CHAPTER 4

RESULTS AND DISCUSSION

4.1 Quality of dried longan

Longan fruits in this experiment were classified into three sizes, large, medium and small. The average diameters of fresh longan fruits for each size were 26.25, 24.47, and 22.80 mm, respectively. The average sizes of dried longan fruits were smaller than their fresh counterparts with the corresponding diameters of 25.46, 23.72, and 22.09 mm, respectively (Table 4.1). The weight ratios of fresh to dried longan which corresponded to all three sizes were 3.40:1, 3.30:1, and 3.31:1, respectively. These ratios were obtained at the moisture content level of 76.0% for fresh longan and 13.5% Wb of dried longan, respectively. Figure 4.1 indicates dried longan components.

Figure 4.1 Components of dried longan: pericarp, aril, and seed

Table 4.1 Quality of dried longan after drying by a hot air oven at moisture content level of 13.5% Wb.

Size	Ratio (fresh/dried)	∅ Fresh longan (mm)	∅ Dried longan (mm)	∅ Fresh - ∅ dried (mm)
Large (AA)	3.41	26.35	25.51	0.84
Medium(A)	3.31	24.53	23.73	0.80
Small(B)	3.30	22.83	22.11	0.72
Average	3.34±0.06	24.57±1.76	23.78±1.70	0.79±0.06

Table 4.2 Moisture content for each part of dried longan: whole longan, pericarp, aril + seed, aril, and seed.

Size	Moisture content for each part of dried longan (%Wb)				
	Whole longan	Pericarp (peel)	Aril+Seed	Aril	Seed
Large (AA)	13.53	7.88	16.19	19.37	9.78
Medium(A)	13.94	6.35	18.47	19.24	9.95
Small(B)	13.22	4.88	15.86	19.48	9.60
Average	13.56±0.36	6.37±1.5	16.84±1.42	19.36±0.12	9.78±0.17

Table 4.2 shows the average moisture content of whole dried longan at 13.56% Wb. The moisture content of pericarp was slightly elevated with the increasing fruits sizes, namely, 7.88, 6.35, and 4.88% Wb, respectively. The moisture contents of aril and seed were not differed significantly among sizes with the corresponding average levels of 19.36 and 9.78 % Wb, respectively.

The data suggests that most of moisture in a longan is in aril, For example, in table 4.2, when the whole longan moisture content is about 13% Wb, the moisture content at aril is about 19% Wb. The aril moisture content is more than the standard at 13% Wb. That means the longan will be damaged by fungi even through the whole longan moisture content most the standard. Therefore, this research considers only the moisture content of longan aril.

4.1.1 Weight ratio of aril, pericarp and seed

The weight ratio of each component (aril, pericarp, and seed) in dried longan at moisture content of 13.5% Wb is tabulated in table 4.3. The results indicated the average weight ratios of longan components were 47.84, 22.61, and 29.54% Wb for aril, pericarp, and seed, respectively. The weight ratio of aril was the highest in comparison with other weight ratios. The corresponding aril weight ratios for large, medium and small fruits sizes were 48.84, 49.99 and 43.77%, respectively. In case of pericarp and seed weight ratios, these numbers were 23.67, 21.34, 22.64%, and 27.49, 28.67 and 33.59%, for large, medium and small fruits sizes, respectively. The opposite trends of weight ratios with increasing fruit sizes could be observed for aril and seed of dried longan. The highest aril weight ratio was recorded for fruit with the larger size while the largest figure of seed weight ratio was obtained with the smaller fruit size. The weight ratio informs that each longan has higher content of aril than pericarp and seed. Therefore, it is easier to use longan aril for moisture measurement.

Table 4.3 Weight ratio of aril, pericarp, and seed of whole dried longan fruits.

Size	Ratio (%)			Total
	Aril	Pericarp	Seed	
Large (AA)	48.84	23.67	27.49	100
Medium(A)	49.99	21.34	28.67	100
Small(B)	43.77	22.64	33.59	100
Average	47.84±3.31	22.61±1.16	29.54±3.23	100

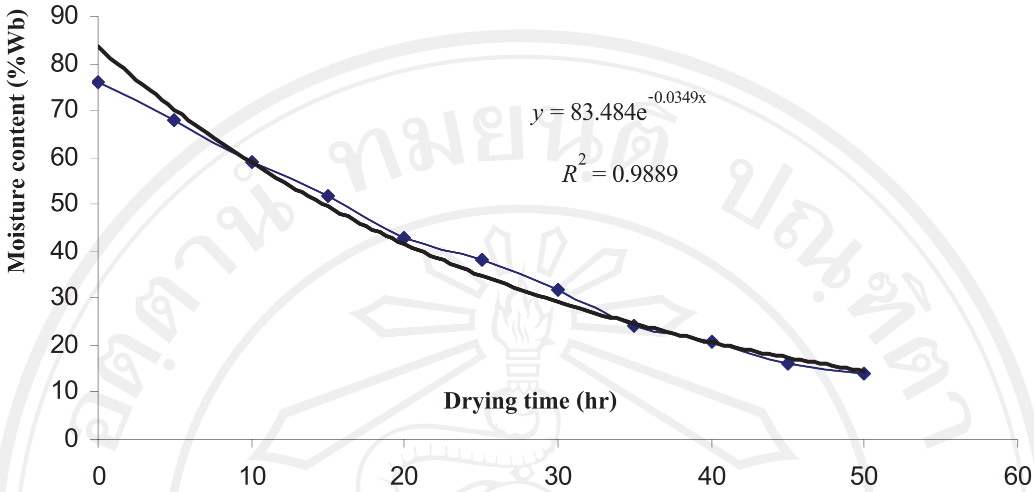

Figure 4.2 Relationship between moisture content and drying time by a hot air oven at 70 °C.

Figure 4.2 indicates the relationship between moisture content and drying time. The drying process was initiated when the initial moisture content of fresh longan was about 76% Wb until the moisture content level dropped eventually to 13.5 % Wb after 50 hours. The analyzed drying curve of aril followed exponential decay equation (Equation (4.1)) with the corresponding coefficient of correlation (R^2) of 0.9889.

$$y = 83.484e^{-0.034x} \tag{4.1}$$

where y = moisture content (% Wb)

x = drying time (hours)

$R^2 =$ 0.9889

4.2 Electrical capacitance of dried longan-based capacitor

The corresponding means and standard deviations of the electrical capacitance at each moisture content level for three bulk densities are tabulated in table 4.4.

Table 4.4 Measured electrical capacitances for dried longan aril with moisture content level ranging from 10 to 25 % Wb and bulk density ranging from 1300 to 1600 kg/m^3.

Moisture content (% Wb)	Electrical capacitance (Mean ± Standard deviation, picofarad (pF))		
	Bulk density (kg/m^3)		
	1300	1450	1600
10	4.0443 ± 0.1351	4.3269 ± 0.2080	4.4420 ± 0.2080
14	5.2406 ± 0.0537	5.2463 ± 0.0863	5.2769 ± 0.0817
18	7.5007 ± 0.2319	7.5785 ± 0.2620	7.5836 ± 0.2923
22	10.2100 ± 0.2379	10.9261 ± 0.1228	11.1206 ± 0.1170
25	12.2879 ± 0.2409	13.0128 ± 0.1248	13.2098 ± 0.1184

The proposed moisture content measurement system acquired the electrical capacitances of dried longan aril with three levels of bulk density between 1300 to 1600 kg/m^3, and five levels of moisture content between 10 to 25% Wb. The increasing trend of electrical capacitance with moisture content was clearly observed. The experimental plots of moisture content versus electrical capacitance at three different bulk densities are shown in figure 4.5 which was later regressed with quadratic equations. These equations could be used as predictive equations as shown in table 4.5 for the moisture content from the measured electrical capacitance.

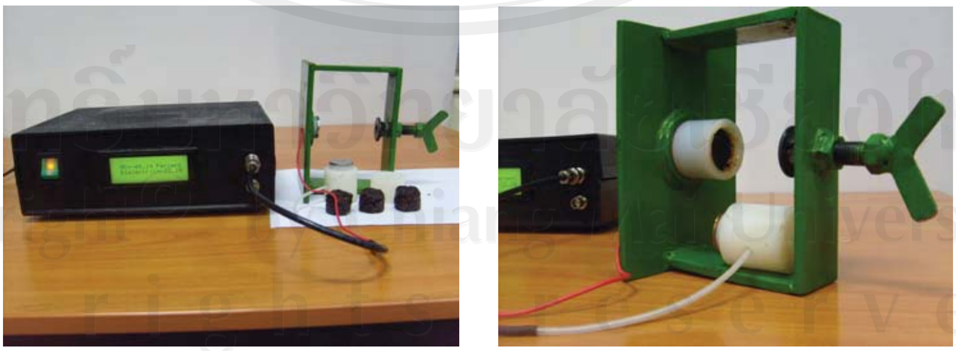

Figure 4.3 Moisture content measurement of dried longan aril with a moisture meter

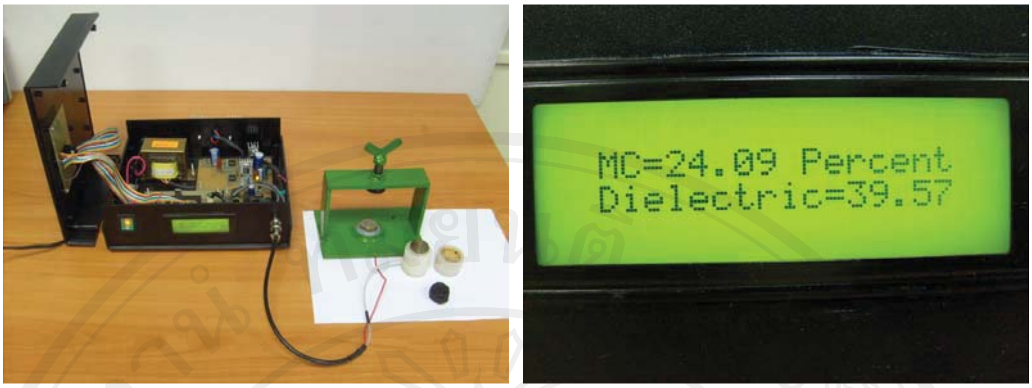

Figure 4.4 Moisture meter and corresponding LCD display

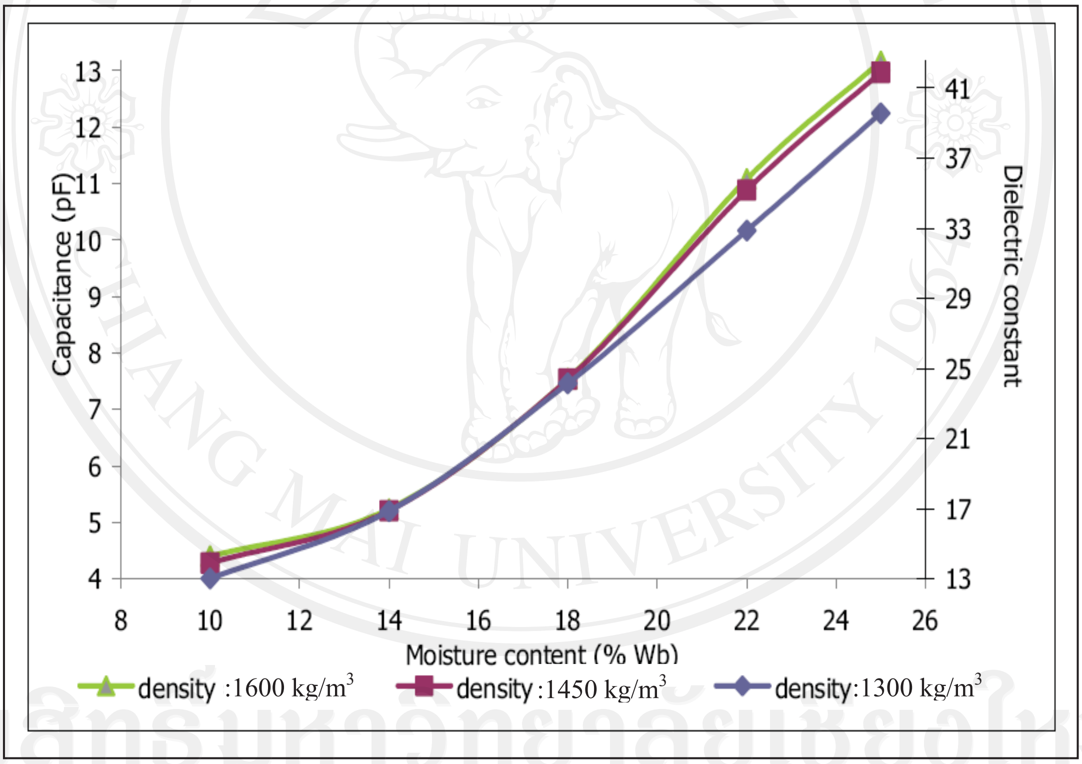

Figure 4.5 Relationship between the electrical capacitance and dielectric constant at five levels of moisture contents and three bulk densities.

Table 4.5 Predictive equations for moisture content from electrical capacitance (x : electrical capacitance (pF) and y: moisture content (% Wb).)

Bulk density (kg/m^3)	Predictive equations for the moisture content	Coefficient of correlation
1300	$y = -0.095\,x^2+3.293\,x+1.310$	0.994
1450	$y = -0.104\,x^2+3.397\,x+1.927$	0.984
1600	$y = -0.104\,x^2+3.397\,x+1.927$	0.980

4.3 Dielectric constant

The relationship between dielectric constant with the moisture content of dried longan aril at three different bulk densities is shown in table 4.6

Table 4.6 Relationship among electrical dielectric constant, bulk density and moisture content of dried longan aril.

Moisture content (%Wb)	Dielectric constant (Mean ± Standard deviation)		
	Bulk density (kg/m^3)		
	1300	**1450**	**1600**
10	13.0222 ± 0.4351	13.9323 ± 0.6696	14.3028 ± 0.6696
14	16.8742 ± 0.1729	16.9002 ± 0.2778	16.9913 ± 0.2629
18	24.1517 ± 0.7467	24.4022 ± 0.8437	24.4185 ± 0.9412
22	32.8753 ± 0.7662	35.1811 ± 0.3953	35.8076 ± 0.3766
25	39.5661 ± 0.7756	41.9003 ± 0.4017	42.5346 ± 0.3813

Because the areas of the two stainless steel plates and the distance between them were known, the electric constants could be calculated based on the capacitances in table 2 using equation (3.1). We can see that the dielectric constant of aril dried longan aril increases with the moisture content. The relationship is also shown as the plots in figure 4.5. Table 4.7 depicts the predictive equations for the moisture content from the dielectric constant.

Table 4.7 Predictive equations for moisture content from dielectric constant of dried longan aril (*x* : dielectric constant and *y*: moisture content (% Wb)).

Bulk density (kg/m^3)	Predictive equations for the moisture content	The coefficient of correlation
1300	$y = -0.009x^2+1.023x+1.310$	0.994
1450	$y = -0.010x^2+1.056x+1.947$	0.984
1600	$y = -0.010x^2+1.081x+2.384$	0.980

4.4 Bulk densities

Figure 4.6 shows the plots of the bulk densities of dried longan aril versus electrical capacitance and dielectric constant at five moisture contents for all 1500 samples.

It is noticeable from figure 4.6 that, for both capacitance and dielectric constant, the bulk densities of 1450 and 1600 kg/m^3 yield rather similar plots. If the bulk density is too low (1300 kg/m^3 in this case), however, the capacitance and dielectric constant will be underestimated. Consequently, this underestimation will lead to an underestimated moisture content. It can easily be seen in figure 4.6,that the bulk density of 1300 kg/m^3 yielded underestimated capacitances and dielectric constants especially at the higher moisture contents. Therefore, the bulk density of dried longan aril in the cylinder should be high enough to be applied to our system. It is recommended to set the aril sample weight to 10 grams for our moisture measurement system. This will lead to the bulk density of 1450 kg/m^3. The moisture content can be estimated from the capacitance by using the equation $y = -0.104x^2+3.397x-1.927$, where x denotes the electrical capacitance (pF) and y denotes the moisture content (% Wb).

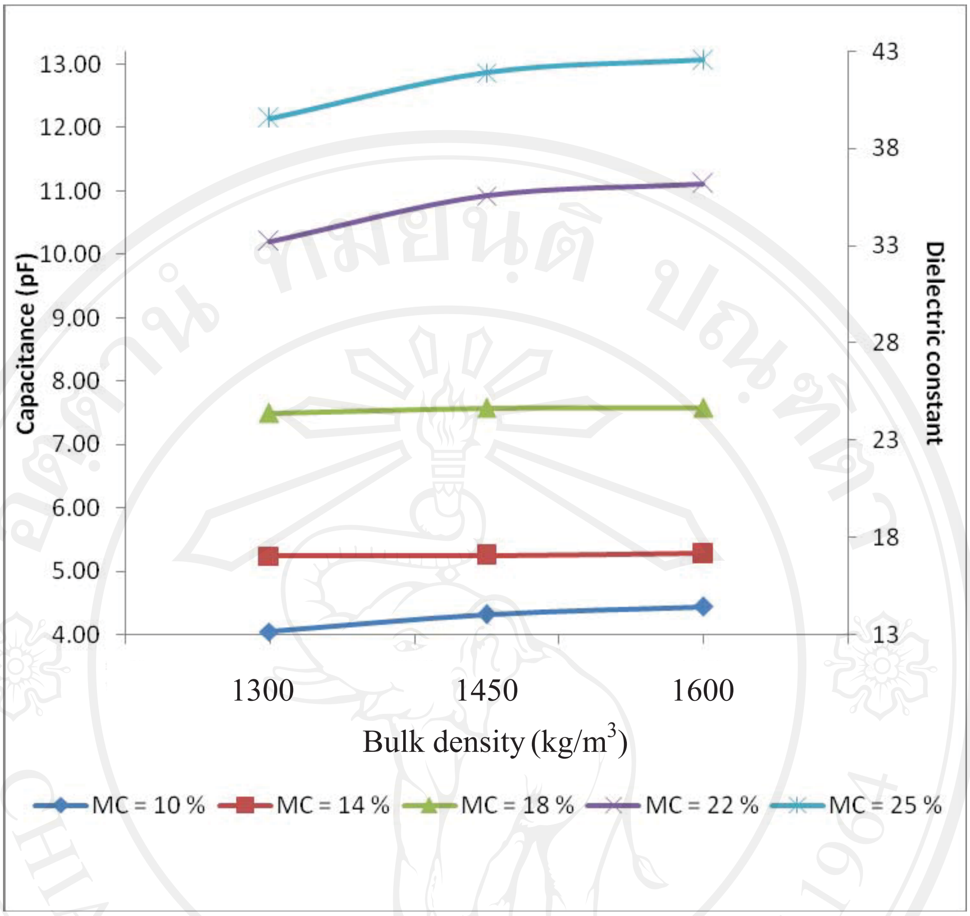

Figure 4.6 Relationship between the electrical capacitance and dielectric constant for three levels of bulk density and five moisture content levels.

4.5 Water activity

Table 4.8 shows the relationship between water activity and moisture content in dehydrated longans. The moisture contents of dehydrated longans considered here are 10, 14, 18, 22, and 25 % Wb. The corresponding mean values of water activity for the five moisture contents are 0.453, 0.565, 0.635, 0.715, and 0.766, respectively. The mean values of water activity in dried longan aril are plotted in term of the moisture contents as shown in figure 4.7. The figure shows that high moisture content leads to high water activity. It should be noted that the moisture content of dehydrated longans in the National Bureau of Agricultural Commodity and Food Standard (2005) has to be less than 0.6 for extended shelf-life.

Table 4.8 Water activity at 10, 14, 18, 22, and 25% Wb moisture contents.

Iteration	Moisture content (% wb)				
	10	14	18	22	25
1	0.426	0.551	0.623	0.715	0.755
2	0.443	0.565	0.629	0.706	0.760
3	0.460	0.566	0.634	0.711	0.766
4	0.457	0.567	0.640	0.716	0.771
5	0.465	0.570	0.645	0.722	0.777
6	0.450	0.576	0.635	0.714	0.768
7	0.463	0.581	0.633	0.719	0.769
8	0.456	0.564	0.639	0.712	0.759
9	0.454	0.566	0.632	0.715	0.768
10	0.455	0.569	0.634	0.720	0.763
Average	0.453±0.011	0.568±0.008	0.635±0.006	0.715±0.005	0.766±0.006

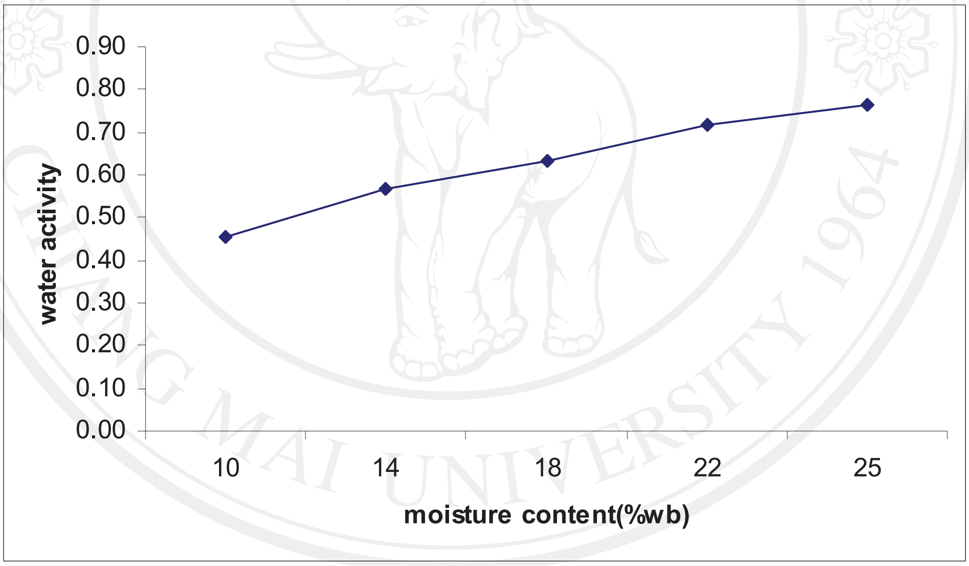

Figure 4.7 Relationship between the moisture content and water activity.

4.6 Blind testing

We performed the blind testing experiments on 47 samples of dried longan aril with 7 different moisture contents to verify that our proposed system works in general. These longan aril samples were not used in any step of the system creation. The numbers of samples are 9, 5, 4, 7, 9, 6, and 7 for 11, 12, 13, 14, 15, 16 and 18 % Wb moisture contents, respectively. These moisture contents were measured according to the official methods and recommended practices of Association of

Official Analytical Chemists (AOAC, 2005). Per our recommendation for using the proposed system, the weight of each aril sample was set to 10 grams and the moisture contents were calculated from the capacitance of the dried longan aril-based capacitor by using the equation $y = -0.104x^2 + 3.397x - 1.927$, where x denotes the electrical capacitance (pF) and y denotes the moisture content (% Wb). To evaluate the system performance quantitatively, we use the mean absolute error (MAE) which is defined as

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|\text{Actual MC} - \text{Measured MC}\right|,$$

where n is the number of the blind test data (equal 47 in this case). We found that the proposed system worked very well in the blind testing experiments. The MAE was 0.721 % Wb moisture content.

4.7 Measurement evaluation

The error computation was based on five different moisture content levels of 10, 14, 16, 18, and 22% Wb at a constant bulk density level of 1450 kg/m^3. Fifty samples of dried longan aril were tested in each case which accounted for the total number of 250 test samples.

4.7.1 Absolute value

Equation (3.14) was applied for the calculation of absolute value.

$$e = Y_n - X_n$$

At 10 % Wb (average value), the error was

$$e = 10 - 10.43 = 0.43$$

From equations (3.14) and (3.15), the percentage of error was

$$\text{Percentage of error } = \frac{0.43}{10} \times 100\,\% = 4.3\ \%$$

Table 4.9 Absolute value and absolute error of measured values at each moisture content level.

Moisture content (%)	Average Y_n	Average X_n	Absolute value (e)	Absolute error (%)
10	10	10.43	0.43	4.30
14	14	14.50	0.50	3.50
18	18	18.79	0.79	4.38
22	22	22.38	0.38	1.72
25	25	25.48	0.48	1.92
		Average	0.52±0.16	3.16±1.27

Table 4.9 shows corresponding absolute value and absolute error for each case of moisture content level. The absolute value lies between 0.38 and 0.79 with an average value of 0.52. The absolute error is between 1.72 and 4.38 with an average value of 3.16.

4.7.2 Accuracy

Equation (3.18) was used to calculate the accuracy value

$$A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right| \times 100\%$$

$$= 100\% - \textit{percentage of error}$$

At 10 % wb (average value)

$$A = 1 - 0.043 = 0.957$$

Equation (3.20) was used in the calculation of accuracy percentage

$$a = 100 \times 0.957 = 95.7\ \%$$

Table 4.10 Accuracy value and percentage of accuracy of measured values at each moisture content level.

Moisture content (%)	Accuracy value	% Accuracy
10	0.957	95.7
14	0.965	96.5
18	0.956	95.6
22	0.983	98.3
25	0.981	98.1
Average	0.968±0.01	96.8±1.29

From table 4.10, the accuracy value is between 0.956 and 0.981 with the average accuracy of 0.968. The percentage of accuracy is between 95.6 and 98.1 % with the average accuracy percentage of 96.8 %. From these values, the accuracy of moisture meter prototype is relatively high.

4.7.3 Precision

Equation (3.21) and (3.22) were used for the calculation of precision value which is subsequently tabulated in table 4.11.

Table 4.11 Precision of measured values at each moisture content level.

Moisture content (% Wb)	Precision
10	0.9741
14	0.9852
18	0.9964
22	0.9883
25	0.9916
Average	0.9871±0.01

From table 4.11, the precision of the invented equipment is between 0.9741 and 0.9964 with the average precision value of 0.9871. It can be concluded that the precision of the prototype moisture meter is relatively high.

4.8 Results for prediction models based on multilayer perceptrons and support vector regression

For parameter settings in the MLP and SVR, we performed extensive experiments to find the best sets of parameters under each condition. For the MLP, we found that two hidden layers with the numbers of hidden neurons of {3,5}, {5,9} and {4,6} yielded the best results for the bulk densities of 1,300, 1,450 and 1,600 kg/m^3, respectively, where the first and second elements of each pair denote the numbers of hidden neurons in the first and second hidden layers, respectively. Furthermore, we found from many experiments that ε-insensitive loss functions with $\varepsilon = 0.0001$ was the best choices for all three bulk densities of 1,300, 1,450 and 1,600 kg/m^3. The regularization parameter C, needed for solving the weight β_i, was chosen to be 100 for all three bulk densities. Finally, the parameter σ was set to 1.35, 0.65 and 0.85 for the bulk densities of 1,300, 1,450 and 1,600 kg/m^3, respectively.

The performances of the proposed models on the training sets of the four-fold cross validation are shown in table 4.12. The average MAE's over the three bulk densities are 1.7578, 0.6157, 0.3812, 0.3113, 0.0103 and 0.0044% Wb for the linear regression, second-, third-, fourth-order polynomial regression, MLP and SVR models, respectively. Table 4.13 shows the performances on the validation sets. The average MAE's over the three bulk densities are 1.7616, 0.6192, 0.3844, 0.3146, 0.0126 and 0.0093% Wb for the linear regression, second-, third-, fourth-order polynomial regression, MLP and SVR models, respectively.

Table 4.12 Average mean absolute error of the training sets using four-fold cross validation.

Bulk density (kg/m^3)	Average MAE (% Wb) (training sets)					
	Linear	**2nd order**	**3rd order**	**4th order**	**MLP**	**SVR**
1,300	1.5331	0.4302	0.3239	0.2499	0.0040	0.0030
1,450	1.8488	0.6703	0.3887	0.3341	0.0131	0.0016
1,600	1.8915	0.7466	0.4309	0.3500	0.0137	0.0086

Table 4.13 Average mean absolute error of the validation sets using four-fold cross validation.

Bulk density (kg/m^3)	Average MAE (% Wb) (validation sets) linear	2nd order	3rd order	4th order	MLP	SVR
1.30	1.5360	0.4334	0.3283	0.2530	0.0062	0.0043
1.45	1.8519	0.6725	0.3899	0.3356	0.0140	0.0100
1.60	1.8970	0.7517	0.4351	0.3551	0.0176	0.0136

The results in table 4.12 show that the polynomial regression models yield higher errors than the MLP and SVR models on the training sets of the four-fold cross validation by about one or two orders of magnitude. The MLP models also yield higher errors than the SVR models by about one order of magnitude.

The results in table 4.13 are very similar to that on the training sets shown in Table 1. On the validation sets, the polynomial regression models yield higher errors than the MLP models by about one order of magnitude. In the mean time, the MLP models yield higher errors than the SVR models by about one order of magnitude.

It can be clearly seen that both SVR and MLP models yield better prediction performance than the models based on linear regression and polynomial regression in both training and validation sets. We can also see that the SVR models yield a little bit better performance than the MLP models in both training and validation sets. It is not surprising that the average MAE's of the training sets are less than that of the validation sets because the data in the validation sets are not involved in the model generation. Even though the average MAE's at the 1,300 kg/m^3 bulk density are less than that at the other two bulk densities, the differences are not much in MLP and SVR models. Therefore, the system would have more robustness to the bulk density variation when the MLP or SVR is applied as the regression model.