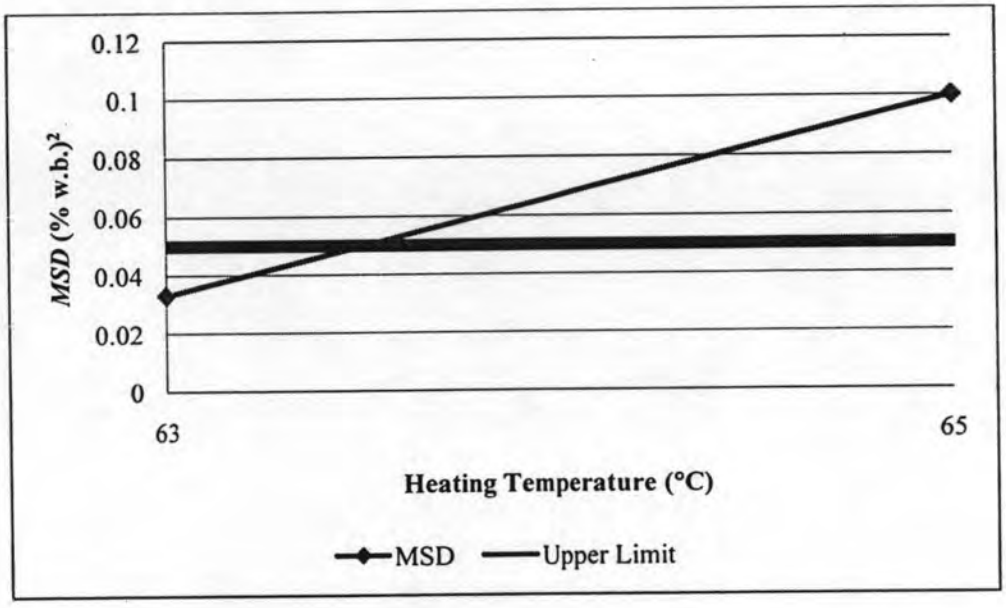

Figure 6.13 *MSD* from heating paddy rice within high moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating paddy rice within high moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.3).

$$M(t)_1 = 27.8, \qquad 0 \le t \le 30 \qquad (6.3)$$

From all heating experiments, they are summarized in Figure 6.14 which illustrates the optimal temperature levels and the mathematical models for heating paddy rice within low, medium, and high initial moisture content clusters.

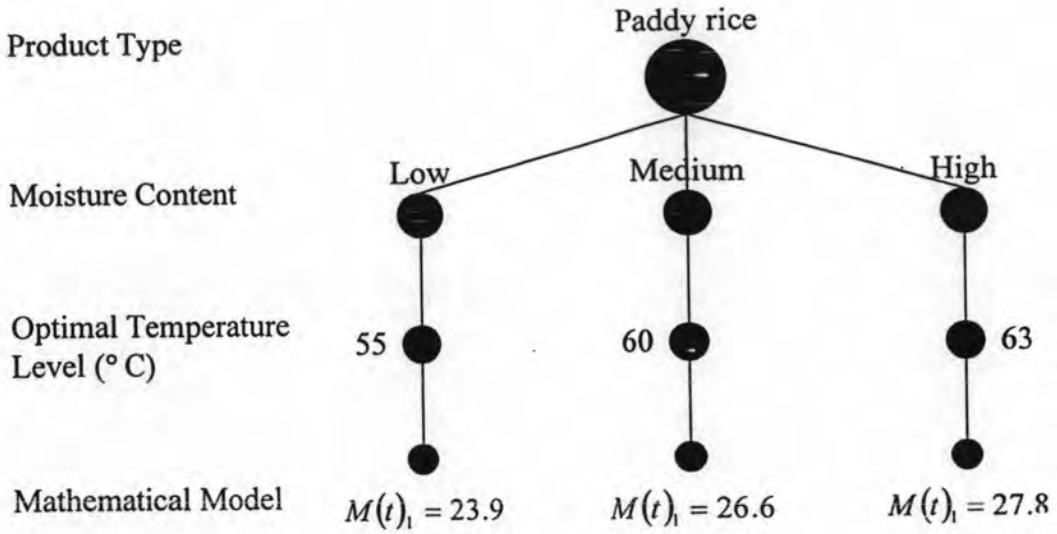

Figure 6.14 Optimal temperature levels and mathematical models for heating paddy rice

6.2 Experimental Results of Cassava Chip

In this phase, cassava chips are heated within five minutes by varying levels of heating temperature. The experimental results are shown as following clustering of the raw materials.

6.2.1 Low Moisture Content

Cassava chips within low moisture content are sampled at an average initial moisture content of 52.4% w.b. They are heated with varying levels of temperature at 90, 95, and 100°C. The experimental results are explained as below.

(1) Heating Temperature Level at 90°C

From Figure 6.15, the initial moisture content of cassava chip is at 52.4% w.b. During heating within four minutes, the moisture content is still same as the initial moisture content at 52.4% w.b. After heating within five minutes, the moisture content is reduced to 52.3% w.b. *MSD* is equaled to 0.016 (% w.b.)^2.

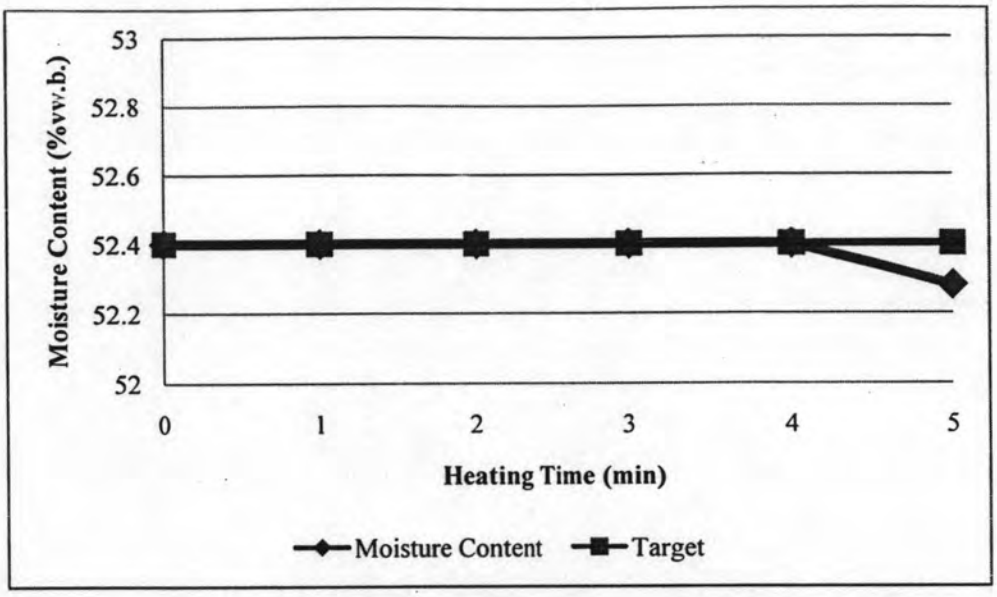

Figure 6.15 Heating result of cassava chip within low moisture content at 90°C

(2) Heating Temperature Level at 95°C

From Figure 6.16, the initial moisture content of cassava chip is at 52.4% w.b. During heating within two minutes, the moisture content is still same as the initial moisture content at 52.4% w.b. After heating within five minutes, the moisture content is reduced to 52.2% w.b. *MSD* is equaled to 0.034 (% w.b.)^2.

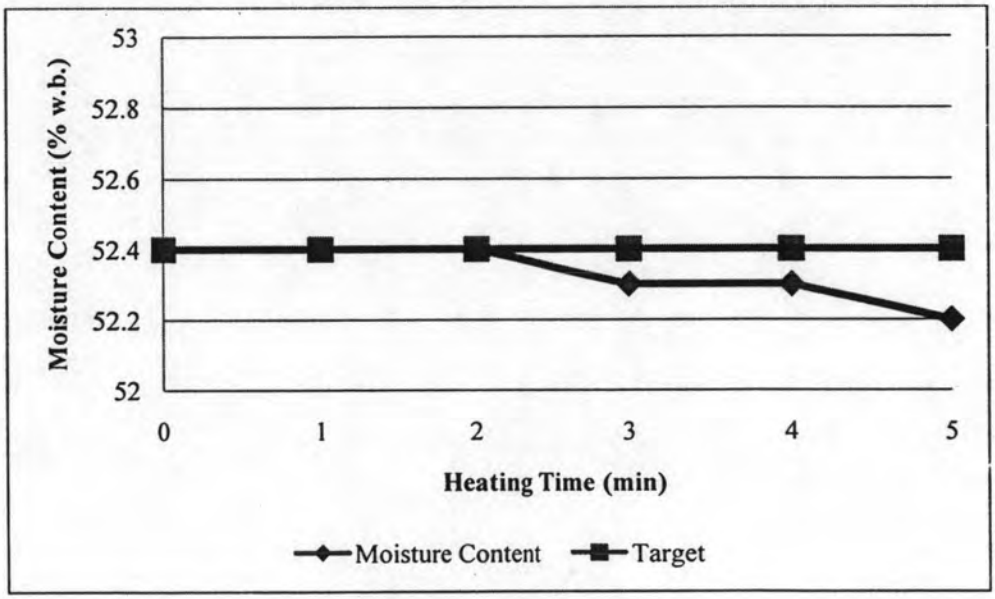

Figure 6.16 Heating result of cassava chip within low moisture content at 95°C

(3) Heating Temperature Level at 100°C

From Figure 6.17, the initial moisture content of cassava chip is at 52.4% w.b. During heating within a minute, the moisture content is still same as the initial moisture content at 52.4% w.b. At the second minute, the moisture content is reduced to 52.3% w.b. and 52.1% w.b. at the third and fourth minutes. After heating within five minutes, the moisture content is reduced to 52.0% w.b. *MSD* is equaled to 0.170 (% w.b.)^2.

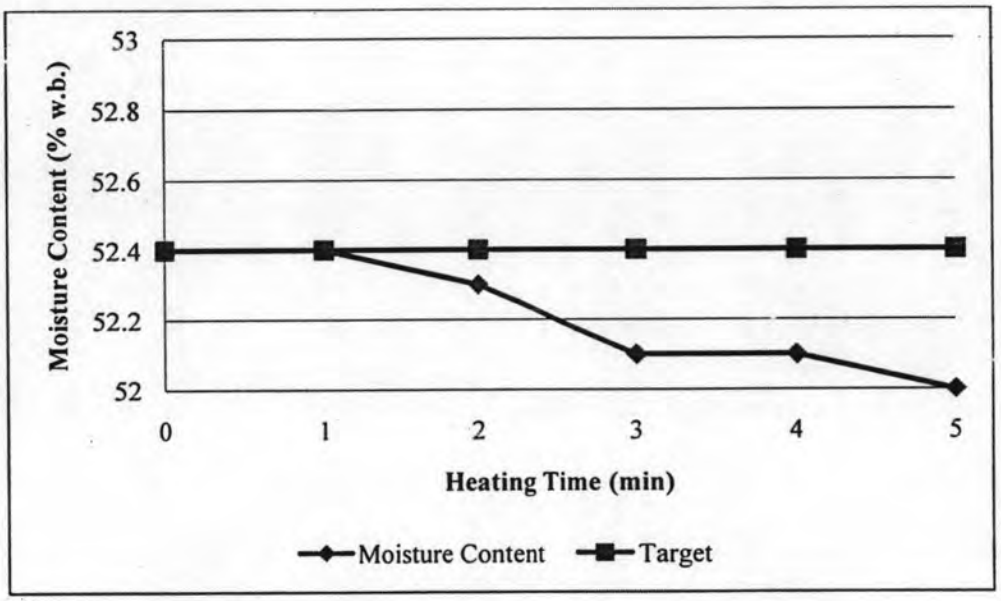

Figure 6.17 Heating result of cassava chip within low moisture content at 100°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.18. It shows that *MSD* from heating temperature level at 90°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating cassava chip within low moisture content is at 90°C.

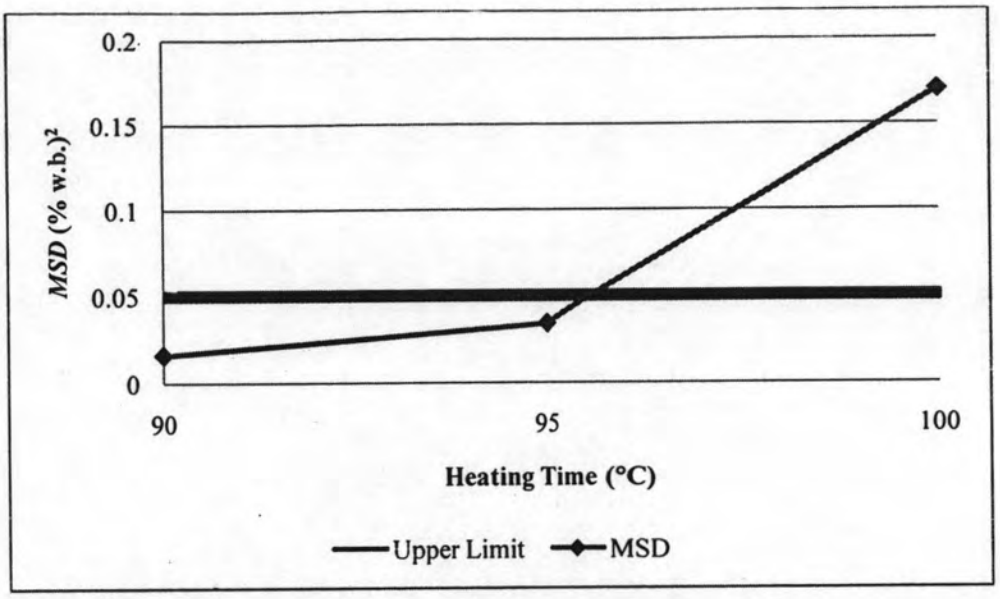

Figure 6.18 *MSD* from heating cassava chip within low moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating cassava chip within low moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.4).

$$M(t)_1 = 52.4, \qquad 0 \le t \le 5 \tag{6.4}$$

where

$M(t)_1$ = the moisture content during heating phase at time t

t = heating time minutes

6.2.2 Medium Moisture Content

Cassava chips within medium moisture content are sampled at an average initial moisture content of 60.1% w.b. They are heated with varying levels of temperature at 90, 100, and 110°C. The experimental results are explained as below.

(1) Heating Temperature Level at 90°C

From Figure 6.19, heating time with 90°C is consumed more than five minutes while the operation is designed to heat within five minute. Therefore, heating with 90°C cannot be used to heat cassava chip within medium moisture content.

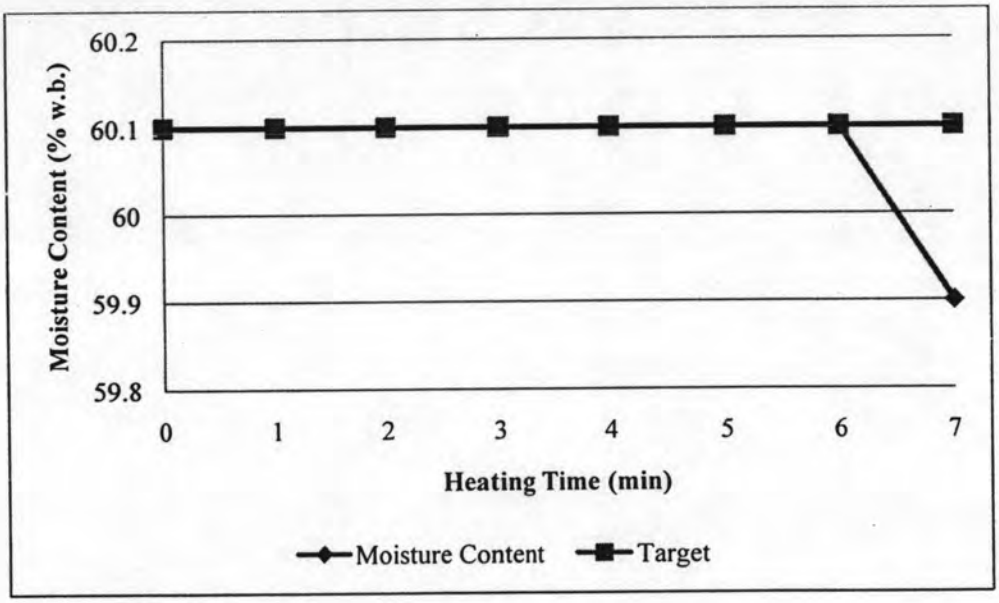

Figure 6.19 Heating result of cassava chip within medium moisture content at 90°C

(2) Heating Temperature Level at 100°C

From Figure 6.20, the initial moisture content of cassava chip is at 60.1% w.b. During heating within four minutes, the moisture content is still same as the initial moisture content at 60.1% w.b. After heating within five minutes, the moisture content is reduced to 60.0% w.b. *MSD* is equaled to 0.016 (% w.b.)^2.

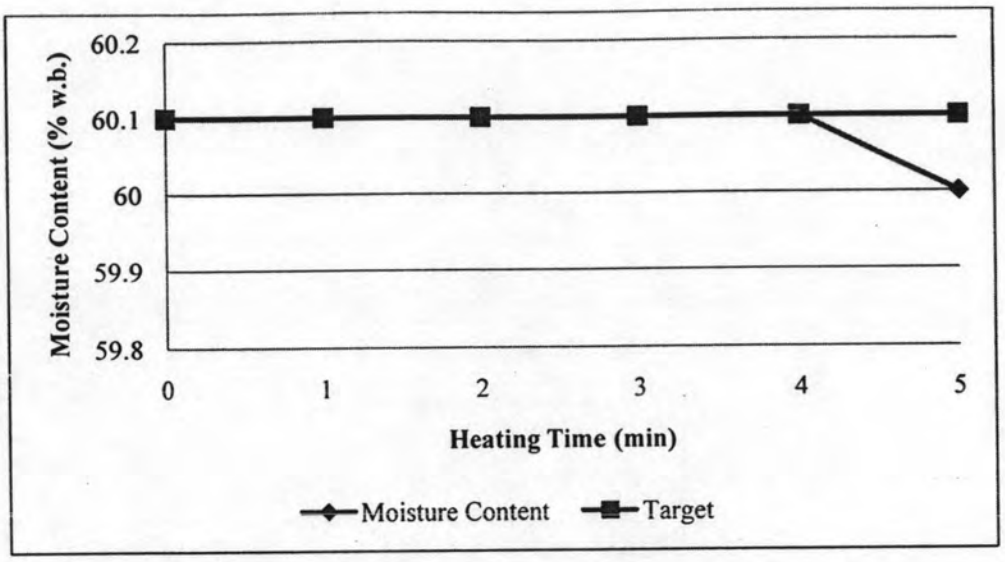

Figure 6.20 Heating result of cassava chip within medium moisture content at 100°C

(3) Heating Temperature Level at 110°C

From Figure 6.21, the initial moisture content of cassava chip is at 60.1% w.b. During heating within three minutes, the moisture content is still same as the initial moisture content at 60.1% w.b. After heating within four minutes, the moisture content is reduced to 60.0% w.b. and 59.9% w.b. at the fifth minute. *MSD* is equaled to 0.068 (% w.b.)^2.

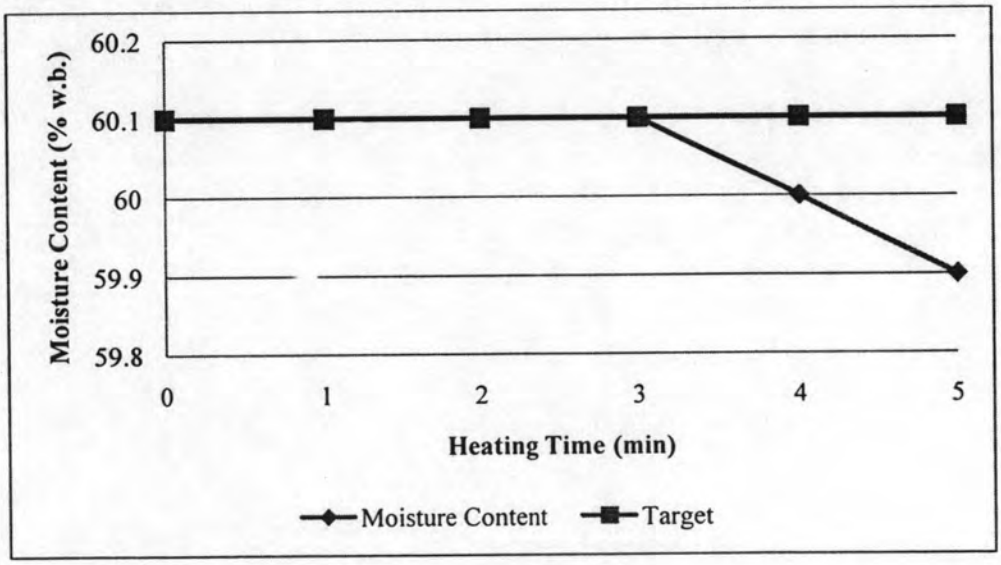

Figure 6.21 Heating result of cassava chip within medium moisture content at 110°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.22. It shows that *MSD* from heating temperature level at 100°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating cassava chip within medium moisture content is at 100°C.

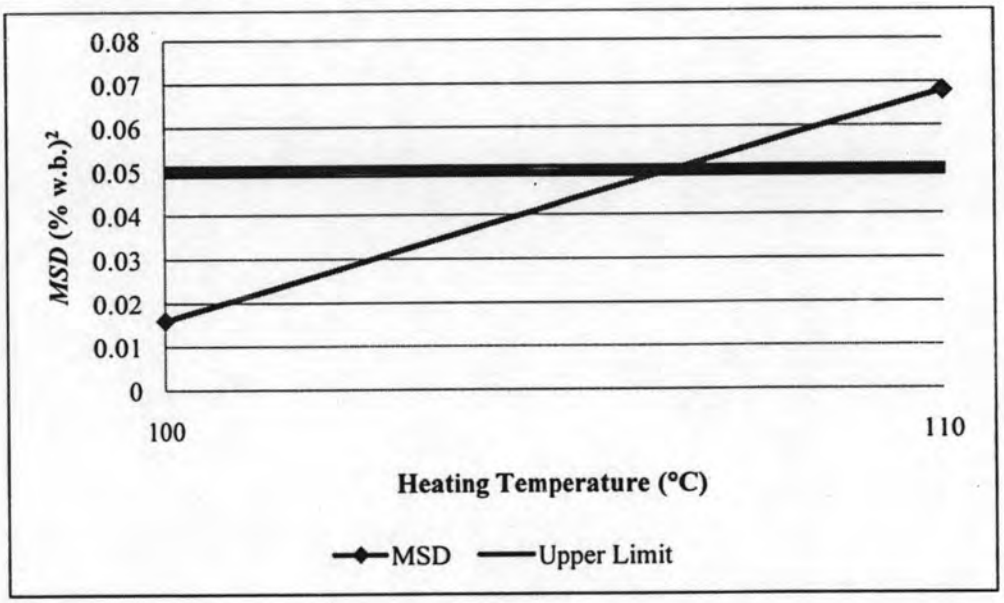

Figure 6.22 *MSD* from heating cassava chip within medium moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating cassava chip within medium moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.5).

$$M(t)_1 = 60.1, \qquad 0 \le t \le 5 \qquad (6.5)$$

6.1.3 High Moisture Content

Cassava chips within high moisture content are sampled at an average initial moisture content of 67.7% w.b. They are heated with varying levels of temperature at 105, 110, and 115°C. The experimental results are explained as below.

(1) Heating Temperature Level at 105°C

From Figure 6.23, heating time with 105°C is consumed more than seven minutes while the operation is designed to heat within five minutes. Therefore, heating with 105°C cannot be used to heat cassava chip within high moisture content.

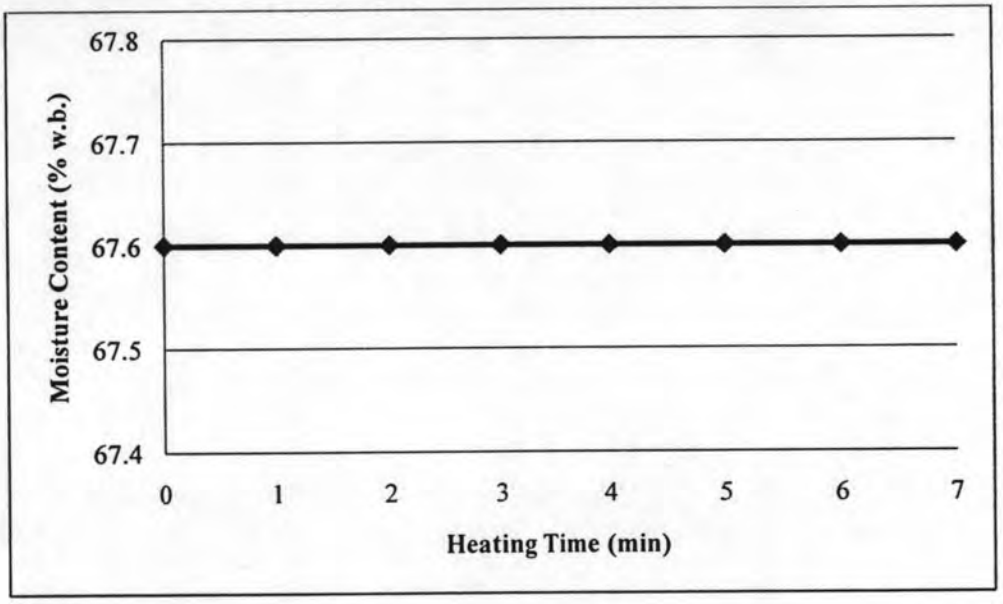

Figure 6.23 Heating result of cassava chip within high moisture content at 105°C

(2) Heating Temperature Level at 110°C

From Figure 6.24, the initial moisture content of cassava chip is at 67.6% w.b. During heating within four minutes, the moisture content is still same as the initial moisture content at 67.6% w.b. After heating within five minutes, the moisture content is reduced to 67.5% w.b. *MSD* is equaled to 0.016 (% w.b.)^2.

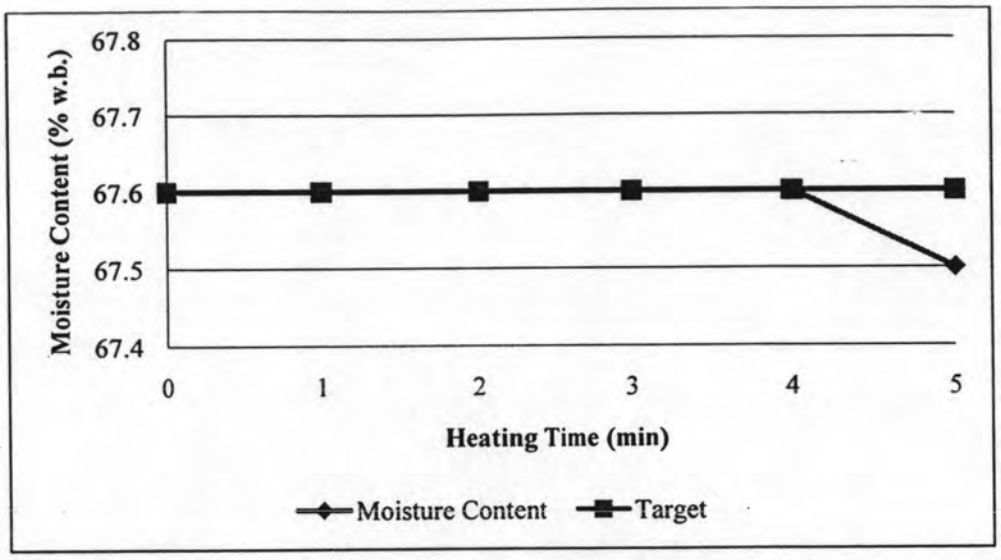

Figure 6.24 Heating result of cassava chip within high moisture content at 110°C

(3) Heating Temperature Level at 115°C

From Figure 6.25, the initial moisture content of cassava chip is at 67.6% w.b. During heating within a minute, the moisture content is still same as the initial moisture content at 67.6% w.b. At the second minute, the moisture content is reduced to 67.5% w.b. After heating within five minutes, the moisture content is reduced to 67.4% w.b. *MSD* is equaled to 0.028 (% w.b.)^2.

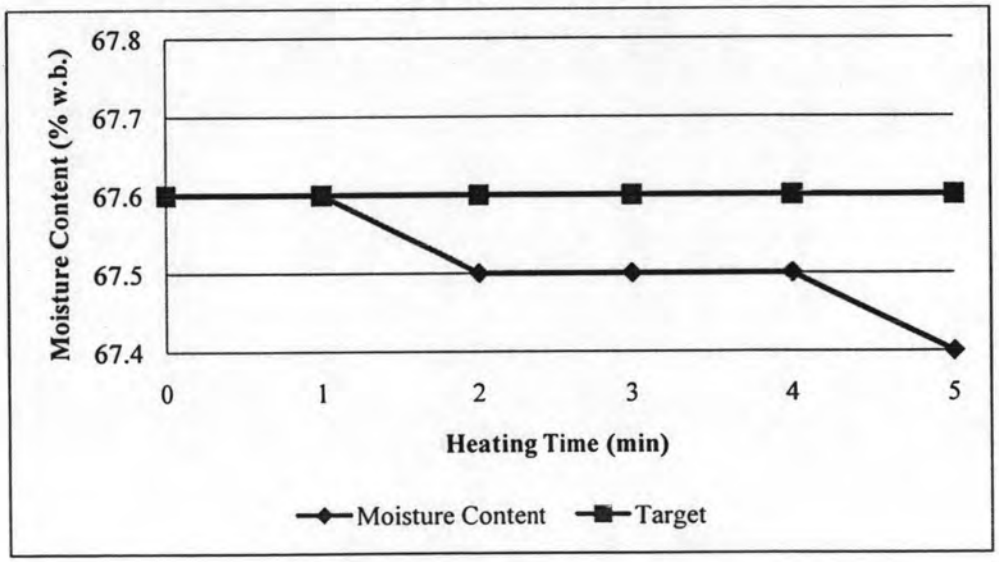

Figure 6.25 Heating result of cassava chip within high moisture content at 115°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.26. It shows that *MSD* from heating temperature level at 110°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating cassava chip within high moisture content is at 110°C.

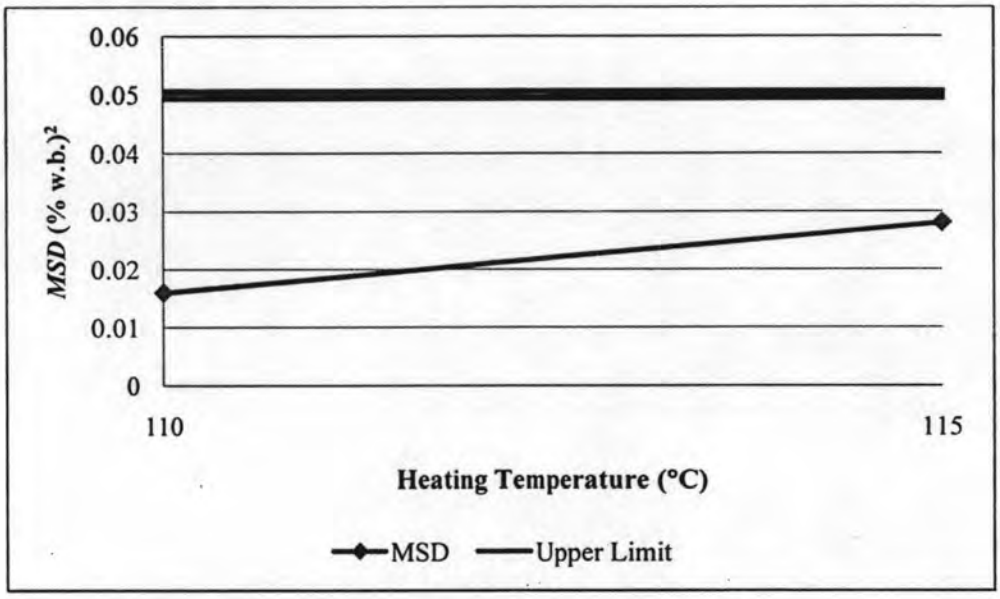

Figure 6.26 *MSD* from heating cassava chip within high moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating cassava chip within high moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.6).

$$M(t)_1 = 67.6, \qquad 0 \le t \le 5 \tag{6.6}$$

From all heating experiments, they are summarized in Figure 6.27 which illustrates the optimal temperature levels and the mathematical models for heating cassava chip within low, medium, and high initial moisture content clusters.

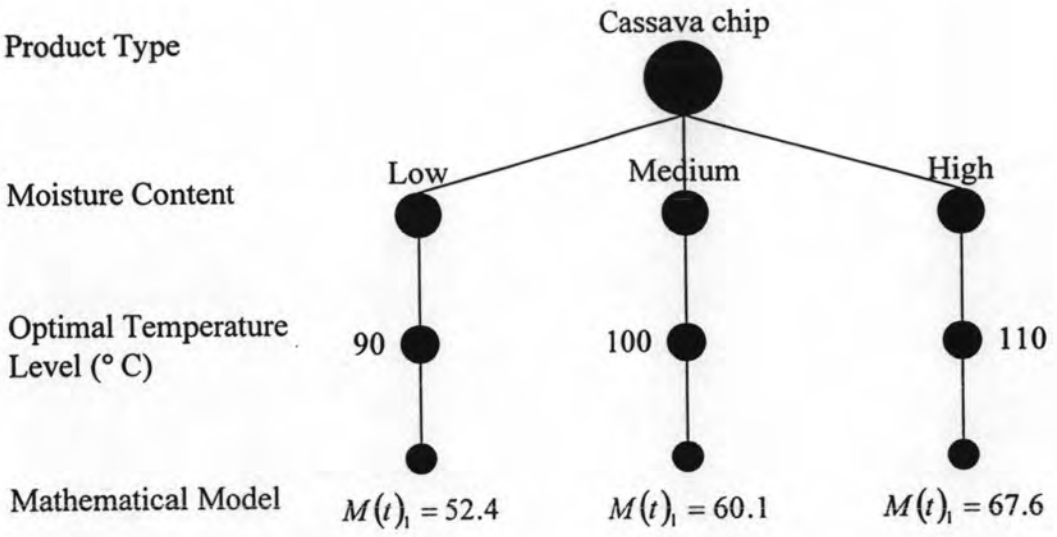

Figure 6.27 Optimal temperature levels and mathematical models for heating cassava chip

6.3 Experimental Results of Tobacco

In this phase, tobacco is heated within three minutes by varying levels of heating temperature. The experimental results are shown as following clustering of the raw materials.

6.3.1 Low Moisture Content

Tobacco within low moisture content is sampled at an average initial moisture content of 17.1% w.b. It is heated with varying levels of temperature at 45, 50, and 55°C. The experimental results are explained as below.

(1) Heating Temperature Level at 45°C

From Figure 6.28, heating time with 45°C is consumed more than three minutes while the operation is designed to heat within three minutes. Therefore, heating with 45°C cannot be used to heat tobacco within low moisture content.

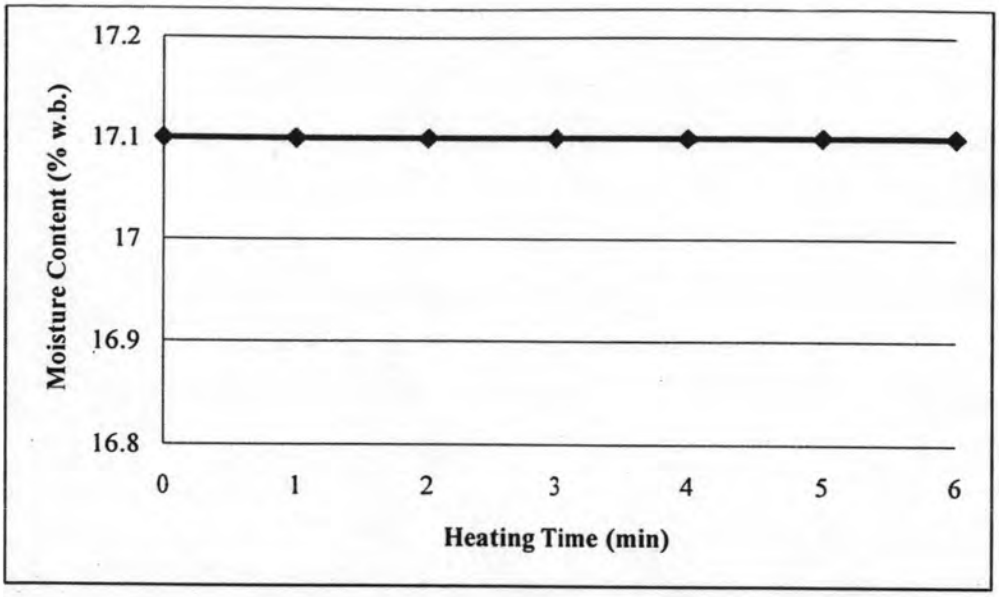

Figure 6.28 Heating result of tobacco within low moisture content at 45°C

(2) Heating Temperature Level at 50°C

From Figure 6.29, the initial moisture content of tobacco is at 17.1% w.b. During heating within two minutes, the moisture content is still same as the initial moisture content at 17.1% w.b. After heating within three minutes, the moisture content is reduced to 17.0% w.b. *MSD* is equaled to 0.013 (% w.b.)^2.

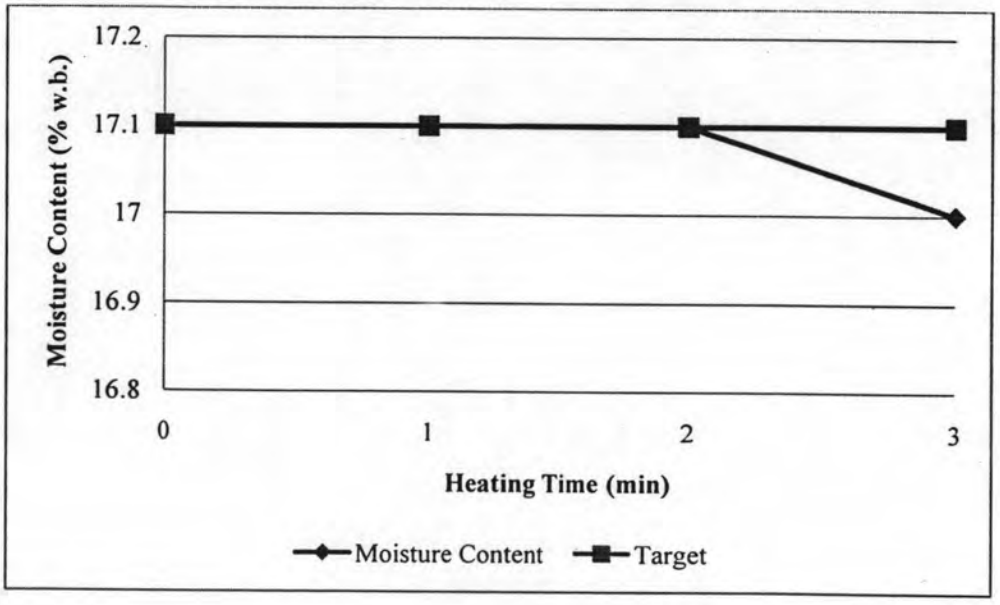

Figure 6.29 Heating result of tobacco within low moisture content at 50°C

(3) Heating Temperature Level at 55°C

From Figure 6.30, the initial moisture content of tobacco is at 17.1% w.b. During heating within two minutes, the moisture content is still same as the initial moisture content at 17.1% w.b. After heating within three minutes, the moisture content is reduced to 17.0% w.b. *MSD* is equaled to 0.017 (% w.b.)^2.

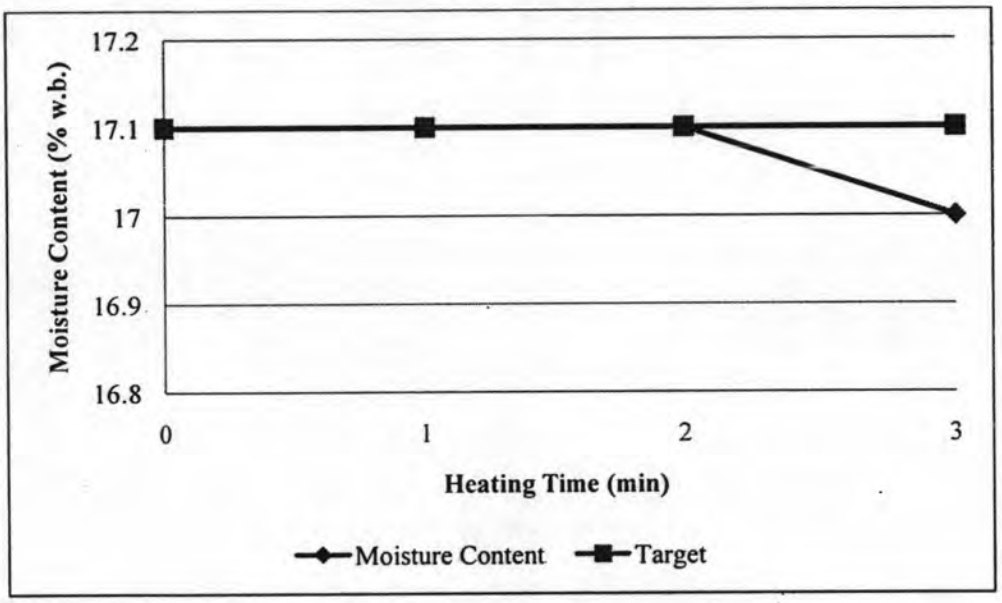

Figure 6.30 Heating result of tobacco within low moisture content at 55°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.31. It shows that *MSD* from heating temperature level at 50°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating tobacco within low moisture content is at 50°C.

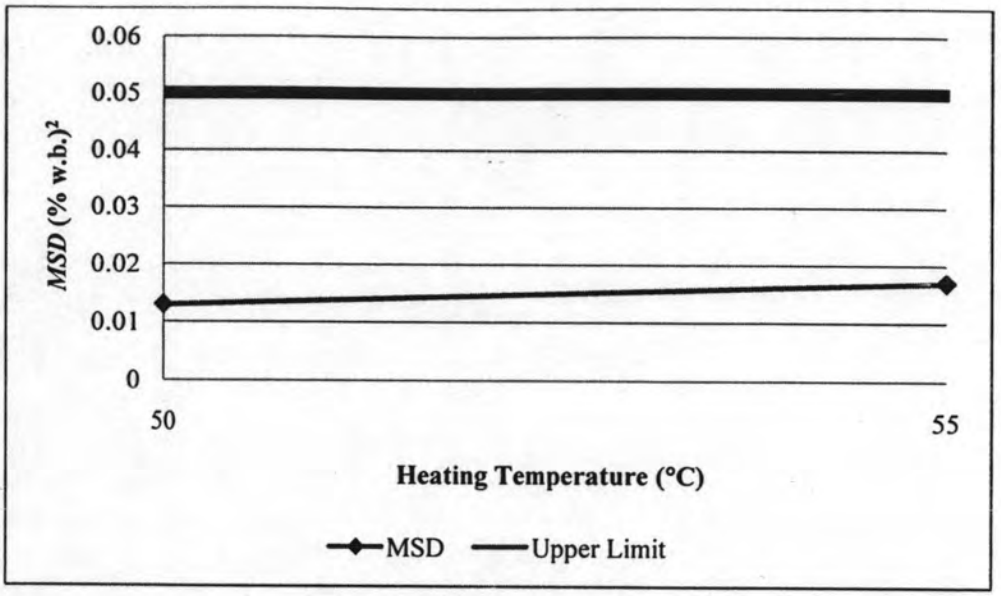

Figure 6.31 *MSD* from heating tobacco within low moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating tobacco within low moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.7).

$$M(t)_1 = 17.1, \qquad 0 \le t \le 3 \tag{6.7}$$

where

$M(t)_1$ = the moisture content during heating phase at time t

t = heating time minutes

6.3.2 Medium Moisture Content

Tobacco within medium moisture content is sampled at an average initial moisture content of 18.3% w.b. It is heated with varying levels of temperature at 50, 55, and 60°C. The experimental results are explained as below.

(1) Heating Temperature Level at 50°C

From Figure 6.32, heating time with 50°C is consumed more than three minutes while the operation is designed to heat within three minutes. Therefore, heating with 50°C cannot be used to heat tobacco within medium moisture content.

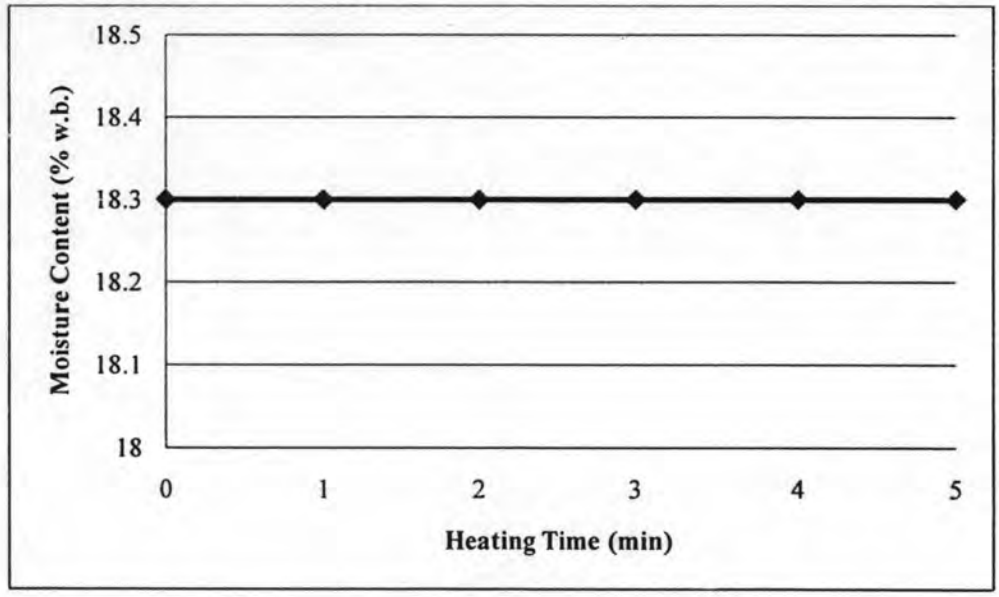

Figure 6.32 Heating result of tobacco within medium moisture content at 50°C

(2) Heating Temperature Level at 55°C

From Figure 6.33, the initial moisture content of tobacco is at 18.3% w.b. During heating within two minutes, the moisture content is still same as the initial moisture content at 18.3% w.b. After heating within three minutes, the moisture content is reduced to 18.2% w.b. *MSD* is equaled to 0.031 (% w.b.)^2.

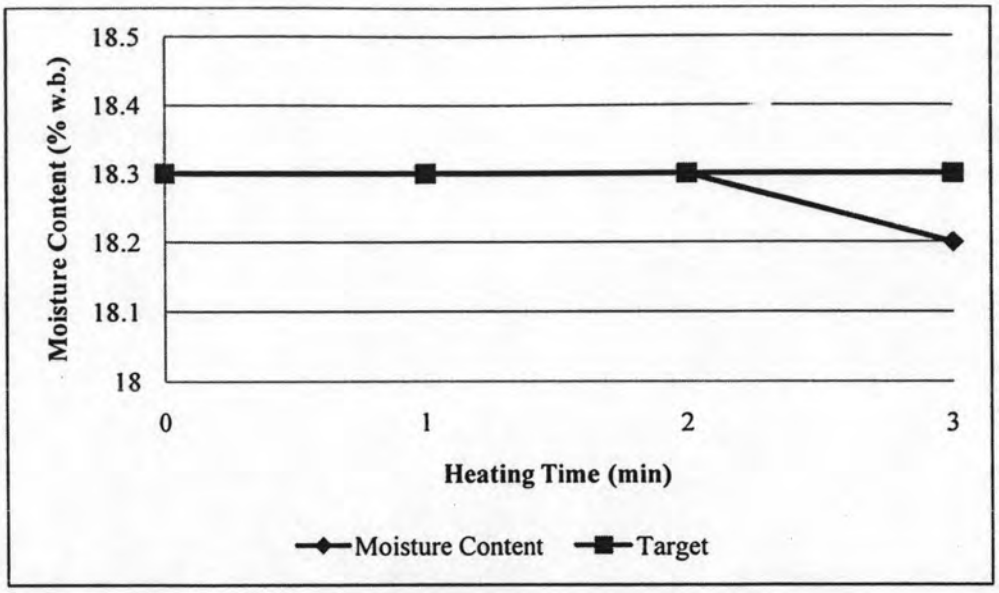

Figure 6.33 Heating result of tobacco within medium moisture content at 55°C

(3) Heating Temperature Level at 60°C

From Figure 6.34, the initial moisture content of tobacco is at 18.3% w.b. During heating within a minute, the moisture content is still same as the initial moisture content at 18.3% w.b. At the second minute, the moisture content is reduced to 18.2% w.b. and to 18.1% w.b. at the last minute of the heating period time. *MSD* is equaled to 0.047 (% w.b.)^2.

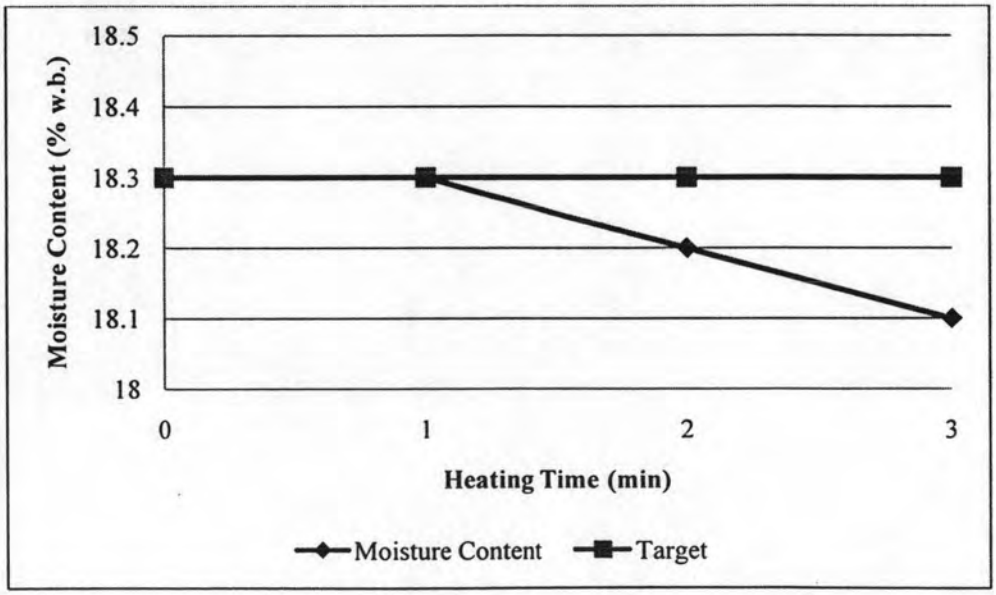

Figure 6.34 Heating result of tobacco within medium moisture content at 60°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.35. It shows that *MSD* from heating temperature level at 55°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating tobacco within medium moisture content is at 55°C.

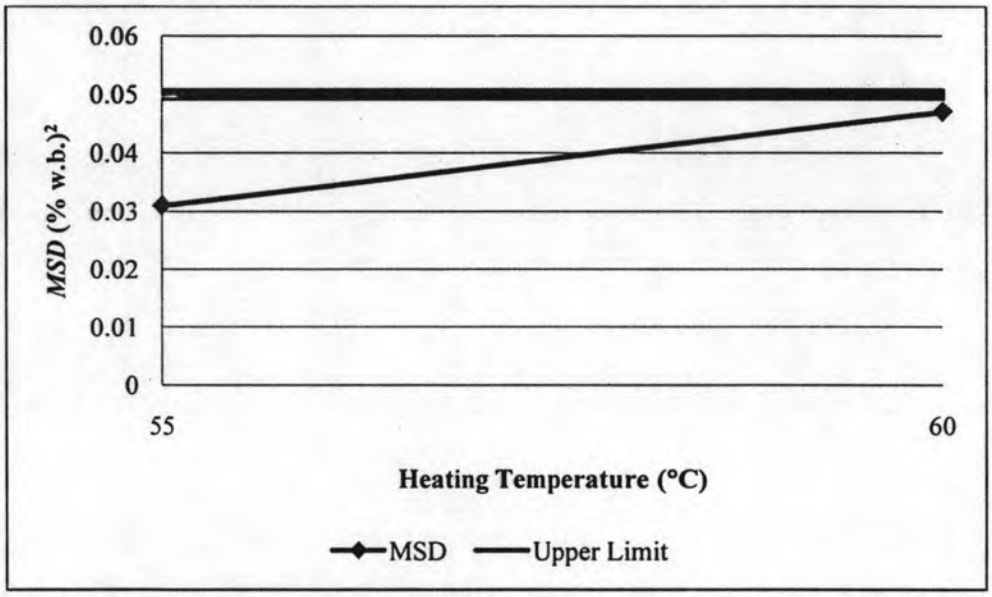

Figure 6.35 *MSD* from heating tobacco within medium moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating tobacco within medium moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.8).

$$M(t)_1 = 18.3, \qquad 0 \le t \le 3 \tag{6.8}$$

6.3.3 High Moisture Content

Tobacco within high moisture content is sampled at an average initial moisture content of 20.0% w.b. It is heated with varying levels of temperature at 55, 60, and 65°C. The experimental results are explained as below.

(1) Heating Temperature Level at 55°C

From Figure 6.36, heating time with 55°C is consumed more than three minutes while the operation is designed to heat within three minutes. Therefore, heating with 55°C cannot be used to heat tobacco within high moisture content.

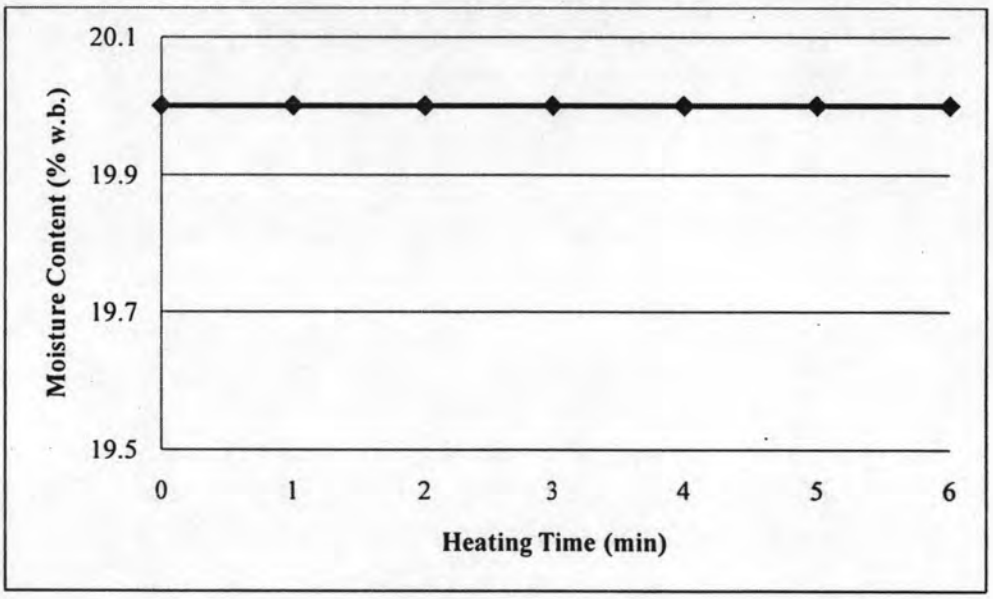

Figure 6.36 Heating result of tobacco within high moisture content at 55°C

(2) Heating Temperature Level at 60°C

From Figure 6.37, the initial moisture content of tobacco is at 20.0% w.b. During heating within two minutes, the moisture content is still same as the initial moisture content at 20.0% w.b. After heating within three minutes, the moisture content is reduced to 19.9% w.b. *MSD* is equaled to 0.024 (% w.b.)^2.

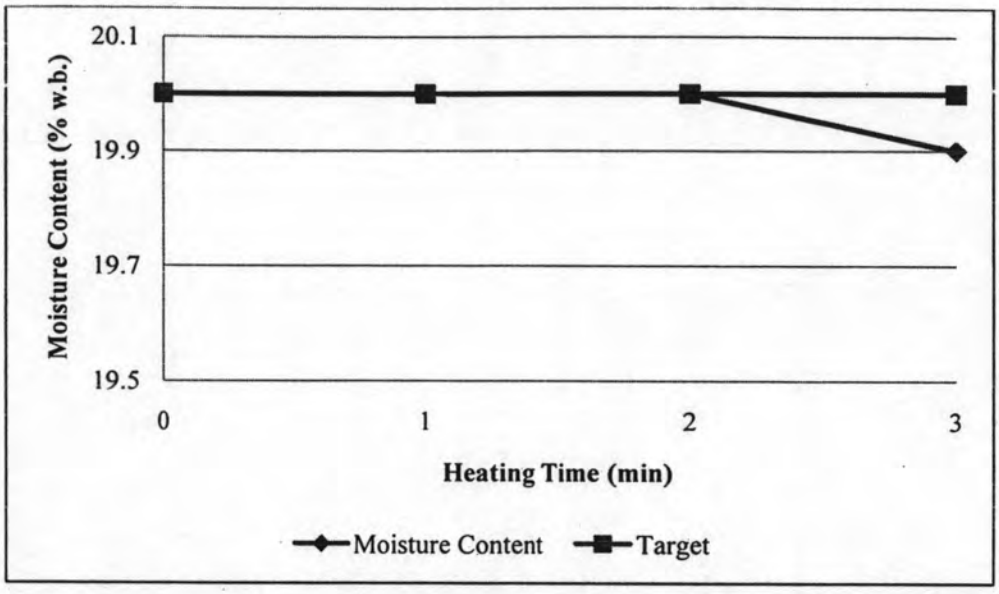

Figure 6.37 Heating result of tobacco within high moisture content at 60°C

(3) Heating Temperature Level at 65°C

From Figure 6.38, the initial moisture content of tobacco is at 20.0% w.b. During heating within two minutes, the moisture content is still same as the initial moisture content at 20.0% w.b. After heating within three minutes, the moisture content is reduced to 19.7% w.b. *MSD* is equaled to 0.117 (% w.b.)^2.

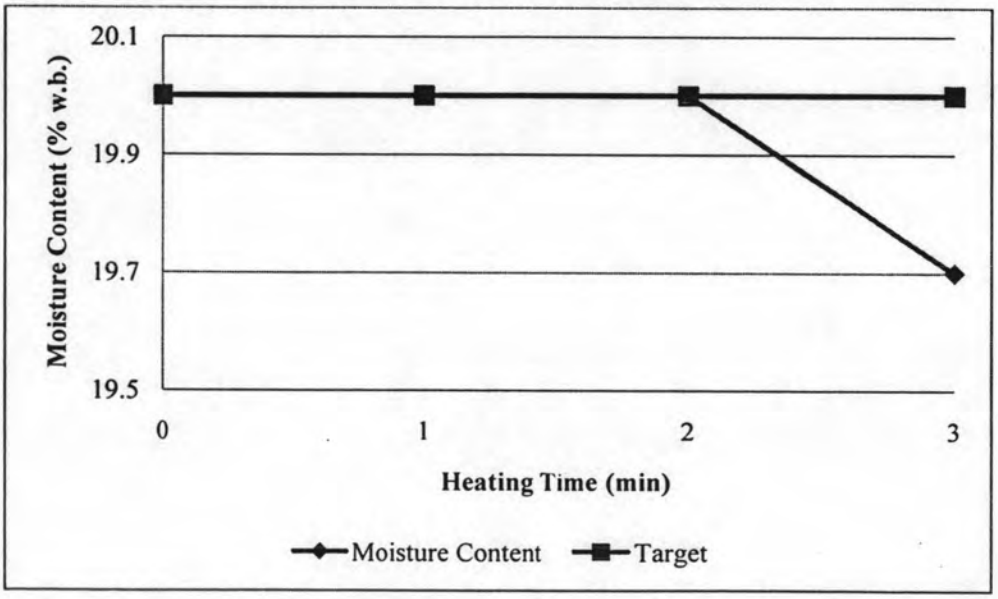

Figure 6.38 Heating result of tobacco within high moisture content at 65°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.39. It shows that *MSD* from heating temperature level at 60°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating tobacco within high moisture content is at 60°C.

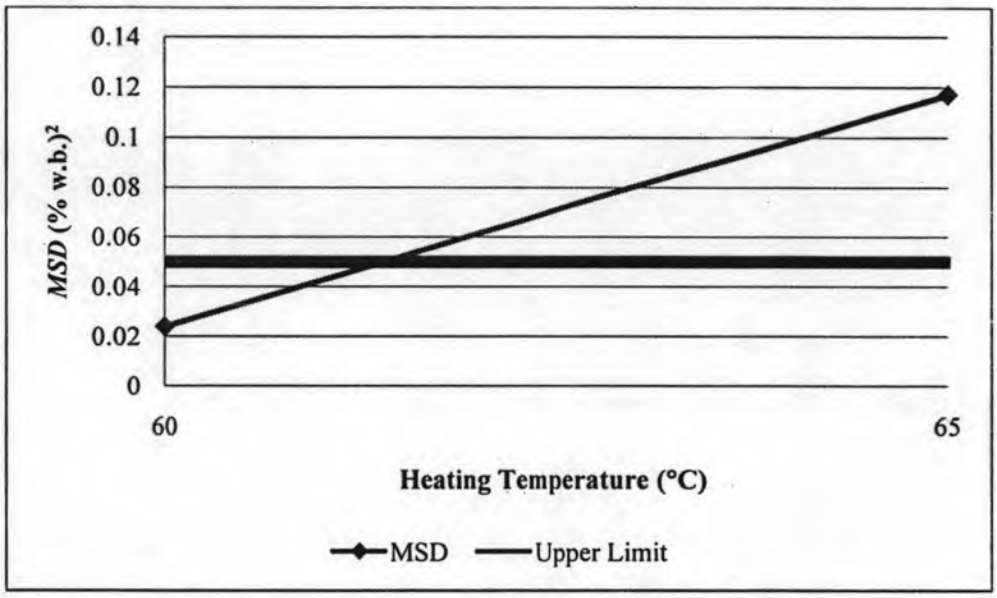

Figure 6.39 *MSD* from heating tobacco within high moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating tobacco within high moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.9).

$$M(t)_1 = 20.0, \qquad 0 \le t \le 3 \tag{6.9}$$

From all heating experiments, they are summarized in Figure 6.40 which illustrates the optimal temperature levels and the mathematical models for heating tobacco within low, medium, and high initial moisture content clusters.

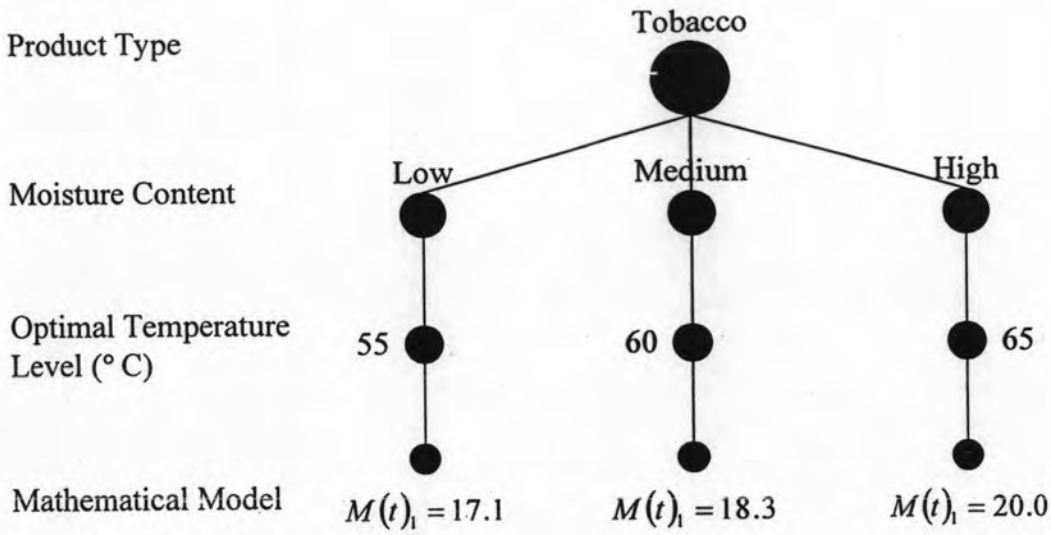

Figure 6.40 Optimal temperature levels and mathematical models for heating tobacco

6.4 Experimental Results of Longan

In this phase, longan is heated within 15 hours by varying levels of heating temperature. The experimental results are shown as following clustering of the raw materials.

6.4.1 Low Moisture Content

Longan within low moisture content is sampled at an average initial moisture content of 87.4% w.b. It is heated with varying levels of temperature at 65, 70, and 75°C. The experimental results are explained as below.

(1) Heating Temperature Level at 65°C

From Figure 6.41, heating time with 45°C is consumed more than 15 hours while the operation is designed to heat within 15 hours. Therefore, heating with 65°C cannot be used to heat longan within low moisture content.

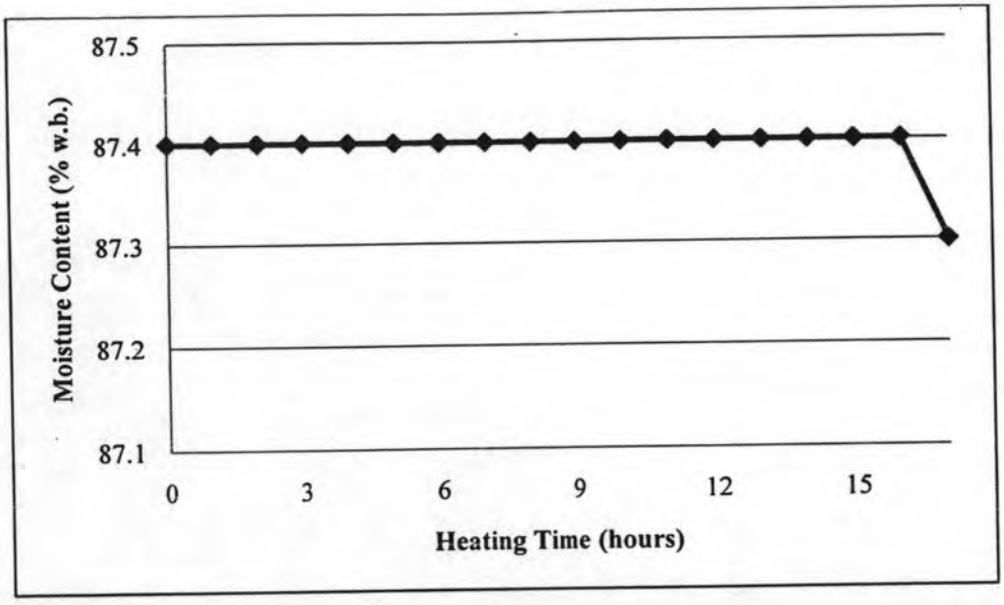

Figure 6.41 Heating result of longan within low moisture content at 65°C

(2) Heating Temperature Level at 70°C

From Figure 6.42, the initial moisture content of tobacco is at 87.4% w.b. During heating within 14 hours, the moisture content is still same as the initial moisture content at 87.4% w.b. After heating within 15 hours, the moisture content is reduced to 87.3% w.b. *MSD* is equaled to 0.022 (% w.b.)^2.

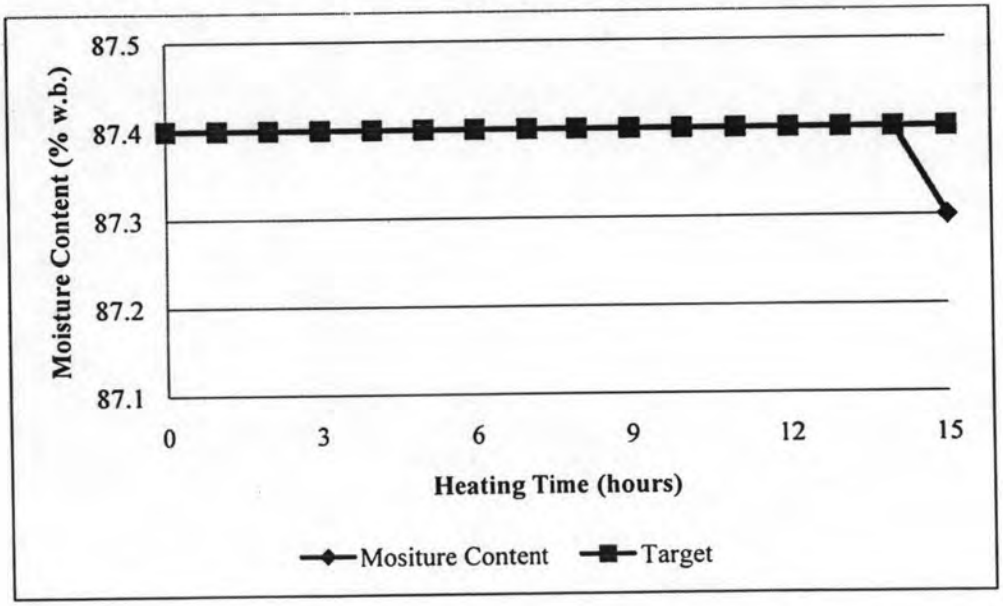

Figure 6.42 Heating result of longan within low moisture content at 70°C

(3) Heating Temperature Level at 75°C

From Figure 6.43, the initial moisture content of longan is at 87.4% w.b. During heating within 12 hours, the moisture content is still same as the initial moisture content at 87.4% w.b. After heating within 15 hours, the moisture content is reduced to 87.2% w.b. *MSD* is equaled to 0.064 (% w.b.)^2.

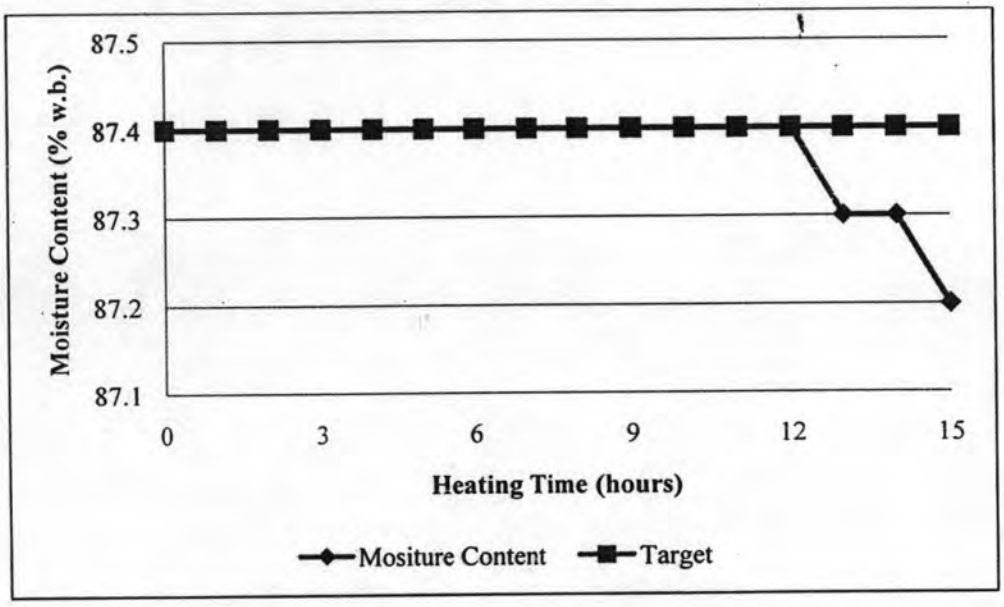

Figure 6.43 Heating result of longan within low moisture content at 75°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.44. It shows that *MSD* from heating temperature level at 70°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating longan within low moisture content is at 70°C.

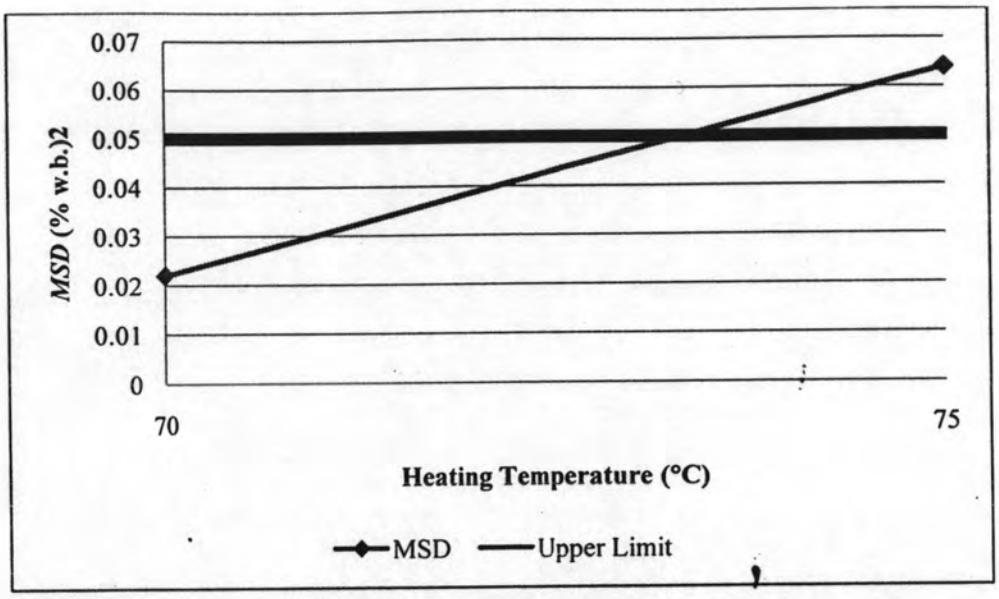

Figure 6.44 *MSD* from heating longan within low moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating longan within low moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.10).

$$M(t)_1 = 87.4, \qquad 0 \le t \le 15 \tag{6.10}$$

where

$M(t)_1$ = the moisture content during heating phase at time t

t = heating time hours

6.4.2 Medium Moisture Content

Longan within medium moisture content is sampled at an average initial moisture content of 91.1% w.b. It is heated with varying levels of temperature at 70, 75, and 80°C. The experimental results are explained as below.

(1) Heating Temperature Level at 70°C

From Figure 6.45, heating time with 70°C is consumed more than 15 hours while the operation is designed to heat within 15 hours. Therefore, heating with 70°C cannot be used to heat longan within medium moisture content.

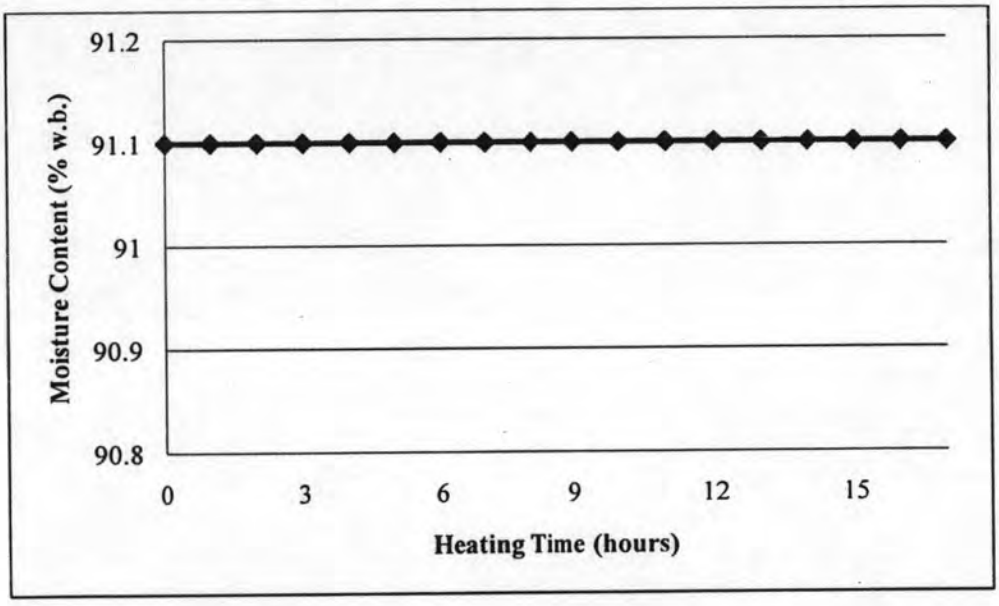

Figure 6.45 Heating result of longan within medium moisture content at 70°C

(2) Heating Temperature Level at 75°C

From Figure 6.46, the initial moisture content of longan is at 91.1% w.b. During heating within 14 hours, the moisture content is still same as the initial moisture content at 91.1% w.b. After heating within 15 hours, the moisture content is reduced to 91.0% w.b. *MSD* is equaled to 0.036 (% w.b.)^2.

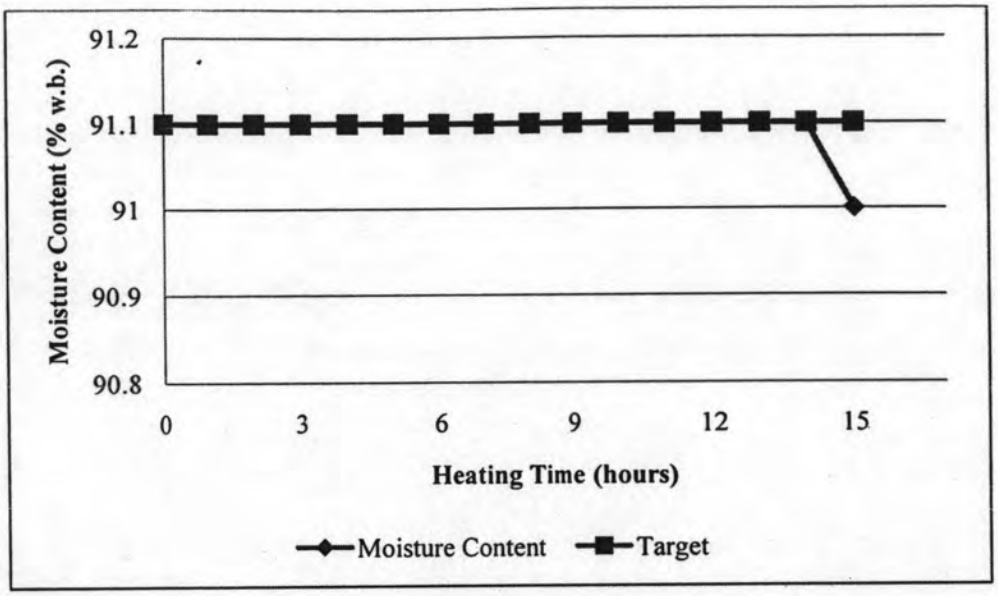

Figure 6.46 Heating result of longan within medium moisture content at 75°C

(3) Heating Temperature Level at 80°C

From Figure 6.47, the initial moisture content of longan is at 91.1% w.b. During heating within 12 hours, the moisture content is still same as the initial moisture content at 91.1% w.b. After heating with 12 hours, the moisture content is reduced continuously. At the last hour of the heating period time, the moisture content is reduced to 90.8% w.b. *MSD* is equaled to 0.092 (% w.b.)^2.

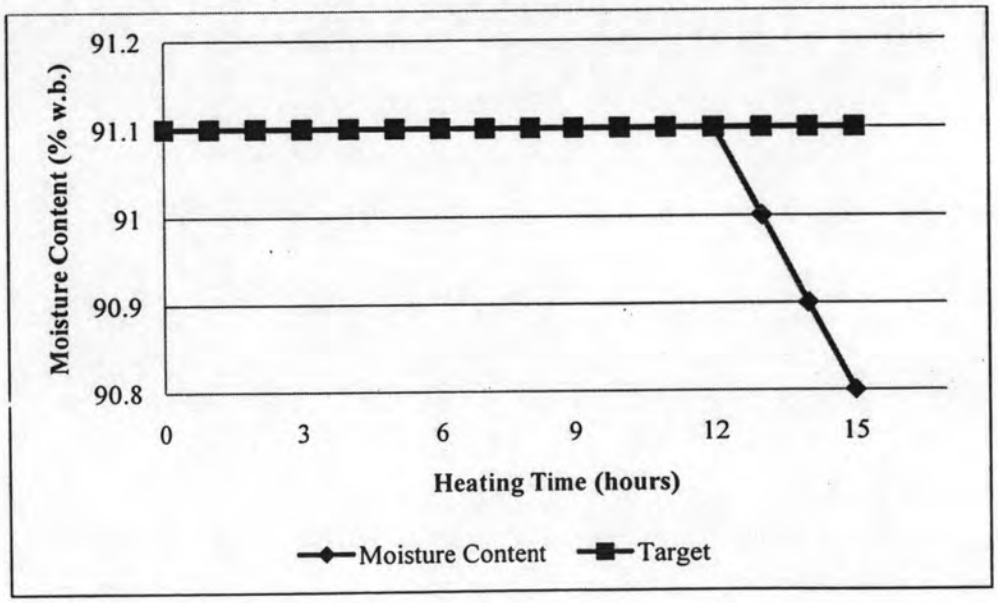

Figure 6.47 Heating result of longan within medium moisture content at 80°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.48. It shows that *MSD* from heating temperature level at 75°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating longan within medium moisture content is at 75°C.

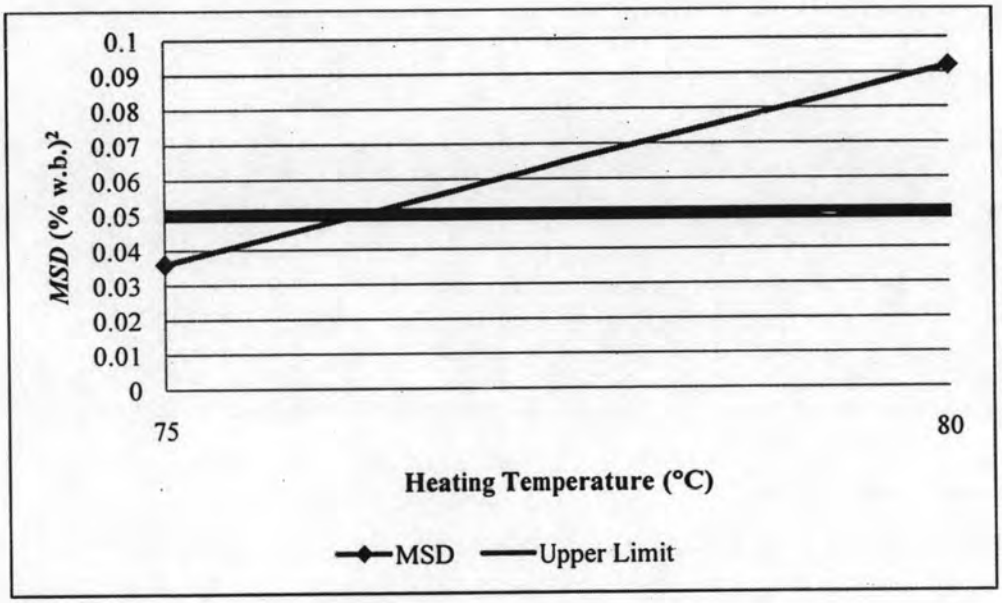

Figure 6.48 *MSD* from heating longan within medium moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating longan within medium moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.11).

$$M(t)_1 = 91.1, \qquad 0 \le t \le 15 \tag{6.11}$$

6.4.3 High Moisture Content

Longan within high moisture content is sampled at an average initial moisture content of 94.3% w.b. It is heated with varying levels of temperature at 75, 77, and 80°C. The experimental results are explained as below.

(1) Heating Temperature Level at 75°C

From Figure 6.49, heating time with 75°C is consumed more than 15 hours while the operation is designed to heat within 15 hours. Therefore, heating with 75°C cannot be used to heat longan within high moisture content.

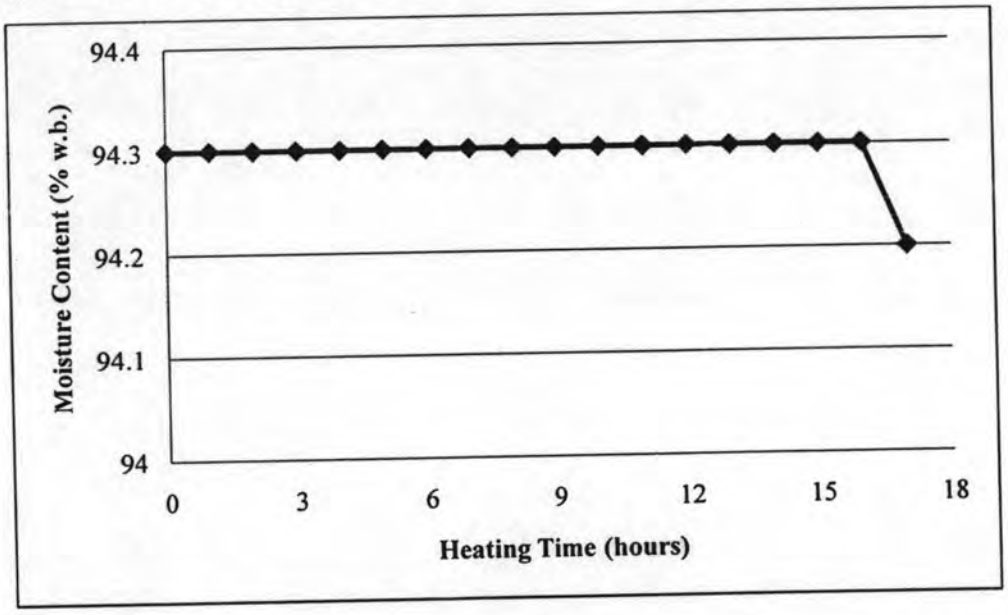

Figure 6.49 Heating result of longan within high moisture content at 75°C

(2) Heating Temperature Level at 77°C

From Figure 6.50, the initial moisture content of longan is at 94.3% w.b. During heating within 14 hours, the moisture content is still same as the initial moisture content at 94.3% w.b. After heating within 15 hours, the moisture content is reduced to 94.2% w.b. *MSD* is equaled to 0.022 (% w.b.)^2.

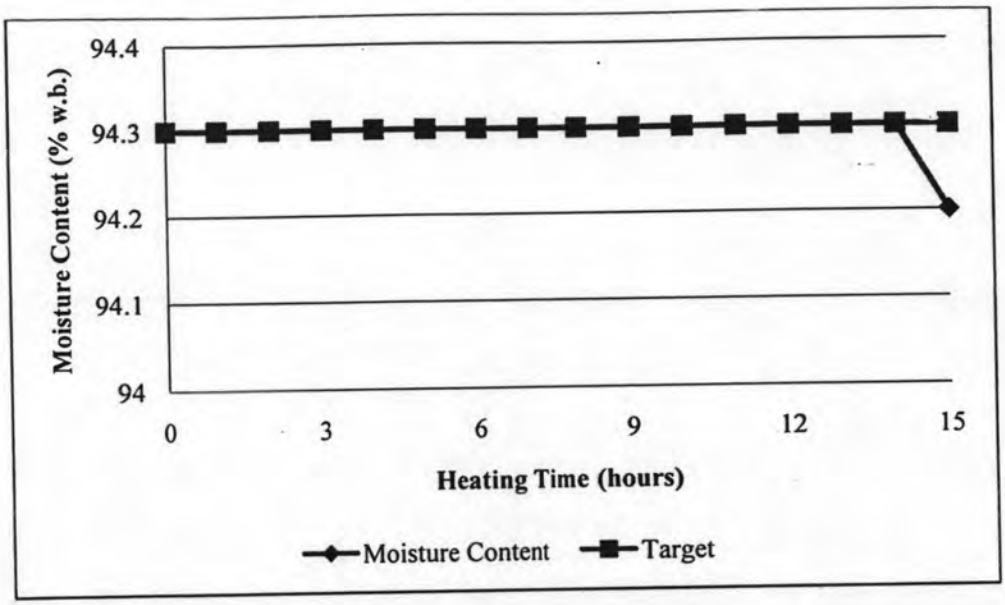

Figure 6.50 Heating result of longan within high moisture content at 77°C

(3) Heating Temperature Level at 80°C

From Figure 6.51, the initial moisture content of longan is at 94.3% w.b. During heating within four hours, the moisture content is still same as the initial moisture content at 94.3% w.b. After four hours, the moisture content is reduced continually. After heating within 15 hours, the moisture content is reduced to 93.8% w.b. *MSD* is equaled to 0.236 (% w.b.)^2.

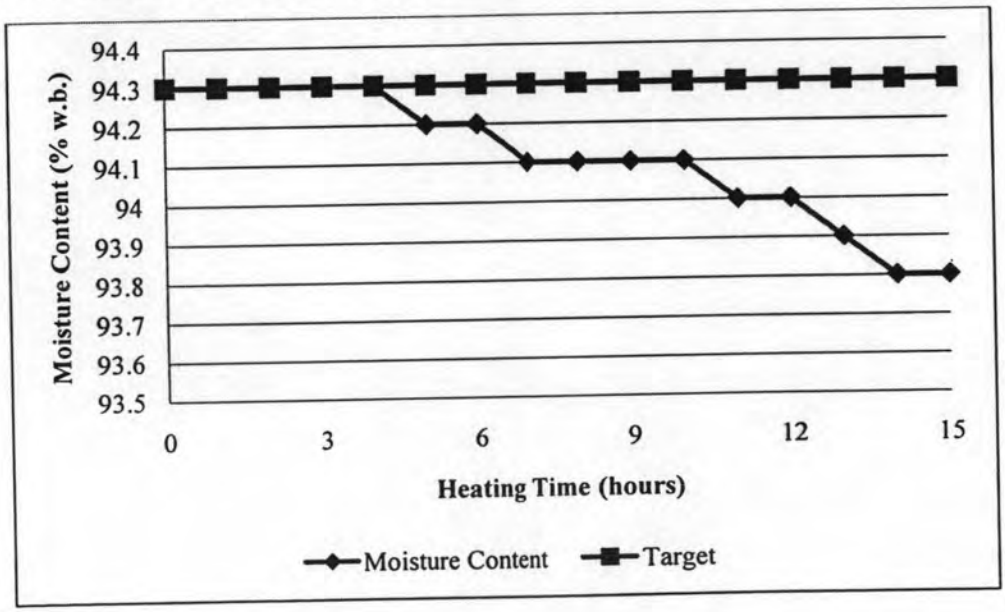

Figure 6.51 Heating result of longan within high moisture content at 80°C

(4) Selecting Optimal Heating Temperature Level

To select the optimal heating temperature level, minimum *MSD* is a criterion to select and the minimum *MSD* has to be less than 0.05 (% w.b.)^2. From all experimental results, their *MSD*s are plotted in Figure 6.52. It shows that *MSD* from heating temperature level at 77°C is the minimum value and less than 0.05 (% w.b.)^2. Therefore, the optimal temperature level for heating longan within high moisture content is at 77°C.

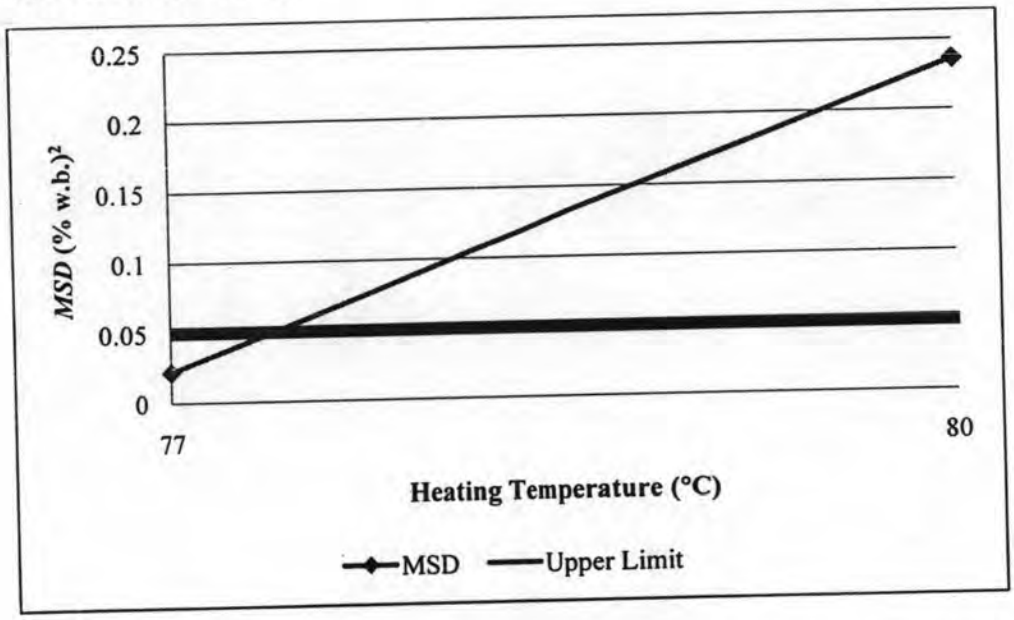

Figure 6.52 *MSD* from heating longan within high moisture content

(5) Constructing Mathematical Model

After selecting the optimal heating temperature level, the mathematical model for heating longan within high moisture content is constructed by Matlab program with function *polyfit*. As a result, the mathematical model is shown as Equation (6.12).

$$M(t)_1 = 94.3, \qquad 0 \le t \le 15 \tag{6.12}$$

From all heating experiments, they are summarized in Figure 6.53 which illustrates the optimal temperature levels and the mathematical models for heating longan within low, medium, and high initial moisture content clusters.

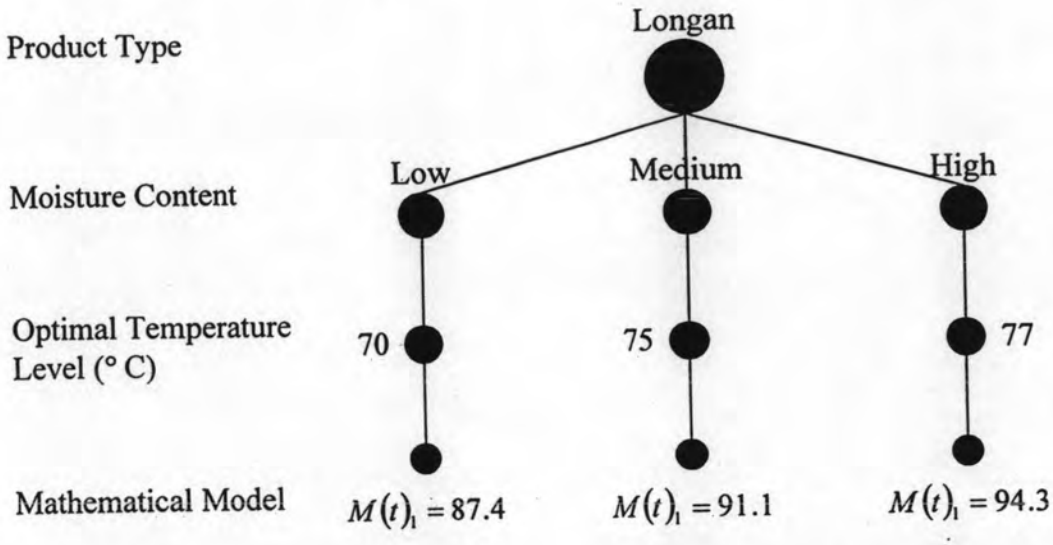

Figure 6.53 Optimal temperature levels and mathematical models for heating longan

6.5 Conclusion

The aims of this chapter are to find the optimal temperature level for heating the raw materials within each cluster and to construct the mathematical models in order to represent the behavior of the moisture content during heating period time. Experiments are conducted by varying levels of heating temperature. The heating temperature level which can minimize *MSD* is selected to be the optimal heating temperature level of the raw materials within their clusters. After selecting the optimal heating temperature level, the mathematical models are constructed by Matlab with function *polyfit*. All mathematical models are in uniform distribution. However, all experimental results of this chapter can be summarized in Table 6.1.

Table 6.1 Summary results of drying process within heating phase

Product	Heating Time	Initial Moisture Content	Optimal Temperature Level (°C)	Mathematical model
Paddy rice	30 seconds	Low	55	$M(t)_1 = 23.9$
		Medium	60	$M(t)_1 = 26.6$
		High	63	$M(t)_1 = 27.8$
Cassava chip	5 minutes	Low	90	$M(t)_1 = 52.4$
		Medium	100	$M(t)_1 = 60.1$
		High	110	$M(t)_1 = 67.6$
Tobacco	3 minutes	Low	55	$M(t)_1 = 17.1$
		Medium	60	$M(t)_1 = 18.3$
		High	65	$M(t)_1 = 20.0$
Longan	15 hours	Low	70	$M(t)_1 = 87.4$
		Medium	75	$M(t)_1 = 91.1$
		High	77	$M(t)_1 = 94.3$